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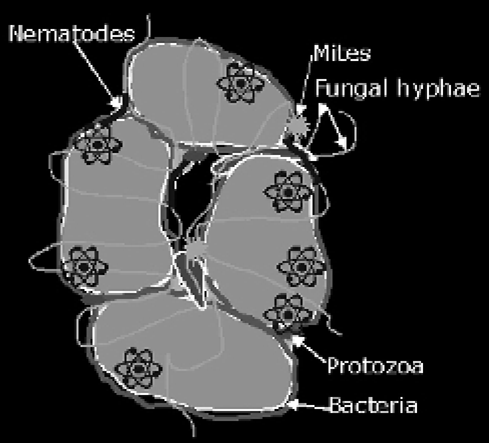
Healthy soils for great turf

Proceedings of a workshop held at Cleveland, 20 February 2006



Queensland Government
Department of Primary Industries and Fisheries

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for
great turf

Proceedings of a workshop held at Cleveland, 20 February 2006

Edited by Cynthia Carson

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The Department of Primary Industries and Fisheries (DPI&F) seeks to maximise the economic potential of Queensland's primary industries on a sustainable basis.

This publication provides information on chemical, physical and biological aspects of soil, all of which contribute to a healthy soil environment for growing turfgrass.

Acknowledgements

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In addition Dr. Neal Menzies and Dr. Weijin Wang were senior authors of papers on soil fertility and organic matter respectively.

The Queensland Turf Producers Association, Parks and Leisure Australia and the Golf Course Superintendents of Queensland were invaluable in advertising and supporting the workshop to their members. Thanks also to the Gold Coast Groundstaff Association for assisting us in advising their members of the event.

Thanks to Keith McAuliffe from Sports Turf Institute for providing an insightful summation of the workshop content at the end of the day itself; and to Larry Cooper, Matthew Roche, Stacey Konias and Judy Boge from DPIF Cleveland also made significant contributions to the success of the workshop.

A final acknowledgement needs to go to Dr Don Loch for his vision in recognising the need for this workshop and for his leadership in many other areas of DPIF's turf research programme.

Cynthia Carson
Senior Extension Horticulturist—Turf

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About the Speakers

(in alphabetical order of surname)

Dennis Baker

Dennis Baker is a qualified soil scientist with over 37 years experience in the private and public sector. Dennis has many achievements and awards in environmental science, specifically in the management of soil attributes such as landscape and acid sulphate soils, as well as specific environmental skills in the management and treatment of stormwater and contaminated soils. Dennis worked in both the Department of Primary Industries and the Department of Natural Resources as a soil research chemist and was manager of the Indooroopilly Analytical Services laboratory. He is currently Director of Environmental Soil Solutions Australia and represents Compost Queensland on the technical advisory committee to the Standards Australia on Soils, Potting Mix and Compost. He is a consultant to many of the leading soil manufacturers in Queensland, as well as the landscaping industry and Department of Main Roads, Queensland.

Kaylene Bransgrove

Kaylene Bransgrove is a scientist with the Department of Primary Industries and Fisheries based at Redlands Research Station, Cleveland. While Kaylene works across a range of project areas in lifestyle horticulture, she is primarily aligned to the Redlands-based turf research group, and a plant disease diagnostic group which is based at Indooroopilly. She has a background in plant pathology and is interested in developing a greater understanding of the disease issues affecting warm-season turfgrasses.

Dr Ram Dalal

Dr Ram Dalal has extensive research and development experience for more than 25 years. A diversity of his experience is evident from a short list of the projects he has been involved during this period. These include: Soil Carbon Dynamics; Carbon Sequestration; Potential of Feedlot Manure for Meeting Crop Nutrient Needs; Landscape Health Monitoring; Monitoring Sustainability in the Grains Industry; Long Term Fertility Trends in Soils of Queensland Cereal Belt; Restoration of Fertility Depleted Soils of Southern Queensland; Conservation Tillage and its Potential to Sequester Carbon and Affect Catchment Salt and Water Balance; Effect of Salinity and Sodicity Levels on Carbon Stocks and Fluxes from Soil; Functional Importance of Forest Biodiversity for Carbon Sequestration; and Greenhouse Gas Emissions from Sugarcane and Mangrove Communities in Coastal Queensland.

Ram Dalal was a senior principal scientist in the Queensland Department of Primary Industries, in Toowoomba until 1996 and since then he has been with the Queensland Department of Natural Resources and Mines, currently based in Indooroopilly. He is also an Adjunct Professor in the School of Land and Food Sciences, University of Queensland, St Lucia, Queensland. He has been a referee for Intergovernmental Panel on Climate Change on Croplands, Land Use, Land Use Change and Forestry, and a Consultant to the International Atomic Energy Agency. As a project team member, his team has been awarded three landcare awards and a DPI Achievement Award.

