

Soil Chemistry: Theory and Practice

1. *Some Basic Theory Revision*

Profile Morphology

The form a soil takes depends on the parent material, climate, slope and organisms (including man) acting over time.

A soil in nature shows certain predictable trends as we proceed down the profile. The Kings School is situated in an area of Shale parent material capping Hawkesbury Sandstone. The typical profile forming on this shale is the Cumberland Clay Loam. It's O horizons, being associated with forest, are typically deep and composed of three distinct layers of forest litter defined by the degrees of decomposition. The A1 horizon is usually 200-500 mm of a loam to clay loam texture with moderate structure and a red brown to dark brown colour. This changes to an A2 which is paler in colour, a lighter texture, and more acidic than the A1 above. An abrupt texture change is usually seen into the B1 that is a red or yellow clay with moderate to strong texture.

The Cumberland Loam is moderately fertile but prone to compaction and truncation (loss of the O and degradation of the A). If treated well, it is amongst the most fertile of Sydney's soils and its use for orcharding and horticulture in the early days of settlement is proof of this.

Slope Position

The Cumberland Loam shows various forms mainly related to slope position. Profile drainage related to position of the profile in the landscape has the most profound effect on morphology after parent material and climate. As you proceed down the Cantena (down-slope) increasing signs of hydromorphic characteristics are seen. These include: -

- ◆ Increasing depth of the pallid or bleached A2 horizon.
- ◆ Decreasing amount of red colour throughout the profile and increasing yellow.
- ◆ More dispersive characteristics due to increase in exchangeable sodium and magnesium and decrease in calcium.
- ◆ Higher pH.

Colour

Colour is the most obvious guide to soil properties. The A horizons in a healthy state (good organic matter levels) are dark in colour. The absence of dark colours and presence of light blonde, grey or pallid colours at the surface are clear signs of degradation.

Texture

Texture is usually directly related to water-holding ability with water holding increasing with clay content.

Resistance to compaction is also strongly related but very strongly structured clays can be resistant. Heavier textured soils must not be worked at moisture contents higher than consistence indicates. Farmers would never work a heavy clay when wet.

Structure

Structure is one of the most important soil properties. The most fertile agricultural soils in the world are clays but a degraded and unstructured clay is almost useless. Preserving soil structure is thus essential in soil care. This is done by observing the following rules:-

- ◆ Do not work the subsoils at high moisture content; wait until the horizon dries out.
- ◆ Use gypsum to preserve responsive structure. If a soil is not gypsum responsive do not use.
- ◆ Protect structured heavy soils by confining traffic to pathways.
- ◆ Use mulches and organic matter at the soil surface to enhance and improve soil structure.

Field Observations

Very many problems in soil care can be solved by intelligent observation.

Inclusions

- ◆ Fe/Mn nodules (red and black rounded nodules) particularly at A/B boundaries are further evidence of periodic waterlogging.
- ◆ Stones or nodules at the surface are likely evidence of past erosion due perhaps to excessive grazing or drought. A1 will usually be absent and the soil may start with a coloured B1. Tree roots exposed, highly compacted. Always try to find an undisturbed forested area nearby to see what the soil should look like in its natural state. Particularly note compaction and structure.
- ◆ Old tree roots in a pasture are a guide to what the natural vegetation may have been like.

Vegetation

An essential tool in site analysis is the spectrum of weeds and natural vegetation present. These can be broadly summarised as: -

- ◆ Thistles, nettles, docks - weeds of high fertility, indicate high nutrient and moisture conditions sometimes associated with animal night refuges or proximity to stockyards.
- ◆ Paspalum and white clover in an unimproved pasture indicate acidic but reasonable fertile conditions.
- ◆ Carpet grass (*Anoxopus affinis*) and dandelion (*Taraxacum spp.*) in a pasture usually indicate low fertility and acidity.

Natural Vegetation

Hydromorphic species, such as *Casuarina cunninghamiana*, *Juncus* and *Scirpus* indicate areas of poor or periodically waterlogged conditions.

