Introduction

Turf is a wholly unnatural ecosystem. One uniform plant species growing on a sandy soil, subjected to frequent fertilization and ‘rainfall’, and highly limited in ecological diversity is almost the exact opposite of a natural ecosystem. Yet this unnatural ecosystem has become an integral part of modern society – hosting the sporting events from cricket to croquet – that absorb many of our leisure hours.

In sports fields, it is essential to strike a balance between the ability of sandy soil to drain quickly and the need to stop nutrients from leaching down.

As such, turf must be managed carefully. Attaining and maintaining a lush green surface on a soil more conducive to Spinifex rather than a trafficked surface requires an understanding of both turf and soil needs, and their relationship/interactions.

The best soil for turf is sandy and well drained. Frequent watering washes nutrients out of reach of the plants’ roots, and so nutrients must be added regularly. Frequent mowing also removes nutrients and organic matter in the clippings. An effective monoculture of a single grass species is an open invitation to pests and diseases that would have to struggle to survive in a more diverse ecosystem.

All of this requires constant attention from the turf manager. Soil and tissue testing is an important part of a turf manager’s tool kit for high quality turf grass management. Tissue testing is best used diagnostically once a deficiency or toxicity is present; regular soil testing aims to catch a deficiency before it can occur.

What soil testing can tell us

1. General soil nutrient profile

Soil chemical analysis provides insight into the overall nutrient profile of the soil.

At a minimum sports field soil tests should include pH, salinity, cation exchange capacity, cation %age, and soil nutrients including phosphorus, potassium, and calcium.

Some nutrient deficiencies (and toxicities) can be detected by eye with experience – for example, nitrogen and iron – but never the exact quantities needed. In addition, some deficiencies can be masked by symptoms of other deficiencies. Further, plants are usually very good at getting by with sub-optimum levels of nutrients. Finally, nutrient availability is influenced by pH, and you can’t tell pH by looking. So even when deficiencies are apparent to the eye, you can’t tell how much is needed, and hidden hunger occurs with no visible signs.
2. **Tracking nutrient changes**

Soil tests on sandy soils can help track changes in levels of all nutrients except perhaps N and S in order to help calibrate nutrient budgets. For example, regular testing will show if K is in gradual decline and will inform decisions to increase K inputs.

3. **Part of the nutrient budget**

Nutrient budgets are an essential tool for the modern turf manager of sandy rootzones. Using research knowledge or experience, annual and seasonal nutrient budgets should be prepared. You can then compare nutrients applied to the soil to nutrients taken up by plants. Experience will allow you to factor in nutrients lost through irrigation/leaching.

With routine soil testing, you can identify any long-term trends in soil nutrition, minimise waste and save dollars by not over fertilizing. The rule of thumb with fertiliser should be a little and often as it can burn plants in large amounts and wash out over time.

**What to watch out for**

In general, the sandier the root zone soil, the less useful soil testing. Sand is almost like a hydroponic medium - it has very low cation exchange capacity (CEC, refer below in ‘understanding the results’). The nutrition of the plants, therefore, is dependent on the soil solution. The nutrient levels of the soil solution are subject to the constant flow of irrigation water and the ionic species dissolved in it. Apply solid fertiliser to the surface of the grass and it is delivered to the root system via irrigation water (e.g. as NO₃, PO₄, NH₄, SO₄ etc.). Although some nutrients can be absorbed through the leaves, the majority of nutrients are taken up in the soil solution.

The low CEC of sandy soils can mean that after a few irrigations the soil may be devoid of dissolved nutrients. If this is when you take your soil sample results may show grossly deficient nutrients and make dire predictions. It may be that the turf is looking perfectly well.

Secondly, nutrient - particularly micronutrient or trace element availability - is poorly predicted by soil tests except at extreme levels. Trace elements are just that, only traces are needed and they are tightly held and recycled within all living things.

Finally, N and S availability are poorly predicted by soil testing. Generally rely upon an N budget consistent with seasonality and wear rates rather than soil tests. S is usually incidental to other fertiliser use and is seldom deficient.