Dr Peter Kopittke

Dr Peter Kopittke is currently a Postdoctoral Research Fellow with The University of Queensland, School of Land and Food Sciences. He is working on a project investigating the heavy metal tolerance of various grass species to be used for the revegetation of contaminated sites. In addition, he lectures in second and third year Soil Science subjects offered by the University of Queensland. His main areas of interest lie within plant metal toxicities, soil fertility, plant mineral nutrition stress and adaptations, and soil salinity and alkalinity. Peter has experience in the disposal of industrial effluent to land, mine site revegetation, and in agricultural systems.

Dr Don Loch

Dr Don Loch was involved in broad-based research on pastures and pasture seed production with the Queensland Department of Primary Industries for 30 years from 1970 to 1999. His work was instrumental in developing technology to support the commercialisation of many new tropical herbage grasses and legumes during an exciting pioneering period with these species in northern Australia. At the same time, he bred two new Rhodes grass cultivars and registered several other new pasture cultivars.

Since moving to Redlands 6 years ago to initiate and lead the Department's new turf research program, Don has been instrumental in developing a wide range of research projects with the turf research group. These cover water use, bioremediation, stress tolerance (salt, shade and temperature), diseases, nutrition, weed control, characterisation and improvement of sports surfaces, DNA fingerprinting, and breeding. Don's own research interests centre on the development and commercialisation of improved varieties of exotic and native grasses, including their propagation, drought, salt and shade tolerance, nutrition, weed control, and general management—in fact, many of the same areas that he worked on successfully for many years in pastures.

Dr Rob Loch

Dr Rob Loch is the Principal Consultant for Landloch Pty Ltd, a consulting firm specializing in soil management. Landloch's work areas include minesites, industrial land, building sites, and agriculture, for locations across Africa, Australia, and the South Pacific. Rob Loch is a Certified Professional Soil Scientist, and an Honorary Research Fellow of the University of Southern Queensland. He has been president of the Queensland Branch of the Australian Society of Soil Science, and a member of the editorial advisory committee of the Australian Journal of Soil Research. Prior to forming Landloch, he was a Principal Soil Conservationist with the Queensland Department of Primary Industries.

Tony Pattison

Tony Pattison is a Senior Nematologist with the Queensland Department of Primary Industries and Fisheries based at South Johnstone, 90 km south of Cairns. Tony's work is currently focused on investigating soil health issues for the Queensland banana industry. The aim of this work has been to develop sustainable banana production systems using on-farm methods of soil health testing with a sound scientific backing. His input into soil health research has been the use of soil nematodes as indicators of soil health and investigations into what soil factors contribute to the suppression of plant parasitic nematodes. Tony's experience draws on work conducted in the banana industry, and also with vegetables, wheat and cotton.

Rachel Poulter

Rachel Poulter graduated from the University of Tasmania in 1992 with a Bachelor of Agricultural Science, with Honours and has recently completed her PhD through the University of Western Australia. Her thesis, 'Investigating the role of soil constraints on the water balance of some annual and perennial systems in a Mediterranean environment' assessed the impact of both chemical and physical soil constraints on the root growth and water use of various annual and perennial pasture species.

Rachel joined the turf research group here at Redlands in late 2003, where she has been involved in screening turf varieties for salt tolerance, in a controlled hydroponic environment. Rachel has also been involved in an investigation of the efficacy of new soil surfactants in combating soil non-wetting characteristics. In February 2006, supported by the Graham Price Travel Study Award from ASPAC, she visited the USA where she met with other researchers in this field, giving her access to information from international research projects.

Session 1: SOIL FERTILITY

What is a Healthy Soil?

Tony Pattison
Department of primary Industries and Fisheries, South Johnstone Research Station, South Johnstone

The discussion of "what is soil health?" often provokes emotive discussion. This is because soil health is a difficult concept to define and individuals have a differing concept of what soil health is, depending on the perspective of soil management. Soil health is promoted as being "*the land of milk and honey*" and being able to solve all the problems of modern agriculture. We take a more realistic view of soil health realising there are a lot of benefits from achieving a healthy soil, but with the knowledge that it may require some hard work to implement, requiring continual fine tuning and it may take some time to see the benefits. The definition we are using is for soil health is:

> *Soil health is the product or outcome of the functioning of the soil system for a given purpose.*

In our case we are talking about the soils ability to function sustainably for the production of turf. We need the soil to support the profitable growth of plants without impacting on the surrounding environment and without degrading the soil resource. This involves balancing applied inputs to promote profitability and greater production against decreasing inputs to protect the environment.

Symptoms of unhealthy soils can vary from poor plant growth, poor water infiltration and soil erosion to continuing plant disease and pest problems and other issues. The symptoms not only show themselves on site, but may also show up as poor water quality leaving the site due to excess sediment and nutrients in water ways. This draws unfavourable attention from the public and environmental regulators, and puts pressure back on agricultural industries to improve management practices.