Other classic associations such as the Red Gum flora of Western Sydney, *Eucalyptus maculata* in clay soils, and Ironbarks in severely acidic clays are important.

Physical Properties

Soil chemistry is profoundly influenced by soil physical properties and visa versa. I have a simple test to determine if soil physics is limiting in a given situation. The test should be done when the soil is moderately moist.

Table 1. A Simple Test of Compaction for Soil

TEST	COMMENT
A finger can be pushed into the soil up to the knuckle.	No compaction, the soil is perfect for bedding plants and annuals.
The finger is difficult but a stick can be pushed in.	Suitable for annuals, perennials and shrubs and turf.
A hand trowel can be pushed in.	Some compaction but suitable for low care shrubs, perennials and trees.
A trowel is difficult but a fork can be pushed in.	Compacted but suitable for rough turf, trees and hardy shrubs.
A fork can be pushed in with difficulty.	Badly compacted, suitable only for rough grassing and some trees and hardy shrubs.

Obtaining the correct physical properties for a given situation is more difficult than adjusting chemical properties. In all cases, physical properties are better established in the beginning for trouble free growing.

Soil Chemistry

The following discussion is a very simplified revision of basic soil chemical properties. It should allow the technician to have a basic understanding of soil test results and why certain recommendations are made.

pH

The acid/alkali balance is very important in maintaining optimum availability of applied nutrients. At very acid pHs, soluble aluminium becomes toxic, phosphate is unavailable and calcium levels can be low. At high pHs, iron and other trace elements are rendered unavailable because they are locked up as hydroxides and carbonates.

The very sandy nature of most turf root-zones means that pH is poorly buffered and is easily changed by fertiliser additions. Urea, ammonium sulphate, and sulphate of iron are the most common culprits leading to the development of acidity. Use of these fertilisers should be combined with regular soil pH checks to keep pH within the range 5.5 to 6.5 (water extract or 5.3 to 6.0 in calcium chloride[CaCl₂]). pH in CaCl₂ is given more emphasis usually.

It is also common to find playing fields and greens established on naturally alkaline soils such as beach sands that contain a high proportion of shell grit. Soils of this type can show pHs of up to 8.0. Iron deficiency (chlorosis and overall paleness) is commonly seen in such soils and constant responses to iron sulphate additions will be seen. It is sometimes possible to add so much iron sulphate over time to bring this pH down and get rid of the lime (ferrous iron is an acidifying agent), but the usual method of control is frequent use of iron chelates as a foliage spray. Other trace elements may also need to be applied as foliar chelates. It is possible to prepare the ground with Ag Sulphur that is highly acidifying but great care is required.

Cation Exchange Properties

The Cation Exchange Capacity (CEC) of a soil is a negative charge existing on soil particles that tends to hold the positive charged cations against leaching. The common cations are sodium, potassium, calcium, magnesium, ammonium and aluminium. The phenomenon is called cation

exchange because it is possible to displace or exchange one cation for another. For example, excessive use of ammonium fertiliser can displace calcium leading to poor buffering and soil acidification. Organic matter and most clays have a high CEC, whereas in sands it is low. A reasonable sized CEC for sandy turf would be 5 meq/100g.

There are many ways to express the amounts of the major cations on the exchange capacity. Some laboratories use parts per million (ppm or mg/kg); some give millequivalents/100g of soil. The problem with this approach is that the correct amount of these cations increases as the CEC gets bigger thus a wide range of cation levels can be acceptable. The correct way to express the amount is to say what proportion of the CEC is filled with each cation, that is, to convert the meq/100g to a percentage of the CEC. Thus, results are more easily understood if expressed as in Table 2,

Table 2. Normal Ranges of Exchangeable Cations

CATION	NORMAL RANGE	COMMENT
	% of CEC	
Sodium	<5	Sodium is not a nutrient
Potassium	5-10	Lower amounts in heavy clays
Calcium	60-75	Calcium must be 3-6 times the Mg level
Magnesium	15-25	Important in chlorophyll production
Aluminium	<2	Toxic element in larger amounts

Phosphorus

This important element is subject to a lot of misunderstanding due to the commonly held view that Australian soils are all low in P. While this may be true for most unimproved soils, in intensively used soil, we often find excessive amounts due to an overemphasis on P in maintenance feed programs. We use the data in Table 3. to interpret results on a Bray (acid fluoride) extract.