**Understanding the Results**

Cation exchange capacity (CEC) is included in most testing packages but one of the lesser-understood results. The CEC of a soil is the capacity of the soil to retain nutrients for use by plant roots. A high CEC - typically 30-40 meq/100 g - ensures that any fertiliser added to the soil will remain in the soil for uptake by roots. But sandy soils have a very low CEC - typically <5 meq/100 g - which is not enough to retain nutrients. Consequently, growers must continually add fertiliser, and often only to have it leached away by rain and irrigation.
Phosphorus retention

Along with nitrogen, phosphorus is an essential resource for turf grass growth. However excessive or incorrect application can lead to loss of the nutrient. Phosphorus is lost through soil erosion as it sticks to soil particles, which is essentially more of a concern during turf development before grass is grown. In regular soils, the phenomenon of P fixation helps retain P in the profile and allows slow release to plant roots. However, in high-grade turf soils, which have so little clay and iron minerals to hold onto the phosphorus, care is required. P is less vulnerable to leaching than N or K due to the presence of bidentate bonding between P compounds and silicate or oxide minerals in the soil. In addition, acid ferruginous sands or calcareous sands can produce iron or calcium phosphate precipitates. The P is not lost so easily from these compounds, but neither is it available to plant roots. The lesson, as for most nutrients applied to sandy rootzone mixes, is ‘a little and often’.

There are many tests for Phosphorus. The most common tests requested in SESL are Colwell and Olsen with Bray sometimes requested. The often higher requirement of a nutrient in heavy soils relates to the plant’s ability to access and extract the quantity required, which is influenced by soil structure. However, in sandy rootzones, this is seldom an issue and recommended P levels are substantially lower than those normally recommended for agricultural soils once a suitably sized ‘bank’ of P has been established. On sandy rootzones, P is less likely to be bound by the soil and Phosphorus Buffering Index – which can be an important consideration on loams to clay loams – is usually insignificant. P can be bound by complexing with iron or calcium at low and high pH values respectively. In spite of this, turf soils are regularly over-fertilised with P as removal rates on turf are quite low – in the order of 3g/sq metre on vigorously growing turf. For this reason, low P fertilisers should be used on turf soils. The NPK ratio of clippings is about 8:1:5 so if a complete fertiliser is used, its NPK ratio should reflect this.

Potassium

In contrast to phosphorus, relatively large quantities of potassium (K) are removed in lawn clippings. K removal rates are in the order of 15g/sq metre from vigorously growing turf. Because K does not form compounds in plants, it remains highly labile. This means that K recycles very quickly out of grass clippings if they are not removed from site, and replenishes the K pool in the soil. K is involved as a catalyst in over 60 enzyme systems; it thickens cell walls and is involved in photosynthesis and storage of carbohydrates particularly into roots. This thickening of cell walls toughens turf leaves making them more resistant to wear, and increasing resistance to disease.

Most texts recognise that potassium is present at high levels in most soils. This is due to the fact that potassium is held in soils in four forms: potassium as a component of soil minerals, fixed potassium, exchangeable potassium and water-soluble potassium. In soil-based profiles, K availability is a feature of mineralogy and past fertility management practices.

Sandy rootzones often have poor reserves of K due to low CECs of most sands. Leaching removes K and where the soil has low CEC, that removal can be very fast if a soluble form of K is used.

Nitrogen

Nitrogen (N) has been likened to the accelerator in a car. If turf growth is not constrained by deficiencies in other nutrients, its growth can be regulated by the amount of N applied. This is particularly the case
on sandy rootzones where delivery of nutrients to plant roots is efficient and quick. As a result, turf managers can control the degree of vigour and lushness with high or low applications of N. However, like K, N is not held in sandy rootzones. The only way N and K can be held in sandy rootzones is through adsorption onto humic colloids. The role of organic matter will be discussed separately, but only the humic fraction has anion exchange capacity and this is always low in a sandy soil. The amount of N applied, or required for good turf growth usually exceeds a sandy soil’s holding capacity. Therefore, nitrogen must be applied based on a nutrient budgeting approach. For environmental, economic and amenity considerations it is best to minimise the amount of N applied. Over application of N can waste money and can lead to disease outbreaks. The golden rule with N is ‘a little and often’. Nitrogen is generally retained better on soil-based profiles in view of the higher organic matter content of these soils. However, N can leach or volatilise from soil-based media too and the same rule of ‘a little and often’ should also apply.