The concept of soil health needs to take a holistic view of the soil. That is, we need to look at the physical, chemical and biological components that make up a living soil, how they interact with one another and how they interact to sustain turf production (Figure 1). We have typically looked at the components of soils as separate categories with little regard to their interactions and dependence on one another. Land use and management decision have a big impact on the interaction of the components that go into making a healthy soil.

Components of a healthy soil

Physical soil properties deal with the arrangement of soil particles and the movement of air and water in and out of the soil. For good physical soil health we need air and water to be in constant supply to promote plant growth. If physical soil properties are lacking, we generally use tillage to improve air movement into the soil or irrigation to supply extra water. We vary rarely think about what effects these practices have on the chemical and biological properties in the soil.

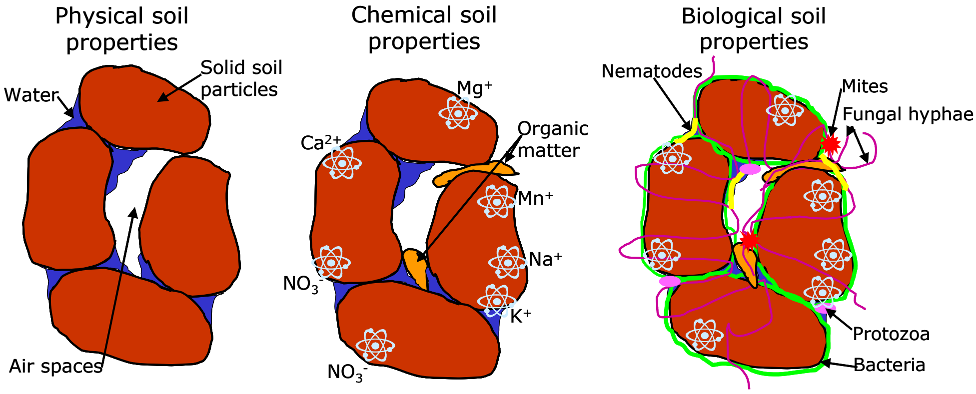


Figure 1: Physical, chemical and biological properties of soil interact to determine soil health.

Chemical soil properties deal with the nutrients in the soil and the soils ability to supply nutrients to the plant. If we think chemical soil health is lacking we can add fertiliser to fix the nutrient deficiencies or amendment, such as lime, to correct a chemical imbalance. It is common place to add a bit more than is required just to make things grow slightly better. In doing so, we give little thought to what this is doing to the physical and biological properties of the soil.

Biological soil properties deal with the living component of the soil. We have traditionally been interested in the biological component of the soil when we get soil pests and disease problems. To overcome these problems we apply pesticides with little regard for the other organisms inhabiting the soil. Many of these organisms play a beneficial role in promoting plant growth by recycling nutrients, creating channels allowing movement of air and water, improving the structure of the soil and suppressing pests and diseases of plants.

Holistic soil management

Good soil health management takes a holistic view of how we can create a soil environment where the physical, chemical and biological components work together to sustain plant growth with minimal impact on the surrounding environment (Figure 2). By measuring soil properties and production indicators, it is possible to develop a set of key indicators for use in soil health monitoring. The indicators can take account of the physical, chemical and biological soil properties, their interaction with one another and their impact on production. This requires monitoring the soil environment and improved knowledge of how a soil functions and how our management decisions impact all the components of on the soil. Ultimately, the land manager will be able to tell when a soil is healthy; by knowing what inputs are needed to grow the plants and how sustainable production is.

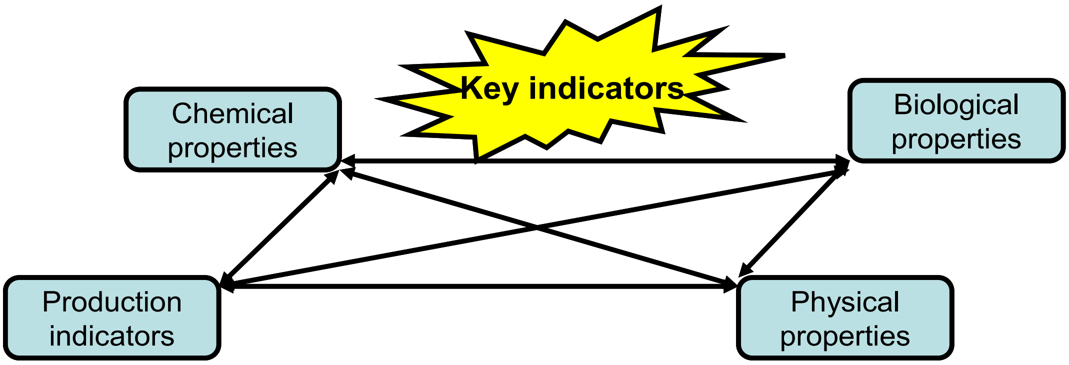


Figure 2: Holistic soil health management requires the monitoring of soil physical, chemical and biological properties and their interaction with one another and their impact on plant production.