Table 3. Guide to Phosphate Sufficiency Bray No 1 Extract

Mg/kg of P	Comment
0-5	Inadequate for all but some native plants
5-10	Adequate for park trees and pasture or fairway grassing
10-20	Adequate for mass planting and good looking turf
20-40	Most turf, upper end adequate for high quality turf
40-80	Annuals and bedding plants
>80	Excessive in almost all situations

For most greens and intensive turf, numbers around 30 mg/kg are usually more than adequate, if the amount is over this, insoluble phosphates can cause trace element problems. The P level can change rapidly in sandy root-zones but in soils it may take a year to see apparent changes.

Producing a test result of the correct format is only one part of the story. Generally the correction of problems and the production of recommendations on rates and special fertiliser mixes will require the services of a skilled agronomist/soil adviser. As a guide to the art of proper pH correction, we use Table 4.

While all these ameliorants are better worked into the soil, this is not possible in an existing turf and surface additions must be used; these are effective, but to incorporate liming agents to greater depth they can be mixed with coring sand and used during coring or hollow tyne operation. The formulation of rates and methods of addition depend on many factors and the services of a qualified turf consultant is usually required, Table 4 gives no information of the rates required.

Table 4. pH and Ca/Mg Ration Adjustment

		pH		
		Acidic	5.3-6.3	Alkaline
Ca/Mg ratio	High	Magnesite or Dolomite	Epsom salts	Epsom salts plus Iron Sulphate
	3-6	Dolomite/ lime	no action	Iron Sulphate
	Low	Lime	Gypsum	Gypsum plus Iron Sulphate

Once these basic properties of pH, Ca/Mg ratio and exchangeable cations have been properly balanced, good responses to a normal feeding program should be seen. However, there are many situations (eg alkaline sand) where continued monitoring and development of fertiliser programs will require skilled advisory help to give the best and most trouble free performance.

Some examples: The typical turf soil and the perfect turf soil. Tables 5 and 6 that follow give a summary guide to selection of soil properties.

Table 5. Physical Requirements based on Particle Size Fractions

Use Category	Definition	Size Fractions					
		Sand				Silt	Clay
		Coarse	Medium	Fine	V. fine		
		1-2	0.2-1	0.1-0.2	0.05-0.1	0.05	0.002
General purpose	Shrub & tree, rough grass	Wide range of soils suitable. Silt should be <10% clay <20%. Suitable Textures range from loamy sands to clay loams.					
Heavy Traffic areas	Mostly turf, under important trees, golf & bowling greens	10%	40%	30%	15%	<5%	<5%
		Mid point of range only				Total <8% silt + clay	
Turf top-dressing	Improving, levelling playing fields	0%	50%	40%	5%	<5% silt + clay	

Table 6. Chemical Criteria

ANALYSIS	SUITABLE RANGE	COMMENT
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PH in water 1:2 or 1:5	5.5 to 6.5	Most landscape plantings
	4.6 to 5.5	Acid loving plants. Grassing OK but not highly vigorous. Many native plants OK
	6.5 to 8.0	Choose alkali tolerant plantings if conditions cannot be ameliorated.
EC 1:2 or 1:5 mS/cm	1:2 extract ratio	1:5 extract ratio
Sandy loams	<0.4	<0.2
Loams	<0.6	<0.4
Clay Loams	<0.9	<0.5
	Salinities above these values should be treated by:- 1. Reclamation based on expert advice 2. Choice of appropriate plant species 3. Rejection if 1 or 2 are not possible	
Cation Exchange Capacity	The balance of sodium, potassium, calcium and magnesium should show:-	
Exchangeable sodium %	<6%	
Ca/Mg ratio	2-6	
Ca plus Mg saturation	65-85%	
Bray extractable P	20-30 ppm	Rough grassing and tree planting
	30-50 ppm	High grade turfing
	30-50 ppm	Exotic trees and shrubs
	10-25 ppm	Native trees and shrubs
	50-70 ppm	Annual garden beds & flowers

2. Applications

Truncated Profiles

Where the A horizons have been removed, the profile has usually lost all its bioaccumulated nutrients and organic matter and bare hard clay is often seen.