**Sulfur**

Sulfur (S) is taken up by plants in the sulfate form and is usually applied in this form [e.g. ammonium sulfate, potassium sulfate, calcium sulfate (gypsum)]. Sulfate is an anion and like nitrogen, is very poorly held in sandy soils. Plant nutrient deficiency symptoms of N and S are similar. Sulfur is important for increasing the protein content of plants, for chlorophyll production, to make enzymes (including nitrate reductase), and vitamins (particularly some B vitamins), and for nodule formation in legumes. Some sulfur is required early in the plant’s life and helps seedlings to survive cool, moist conditions. Although plants require similar amounts of phosphates and sulfates, 90% of phosphorus demand is early in the life of the plant whereas 90% of sulfur demand is required late in the season. Plants take up phosphate more readily than sulfate. This means that heavy applications of phosphates can suppress sulfate uptake.

**Micro-nutrients**

Micronutrients are present in the soil at parts per million or parts per billion. They are weakly held in sandy soils but large roots systems can potentially forage widely in sandy soils. Roots are often more constrained in soil-based media due to compaction and while trace elements may be present in higher amounts, they may be inaccessible. The use of tissue testing is particularly important for trace elements as this will indicate if plants are accessing sufficient trace elements to meet their physiological needs.

**Topdressing with compost?**

Over the past 5 years we have seen an increasing use of recycled organics (mainly compost) for topdressing. On the plus side, compost adds some nutrients and increases soil organic matter content, which is critical to retention of soil nutrients. Turf certainly responds to topdressing with compost. On the minus side, it may result in the development of a very fine organic layer at the surface that reduces drainage. In addition, an organic layer from compost applications can create a slippery surface reducing traction underfoot and impacting on the quality of the playing surface. Use of compost should be seen more as a method for stimulation of the turf than to improve physical attributes.

The following keys to success might be useful when attempting to maximize the implementation of compost topdressings while minimizing any potential detrimental effects associated with this practice.
- **Determine your goals for implementing a compost topdressing program.** Are you interested in composts as organic fertilizers, soil conditioners or to introduce a form of disease suppression? Determine your goals and expectations early in the process.

- **Get to know your local compost producers,** distributors, other superintendents that have tried using composts, university staff working in the area, and state and local solid waste authority personnel and regulations.

- **Remember that not all composts are created equal.** Some positively, others negatively, and some have no impact on turf health and the more you know about the compost you are considering, the greater the chances of a successful outcome.

- **Pay close attention to the consistency or variability of product’s quality.** The amount of bulking agent present, the degree of maturity, the particle size, and texture of the compost are four important things to look out for.

- **Make it your business to know WHAT you are applying** (elemental analysis, pH, CEC, parent material of compost, process by which it was generated, nutrient release characteristics, organic matter and ash content, soluble, ammonia, organic acids, etc).

- **Combine compost topdressing applications** with spring and autumn core cultivation events via blending with cores and dragging.

- **Modify your application rates to meet your target fertility goals.** Maximize the potential benefits of the compost topdressings by making applications when the turf is actively growing.

- **Develop an effective application strategy** that can be completed in a relatively short period of time from the time the compost is applied to the time irrigation is applied to the turf.

- **Always include an appropriate set of internal control plots** so that you can truly gauge the effect of a newly implemented management practice. Specifically in the case of evaluating the effects of a compost topdressing program on fairways, you might consider including both a non-treated area (no coring or compost) and a cored but not topdressed area to assess the effects of your coring and topdressing programs. Without such internal control areas, it is impossible to accurately assess any practice.

- **Consider modifying your standard fertility program** to account for the additional nutrients being applied or incorporated.
Foliar Analysis

Many labs and consultants believe foliar testing can answer all questions for all parties. While a very useful tool for calibrating fertiliser responses and fertiliser programs it is our experience that foliar analysis has some profound difficulties that mean it is only useful in conjunction with soil analysis and “whole system” consulting.

There are many reasons for this including-

1. Efficient homeostatic mechanisms in living things that mean even when a plant is near death, it has a composition close to normal. If a nutrient is limiting the plant’s growth slows to ensure that that limiting element does not become so limiting that necrosis sets in. It is very rare to see gross deficiencies or toxicities in foliar analysis.