Soil pH and Liming

Dr Neal Menzies and Dr Peter Kopittke
School of Land and Food Sciences, University of Queensland, St Lucia, Q'ld, 4072.

Take Home Messages:

1. Soil acidity often limits plant growth due to aluminium and manganese toxicity, calcium, magnesium, molybdenum and phosphorus deficiency, and reduced microbial activity.
2. You only need to add enough liming material to overcome the growth limitations – typically a pH of 5.0-5.5 will overcome aluminium toxicity.

Soil acidity (measured as the soil pH) is probably the most measured property of soils because of its profound effect on soil chemistry, nutrient availability and biological activity (and because of the ease with which the measurement can be made). Soil acidity refers to the concentration of H^+ ions in solution. Solutions with high concentrations of H^+ are acidic, and those with low concentrations of H^+ are alkaline. Soil acidity specifically refers to the concentration of hydrogen ions (H^+) in soil solution. Measurement of acidity is expressed in terms of a pH scale:

$$pH = - \log_{10}[H^+],$$

where H^+ is the concentration of H^+ ions in mol/L. The majority of soils have a pH between approximately 5 and 7 (in higher rainfall areas) or 7 to 9 (in lower rainfall areas). Generally, within this pH range (5 to 9), pH has no direct effect on plant growth.

Our early understanding of crop nutritional requirements and their response to soil conditions came through observation; the progressive development of hypotheses about soil-plant relationships which could then be rigorously tested. An example of this is the pH – nutrient availability diagram (Figure 1) initially proposed by Pettinger (1935) and later modified by Truog (1946). We now understand that the relationships depicted in Truog's diagram describe what was common for the soils on which he was working (north-eastern US), but are by no means universally applicable. Indeed, the diagram is probably wrong as often as it is right, and it is a shame that it is so frequently reproduced.

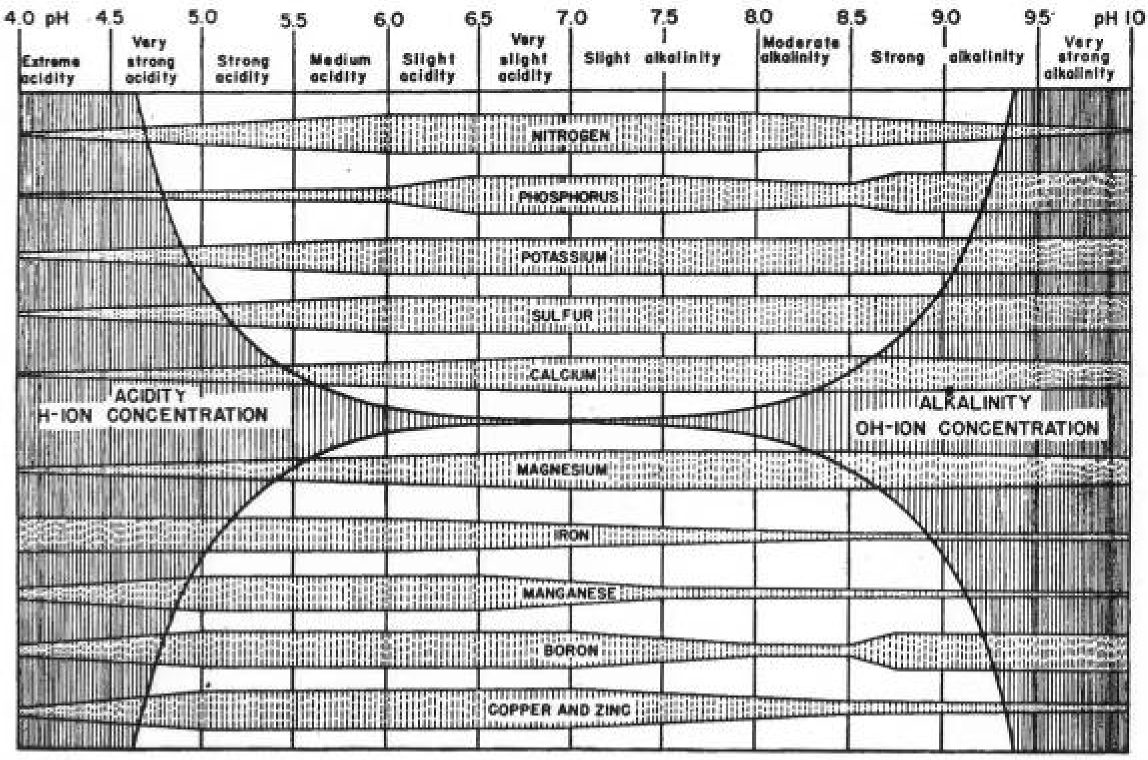
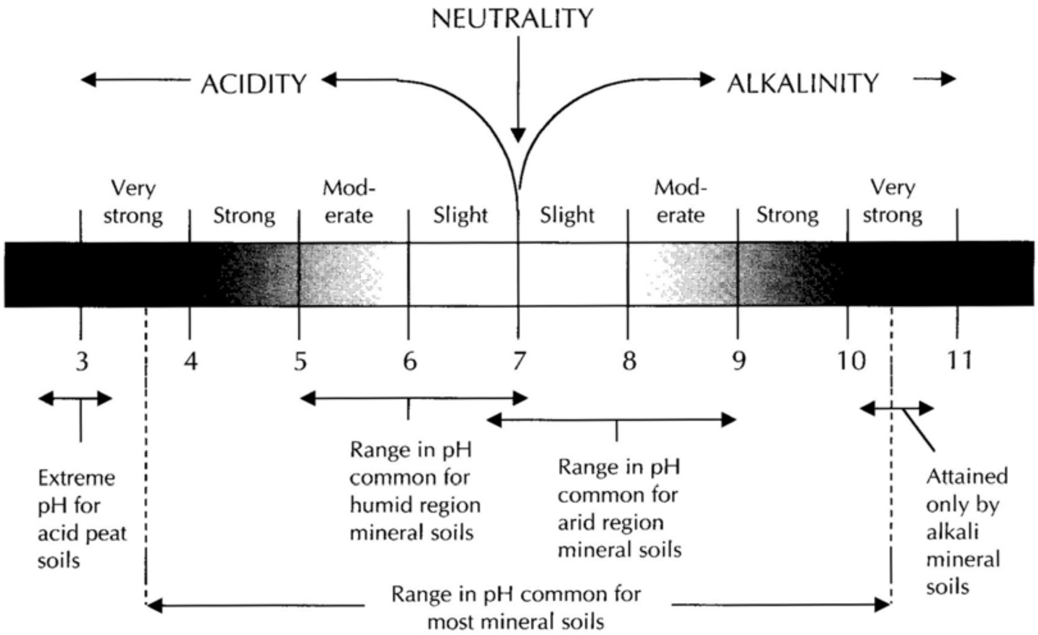