Re-establishment of the vegetation requires man to intervene to reimpose a bioaccumulated layer with a combination of:-

- ◆ Ameliorants such as gypsum.
- ◆ Fertilisers.
- ◆ Organic matter
- ◆ Imported A horizons
- ◆ Physical protection to ameliorate the surface physics (temperature, moisture, and wind extremes).
- ◆ Time.

Tree Health

The benefits of trees in the landscape do not need discussion here, but very often trees' needs are not understood or considered. The main enemy of trees can be discussed under the following categories.

- ◆ Soil Compaction

Especially in schoolyards, the soil can become very compacted. This is mainly due to the fact that the soil area must be used for student's needs even when the soil is wet. The farmer would not work or traffic a soil when wet but the groundsman has no such luxury. When wet, a soil has lower strength and is easily compacted by human feet. Remember that the pressure a person's foot exerts on the soil is at least as much as a wheeled vehicle which applies pressure exactly equivalent to the tyre pressure; 20 to 60 psi.

Compaction can be a rapid event, waiting for nature to reverse the compaction is much slower. The best solution to the problem is to install a sandy root-zone under the tree just as you would for a high-grade playing field. Such root-zones will still conduct water, oxygen and nutrients even when fully compacted.

◆ Interruption to nutrient cycling.

In the forest the O horizon of bioaccumulated nutrients is essential to the growth of the trees. With remnant trees and planted trees, the leaf litter layer is almost always absent and the longevity of the tree is shortened. In the natural forest a Brush Box may live for over a thousand years. In an urban soil we are lucky if the tree lasts 100 years before senility sets in.

Actions which will assist the tree are:-

- Returning mowings to the soil (do not remove clippings); do not mow wet soil.
- Learn to like the natural appearance of leaf litter and do not remove it.
- Prevent pedestrian access to important groups of trees.
- Install mulched garden beds under tree canopies where possible.
- Use fertilisers, based on soil tests, to apply those nutrients lost through interruption to nutrient cycling.

◆ Raising soil levels around tree roots.

This is the commonest cause of acute tree decline and is nearly always fatal to large established trees. There are methods of avoiding tree death by suspended slabs, gravel layers etc but none of these can be guaranteed to save the tree. If it must be done, always use surface layers of a coarser texture than the existing topsoil.

3. Use of Fertilisers

Mineral and organic fertilisers are commonly used to enhance plant growth. They are not a substitute for correct physical properties but they can make plants more resistant to physical stress.

Fertilisers are divided into straights meaning single salt fertilisers such as ammonium nitrate, superphosphate, nitrate of potash, sulphate of potash, and compound fertilisers that are mixtures of straights. All organic fertilisers are compound. Both types can be applied as solid basal dressings before planting, side dressing during growth, or as liquid feeds having the advantage of rapid introduction to the root-zone. Many can be applied as foliage feeds but root uptake of nutrients is more efficient. Foliage feeding is mainly used to rapidly correct known deficiencies.

Straights are used to correct known deficiencies determined through observation of symptoms or by soil testing.

Compounds are generally used on some kind of regular basis to generally improve plant growth. The ideal compound will apply ratios of nutrients in the exact proportions the plant needs them. A plant is composed of NPK in the ratios 5:1:3 in general terms and a fertiliser used regularly should reflect this.