2. Difficulty in distinguishing between a real and a physiological deficiency given the many complex nutrient interactions that occur. Thus copper, for example may be deficient not because the soil is low in copper but because excess phosphorus renders it physiologically inactive.

3. Lack of a large data base for a given species or annual range data base for a wide range of species used in the turf industry.

4. Difficulties in distinguishing physiological nutrients in tissue from those on the exterior of a leaf. Iron is a particularly difficult element in this regard and we do not believe we have ever seen a turf foliage sample not contaminated with surface iron deposits.

5. The foliar analysis tells us nothing about why the nutrient is deficient/toxic.

Table 1 is a list of typical ranges for plant nutrients in the young foliage of turf grasses. It has been generalised across a number of species. Note how wide the range of some elements is in turf tissue associated with perfectly normal growth.
### Table 1. Typical Ranges of Plant Nutrients young leaves of Turf grasses.

<table>
<thead>
<tr>
<th>Element</th>
<th>% by dry weight</th>
<th>ug/g dry weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen N</td>
<td>2.0-4.5</td>
<td></td>
</tr>
<tr>
<td>Phosphorus P</td>
<td>0.2-0.5</td>
<td></td>
</tr>
<tr>
<td>Potassium K</td>
<td>2.0-4.0</td>
<td></td>
</tr>
<tr>
<td>Calcium Ca</td>
<td>0.5-2.0</td>
<td></td>
</tr>
<tr>
<td>Magnesium Mg</td>
<td>0.1-0.5</td>
<td></td>
</tr>
<tr>
<td>Sulphur S</td>
<td>0.2-1.0</td>
<td></td>
</tr>
<tr>
<td>Iron Fe</td>
<td>100-500</td>
<td></td>
</tr>
<tr>
<td>Manganese Mn</td>
<td>30-100</td>
<td></td>
</tr>
<tr>
<td>Zinc</td>
<td>40-100</td>
<td></td>
</tr>
<tr>
<td>Copper Cu</td>
<td>5-50</td>
<td></td>
</tr>
<tr>
<td>Boron B</td>
<td>5-50</td>
<td></td>
</tr>
<tr>
<td>Molybdenum</td>
<td>1-4</td>
<td></td>
</tr>
</tbody>
</table>


Remember that these results have been generated by looking statistically at a wide range of plant tissue analyses.

**Making the Most of Testing**

Some general conclusions would be:

- That soil and foliar testing alone may be able to pick out gross abnormalities in nutrient testing but are difficult to use in isolation for fine tuning fertiliser programs.

- Soil analysis alone is a very crude tool for predicting nutrient uptake and is most useful for obtaining the correct balance of pH and cation exchange properties associated with healthy normal soil.

- To inform and refine fertiliser programs an integrated approach using actual growth observations, together with soil and foliar analysis and a skilled and experienced interpreter is needed.

**Sampling Soils and Foliage**

The general concept is to submit to the lab a “representative” sample of soil, foliage, or water. For turf culture the following rules should be observed:
1. Divide areas off into “land units”. In agriculture this is usually a paddock but in turf care it is any unit which has been treated in the same manner and has the same or similar soil properties. It could be a football ground, a green, a fairway, or sections of a fairway showing two different soil types.

2. Use a spade, corer or purpose built sampling corer to take subsamples from 0-100mm (as a general rule) but whatever you do take from the same depth in each subsample.

3. Take approximately equal sized subsamples from each subsampling point and combine together.

4. In a very uniform land unit such as a sand table green 6 subsamples is our usual advice, in a natural soil which is inherently more variable, 12 is our advice.

5. Remove turf and thatch being careful not to lose too much soil when discarding.

6. The usual advice is coning and quartering but breaking up cores and thoroughly mixing in a bag about 5 times the volume of the combined subsamples is adequate.

7. Once thoroughly mixed take about 200 grams (2 cup-fulls) for most chemical testing labs.

In some cases targeted (deliberately biased) sampling is performed such as to check salt accumulation at the surface, phosphorus distribution down a profile, or the development of acidic layers. Seek specialist advice from your consultant or laboratory about this.

Sampling for physical analysis is very different and depends on the purpose of the exercise. Consider the following examples-

1. Permeability or infiltration rate. For soils this has to be done in undisturbed soil cores or preferably in the field. Do not send us bags of pulvred soil for permeability, the results tell you more about structural stability than field permeability. In sandy rootzones this is also true if surface organic matter and thatch layers are present but in general disturbed sands can be repacked to give meaningful permeability because they have no structure.