FIG. 1.—Diagram illustrating general trend of relation of soil reaction (pH) and associated factors to the availability of plant nutrient elements. Each element is represented by a band as labeled. The width of the band at any particular pH value indicates the relative favorableness of this pH value and associated factors to the presence of the elements in question in readily available forms (the wider the band the more favorable the influence), *but not to actual amount necessarily present*, this being influenced by other factors, such as cropping and fertilization. The width of the heavily cross-hatched area between the curved lines at any pH is proportional to the hydrogen-ion concentration (intensity of acidity) to the left of pH 7, and to the OH-ion concentration (intensity of alkalinity) to the right of pH 7.

Figure 1. Truog's observation based diagram showing change in availability of nutrients with pH. These relationships were generally true for the soils that Truog worked on, but are certainly not universally applicable.

Because most soils used in the turf industry have a pH < 7.0, we will limit our discussion to soil acidity (i.e. a pH lower than 7).



Soil Acidity

Acid soils have a number of chemical characteristics that can limit growth. These include aluminium (Al) and manganese (Mn) toxicity, calcium (Ca), magnesium (Mg), molybdenum (Mo) and phosphorus (P) deficiency, and reduced microbial activity. An example of how Ca, P, Mn and Al can change as a soil decreases in pH can be seen in Figure 2.

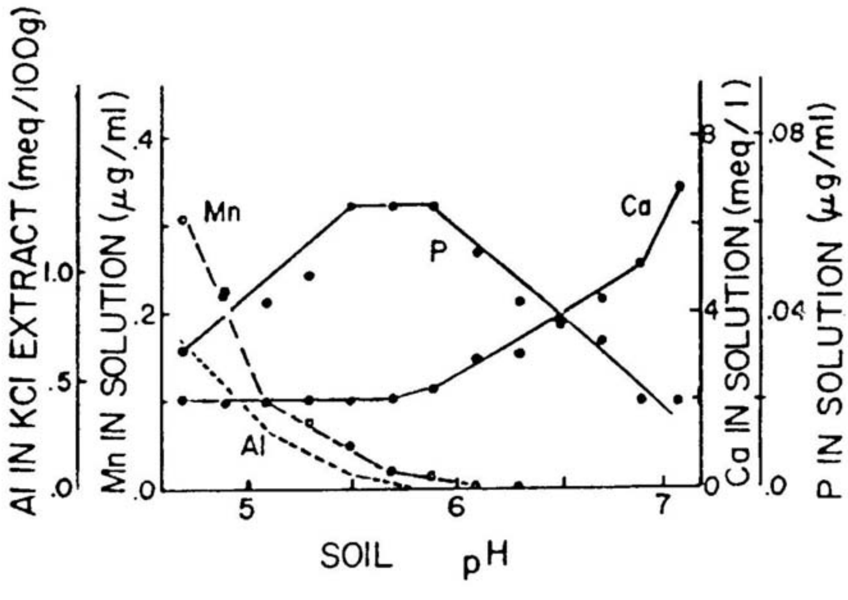


Figure 2. Extractable Al and Mn, Ca and P in saturation extracts of soil samples taken along a continuous function transect in Hawaii.