I am critical of many compounds used on a regular basis, particularly in turf care. The assumption that Australian soils are low in P has led to an overemphasis on P in compound fertilisers. I would propose that we divide these fertilisers into "Establishment" and "Maintenance" fertilisers. No 17 lawn food for example is too high in P for maintenance and leads to excessive P accumulation in soils. It is an excellent establishment fertiliser for turf on new ground but I would prefer that you maintain turf with a feed containing more potassium and less phosphorus. ie

	NPK ratio
Turf Establishment	15:10: 5
Turf maintenance	15: 2: 10

Note that the maintenance feed reflects the composition of plant tissue. This approach should also apply to feeding all soils.

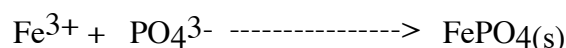
Compounds can be broken down further into low and high analysis. In intensive use, the high analysis fertiliser is preferred. Despite the higher cost, they are better value for money given that you are not buying unwanted salts, generally sulphate.

Sometimes a deliberately biased fertiliser is chosen to correct known soil problems. If a soil is shown to be very low in potash we may choose a one off application of a very high K level for example. Do not play with these ratios unless soil properties are known. If the correct NPK ratios cannot be found in the commercial range then some suppliers will make special blends for you.

Fertilisers do affect other soil properties, particularly pH and in high use situations pH should be checked regularly and adjustments made.

A special case is the feeding of P sensitive native plants. It has been shown that some native plants (by no means all) are sensitive to excessive amounts of P and suffer toxicity symptoms if fed high amounts. Symptoms of this toxicity are various but include lack of growth, apparent iron deficiency (interveinal chlorosis of youngest leaves), red colours starting in oldest leaves, drop of oldest leaves, tip necrosis in the worst cases, and a susceptibility to root rot fungi such as phytophthora. The condition can occur in pot culture and in soils and is often a compounding factor in transplant and environmental shock. Plants most susceptible are plants in the Proteaceae, Rutaceae, some Fabaceae and Mimosaceae, some Myrtaceae and Haemodoraceae have been shown to exhibit problems.

Recent research has shown clearly that this is essentially a nutrient interaction between iron and phosphorus. Addition of high levels of phosphate to a soil results in an insoluble phosphate being formed-



This is the same reaction resulting from rust converter being painted on rusty metal, phosphoric acid being the active ingredient. It is known from crop plants that high P levels can induce Cu, Zn, and Fe deficiencies. This is called a nutrient interaction.

The same reaction occurs in the plant tissue and the P sensitive plant exposed to excessive P uses all its iron reserves to lock up P in harmless form. Combine this with a limited iron supply and you have problems.

The key to avoiding this problem is limiting P inputs and maximising iron supply. You can do this by-

- ◆ Using only low P fertilisers, such as native plant food or, in the most sensitive plants, no P fertilisers such as Nutricote purple.
- ◆ Maintaining an acidic soil pH thus improving iron supply and locking up P in the soil.
- ◆ Using sulphate of iron to both lower soil pH and add essential iron.

Fertilisers that we have found particularly dangerous are poultry manure based products, mushroom compost, fertilisers containing high levels of water soluble P (eg those containing superphosphate). Some fertilisers such as blood and bone are high in P but can be safely used at least in the first few dressings as the P is in insoluble form. Remember that once P has been added to a soil it sticks there and can never be removed.

CASE STUDY CRIB POINT MORNINGTON PENINSULAR

Sandy red podsolics on medium grained Sandstone.

Very sandy A horizon, heavy sandy clay B horizon.

Some areas covered in Native vegetation, one small area around an old house showing a darker loamy A horizon and supporting self regenerating exotic perennials and old orchard trees.

Chemical property	Native topsoil	Native weathered subsoil	Sandstone	Old orchard topsoil
pH	4.7	5.8	6.0	6.7
Exchangeable Cations (% of CEC)				
Sodium	5.1	2.9	10.5	1.1
Potassium	3.0	1.9	1.5	3.3
Calcium	47.0	25.0	19.8	80.9
Magnesium	38.5	70.1	68.2	14.7
Aluminium	6.3	0	0	0
CEC	4.6	11.9	5.3	14.0
Ca/Mg ratio	1.3	0.4	0.3	5.5
Phosphorus	0	0	0	13.0

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