2. Density. Sands can be repacked but for soils intact clods about 25-50mm diameter for analysis by the “waxed block displacement method” give the most reliable results.

Taking foliage samples requires-

1. New shoot growth to be harvested. Do not include dead and thatch material.

2. Clean, sharp mower blades are acceptable if the catcher is clean and empty and you are not concerned about the accuracy of the iron measurement.

3. Otherwise use clean, sharp scissors and a sheet of paper.

4. Provide about 100gram wet weight minimum (10-20g dry weight).

5. Keep samples in a paper bag to start the drying process and avoid sweating and place in the fridge until pick up. Do your best to ensure they get to the laboratory within 24 hours.

6. Do not sample after foliage spraying with liquid feed, chelated trace element solutions or spreading fertilisers. Wait at least a week to a fortnight respectively.

7. Sample only when turf is actively growing.
Plastic gloves should be worn if monitoring sodium chloride levels but clean hands do not usually affect other results.

Spring is the usual time when foliar testing is performed but in fact high Summer will give a better “historical record” of your early season feeding program. Spring testing may tell you more about the plant’s reserves from last season. Targeted foliar analysis, for example N, can be used at any time to inform the current feeding program.

Remember that mobile nutrients, e.g. N, S show more rapid responses to feeding programs than elements that are stored and immobile e.g. P, Ca, Mg. Analysis for the least mobile elements such as metallic trace elements may reflect nutritional episodes several months ago.

The following effects of storage on soils and foliage should be recalled-

1. If storing wet soil samples sealed in plastic, anaerobic conditions can seriously alter pH, N, P, and S results. Preferably do not sample when very wet or dry them somewhat prior to packing and get them to the lab within 24 hours. Air drying your own samples can save you some costs at some labs.

2. Drying produces various artifacts in soil sampling. There is some considerable merit in adopting the Australian Standards approach to potting mix and soil sampling, keep them in field condition and perform extracts on a volume basis.

In the Laboratory

All soil analysis is basically in three stages-

1. preparation of the sample to produce a uniform dry product
2. weighing and extraction of the soil with various solutions for the different tests-
   - pH – water and/or Calcium chloride
   - EC- water
   - Soluble salts – water
   - Exchangeable cations and ECEC – most common is ammonium chloride
   - P – solutions that dislodge the phosphate from its bound form on iron and aluminium minerals e.g. flouride, (Bray), carbonate (Colwell and Olsen).
   - Available N and S – water or dilute acetate solutions
   - Trace Elements- organic chelating agents e.g. DTPA, EDTA.
3. Shaking the soil with its extracting solution for a standardised period of time
4. Clarifying and preparing the extract solution by centrifuging, filtering etc.
5. Presentation of the clear extract solution to various devious and very expensive instruments. e.g.- pH, Nitrate, Sulphate, Ammonium chloride – ion selective electrodes.

Metallic ions e.g. Na, Ca, Mg, K, Fe, Zn, Mn, Cu – atomic absorption spectrometers
Phosphate, ammonium, sulphate chloride, colourimetric analysis (make it react with something to form a colour that can be measured).

Just about everything except pH: Inductively coupled plasma (ICP) arc spectrometry with magnetic resonance spectrometry detection for trace elements.

ICP is the most modern technique and potentially the cheapest if high volume analysis is performed. Being very expensive the instrument suits only the larger labs.

6. All these instruments compare the electronic readout of the extract with that of standards and control soils. Calculation of results is now automatic in most instruments and printouts are transferred electronically or manually to databases for result compilation.

7. In some, supposedly more advanced result formats, bar charts or histograms are given comparing your result with a supposed “normal range”. While visually attractive such presentation can be very naive. Normal for what, couch in NT or ACT, Spring or Summer? Such result formats can lead to erroneous interpretation and are highly subject to opinion evidence. They work well in human pathology labs because humans have a very advanced homeostatic mechanism, are a single species, and vast amounts of historical statistics are available.