In acid soils, the toxicity of Al to plants is recognised as one of the major constraints to plant growth. Al toxicity affects root length and causes distinct discolouration—the greater effect of Al toxicity is on roots rather than shoots. The effect of Al on root growth can be seen below in Figure 3. Aluminium toxicity also reduces aboveground biomass (although the effect on root growth is greater).

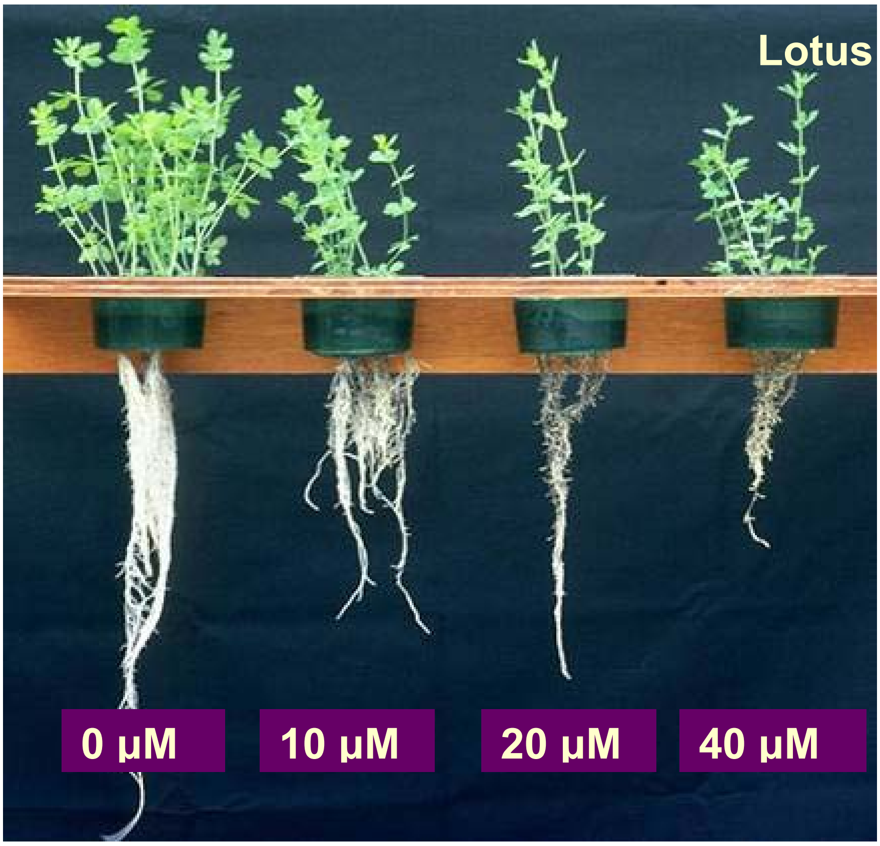


Figure 3. Influence of Al on the growth of Lotus.

A low soil pH can also cause deficiencies of Ca, Mg, Mo and P. Deficiencies of the major cations occur because the Al displaces cations such as Ca, Mg, and K from the soil exchange, increasing their susceptibility to leaching and thus loss from the soil profile (Figure 4).

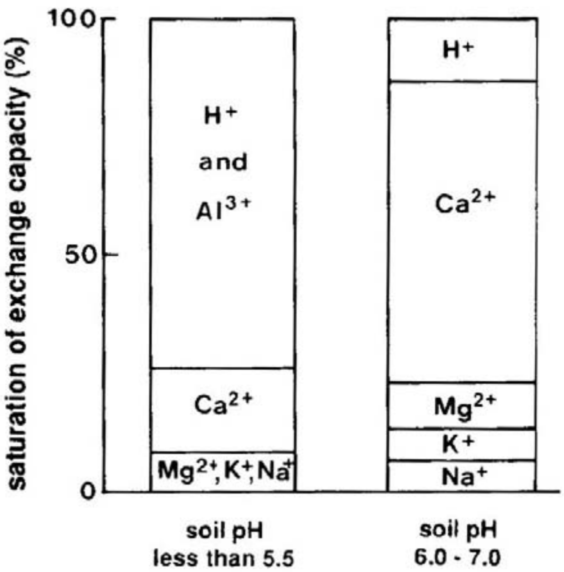


Figure 4. Proportions of major exchangeable cations in an acid soil, and a near-neutral soil.