8. Some labs (usually fertiliser labs) employ special software to recommend fertilisers. Given what I have said about the deficiencies of soil testing in predicting nutrient requirements I remain highly sceptical of this approach. The real skill is for an experienced turf consultant or consulting analyst to combine the information from the soil, plant tissue and background fertiliser and site history to produce an integrated soil management program. This may or may not involve changes to your fertiliser program.

Our lab is using the single extract “Mehlich III” extract for rapid analysis of available nutrients. Being rapid and cheaper it is possible to use such tests more frequently throughout the growing season to monitor fluctuations in the labile nutrients such as nitrogen, phosphate (especially in sandy rootzones), sulphate and trace elements.

Concluding Remarks

Your job as a green keeper / turf manager is not to be an expert analytical interpreter but to know enough to ensure the samples are representative and you understand why the consultant has come to the conclusions they have. A close parallel would be the informed patient in the doctor’s surgery understanding why the doctor has made a certain prescription instead of just meekly accepting it. This extends to the type of testing performed also. Managers should ask whether their current testing is answering their questions.

With experience, of course, you will be able to perform more and more interpretation for yourself and get the specialist in only when you are out of your depth. With some simple laboratory apparatus the advanced turf manager could perform more tests for themselves to improve the frequency of monitoring. This could include-

- pH and EC,
- nitrate, ammonium, and phosphate using test strips.
Examples of Interpretation Difficulties

Example 1: We had a turf grower with the clearest foliar iron deficiency symptoms you have ever seen (interveinal chlorosis leading to striping and overall yellowness). Everything pointed to it including an alkaline soil pH, excessive phosphorus levels (P locks up iron), worse in cold weather and a patchy pattern correlating with undulations in the ground. Strangely, he had used iron sulphate well watered in with no result. Foliar analysis showed perfectly normal iron levels when great care was taken to sample only fresh clean foliage before any mowing occurred. We never see anything but elevated iron results in turf (probably due to proximity to soil, iron from mower blades etc). We decided to ignore the foliar analysis and get him to trial foliar chelated iron as well as soil applied iron repeatedly for 2 weeks. Result: rapid improvement after about 2 weeks. It was iron deficiency. The reason he had not seen an improvement previously was that the iron he added was quickly locked up in the alkaline soil. Only by repeated application and a direct chelated iron application was enough iron made available physiologically to assist the plant overcome the deficiency.

We have come to the conclusion that diagnosing iron deficiency in turf is impossible without being armed with soil and foliar testing, examining foliage for symptoms, having knowledge about fertiliser programs and using an integrated interpretive approach based on an in depth knowledge of soil chemistry and nutrient interactions. The same can probably be said about other trace elements. How many green keepers have this knowledge and how many labs provide such a level of consulting?

Example 2: We sometimes get the opportunity to see a foliar and soil test together. In one such instance the soil in question showed fairly normal properties, pH was around 5.7, there appeared to be normal exchangeable cation levels especially potassium, but the extractable iron and manganese levels looked high. Phosphorus level was normal.

The foliage tests showed several things quite clearly-
1. Normal P and K levels: not surprising given the soil test results.
2. Very deficient Ca and Mg levels despite apparently adequate levels on the CEC.
3. Very over-range iron, sulphur, and manganese levels.

Putting the soil and foliage tests together with field observations the full story emerged-
1. Regular feeding with NPK fertiliser meant that the rather small CEC in a sandy rootzone was simply incapable of supplying the necessary Ca and Mg (remember that feeding with one element leads to a demand for others as growth is stimulated). It is also possible that high K input has limited Mg supply (nutrient interaction).
2. Poor drainage conditions had increased the uptake of manganese since its mobility is increased in poor aeration conditions; this was explained also by the high soil test.
3. In order to maintain greenness in the poor drainage conditions the manager had over-used iron sulphate some of which resided on the foliage.

This result then clearly illustrates an interaction between different nutrients, an interaction with physical conditions, and the deficiencies of many feeding programs. Of particular interest is Calcium. This element should be the focus of increasing research for sandy rootzone culture. In hydroponic culture
calcium is the most problematic element since it has low solubility in aqueous environments, and low mobility within the plant. It has been found in hydroponics, for example, that the best way to increase calcium in the plant is not to add more to the solution but to drop the salinity of the feed solution dramatically, in doing so, growth rates overall are reduced and calcium catches up. A sandy rootzone culture is effectively hydroponic culture, how many fertilisers contain available calcium?