Lime

The benefits of liming acid soils have been known for a long time; I have a reprint of an excellent essay by Edmund Ruffin (Ruffin 1832) on the use of lime on acid soil. Ruffin's work popularized the use of lime in Virginia, transforming the economy of the upper-south from poverty to agricultural prosperity. Ruffin built his work on even earlier studies. Interestingly, Ruffin provides a very accurate description of lime induced magnesium deficiency (although he did not recognize it as such).

So the use of lime has a long history, and there is no doubt that its application can greatly improve yields on acid soils. This is well illustrated by the effect on sunflower growth in Figure 5.

Figure 5. Liming can have a profound effect on plant growth in acid soils. In this situation, lime has been applied to the area at the rear of the photo, while the foreground was not treated.

The key question with liming is what pH should we lime to? In the late 1960's, US scientists were advocating lime application to achieve a pH of 6.5 to 7.0. The basis for this was that on the geologically young, high organic matter soils on which they worked (Mollisols), legumes such as clovers and lucerne showed yield increases up to this pH level—the reason for this is still not clear. When this liming philosophy was applied more broadly, especially to geologically old soils (highly weathered soils), it was found that a range of detrimental effects resulted (eg (Kamprath 1971). In their extensive review of the results of liming experiments conducted in Australia, Cregan, Hirth and Conyers (Cregan et al. 1989) concluded that "liming to maintain a near-neutral, arbitary pH, e.g. pH 6.5 (1:5 soil:water) cannot be justified in terms of plant response across a range of agricultural species". Most recommendations for highly weathered soils now aim to reduce aluminium and manganese to non-limiting levels, and hence target a pH in the pH 5.0 to 5.5 range.

It is also necessary to consider the particle size of the liming material. Finely ground materials react quickly and thus a small application is effective (Figure 6). However, given enough time, all of the lime would dissolve.

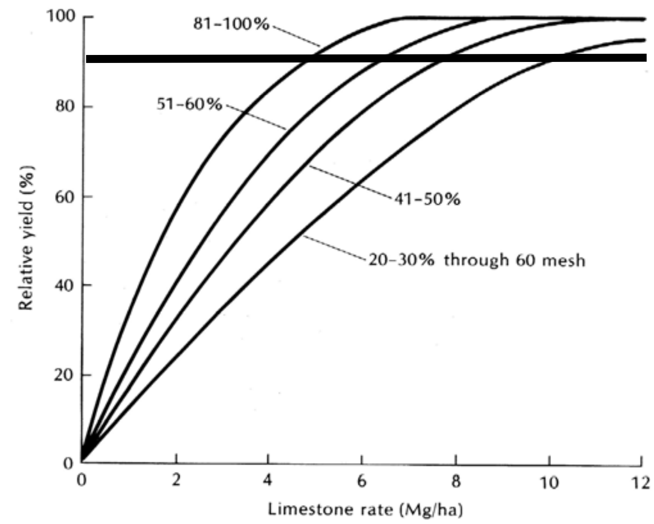


Figure 6. The effect of particle size of liming materials on plant growth.

Occasionally, lime is applied to increase the soils calcium status. One issue that needs to be considered is the effect of pH on lime solubility. The solubility of lime decreases 100 fold for each unit increase in pH (Figure 7).

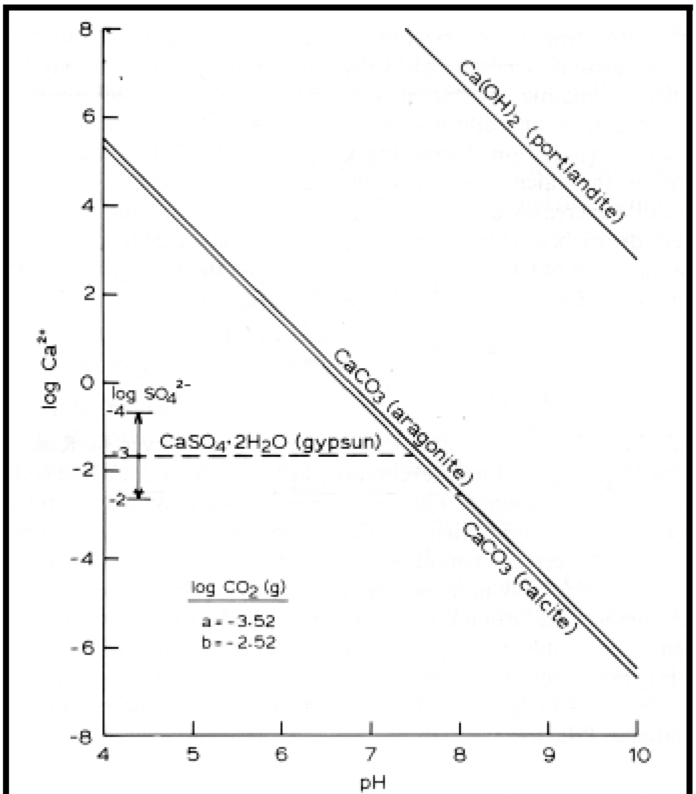


Fig. 7.2 The solubility of various calcium minerals in soils.

Figure 7. The effect of pH on the solubility of calcium containing materials. In this graph, the solubility is described by the activity (read concentration) of calcium supported in solution by dissolution of the mineral. For gypsum, solubility is not altered by pH, so the solubility line is horizontal. Note the log scale here for Ca, each unit decrease on this scale is a 10 fold decrease in concentration of Ca in solution.

It is critical to remember that these dissolution reactions are an equilibrium system. For example, solid phase lime (calcite) in a soil will be in equilibrium with the soil pH, the atmospheric CO_2 concentration, and the Ca^{2+} in solution.

$$CaCO_3 + 2H^+ \rightarrow Ca^{2+} + H_2O + CO_{2\,(gas)}$$

For a soil with a pH of 8, solid calcite will be in equilibrium with the soil atmospheric CO_2, and with a soil solution Ca concentration of ≈ 1 mM. If you add more lime, nothing will happen!—the soil solution calcium concentration will not increase, nor will the exchangeable calcium concentration. In this instance, another source of Ca (such as gypsum—$CaSO_4$) would be more appropriate.

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Soil Nutrient Testing: How to Get Meaningful Results

Dr Donald S. Loch
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%) Exch. K (ppm)	Ammonium acetate Ammonium acetate	<0.1 <40	0.1-0.2 40-80	0.2-0.5 80-200	0.5-1.0 200-400	>1.0 >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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Cation Exchange Capacity and Cation Saturation Ratios

Dr. Neal Menzies and Dr. Peter Kopittke
School of Land and Food Sciences, The University of Queensland, St Lucia, Q'ld.

Take Home Messages:

1. The ratio of exchangeable calcium and magnesium in soil will not influence plant growth, except at extreme values seldom encountered in 'normal' soils.
2. Soil structure is maintained across a range of saturation ratios, whilst in sandy soils, the cation saturation ratio is irrelevant in terms of soil structure.
3. Evaluate nutritional strategies yourself using trials, before adopting them on a broad scale.

Cation Exchange Capacity

The clay minerals (and organic matter) within soils are typically negatively charged. This negative charge is a very important property of the soil because the cations (such as Ca^{2+}, K^{+}, and Mg^{2+}) in the soil solution (the water within the soil) are attracted to this negative charge. This acts as a reservoir of nutrients for plants, and helps prevents nutrients from leaching through the soil.

When you have your soil analysed, you will typically get a report telling you the cation exchange capacity (CEC) of your soil and the amount of exchangeable Ca, K, Mg, and Na that it contains. The CEC is simply a measure of how much negative charge your soil has, and the larger the CEC, the more cations your soil can 'hold'. For sandy soils, the CEC is typically less than 5 $cmol_{(c)}$/kg (meq/100g), whilst for heavy clay soils the CEC is often 50-60 $cmol_{(c)}$/kg. The exchangeable Ca, K, Mg, and Na concentrations are either presented as a percentage of the CEC (i.e., as a 'base saturation ratio'), or as a concentration. For example, if you had a soil with a CEC of 10 $cmol_{(c)}$/kg which consisted of 5 $cmol_{(c)}$/kg of Ca, 2.5 $cmol_{(c)}$/kg of K, 2.0 $cmol_{(c)}$/kg of Mg, and 0.5 $cmol_{(c)}$/kg of Na, then this would be equal to 50% Ca, 25% K, 20% Mg, and 5% Na.

Increasingly, the exchangeable cations are reported as the percentage of the CEC (as a saturation ratio) which is then related to an 'ideal saturation range'. Typically, this 'ideal range' is something like: 65% Ca, 10% Mg, 5% K, 3% Na, and 17% H. However, *there is no ideal saturation ratio!*

Cation Saturation Ratio

For this paper, I have been asked to address a range of areas where you may have been receiving conflicting viewpoints. In doing so, I do not intend to present "both sides of the argument", but rather to present what is the accepted scientific viewpoint, and some of the knowledge that brings us to that viewpoint. This is not intended to be an esoteric scientific paper, so I have not rigorously conformed to a scientists writing style (you will thank me for this). I present authorities (the published scientific papers which establish a point) only where it is interesting to be able to tie down the time when the work was done, or where the particular study is directly relevant to the broad topic being discussed.

History

During the 1940's and 1950's there were a series of reports proposing "ideal" proportions of exchangeable cations in soil (Bear et al. 1945; Bear and Toth 1948; Graham 1959). The proposed ranges were 65 to 75% Ca^{2+}, about 10% Mg^{2+}, 2.5 to 5% K^{+}, and 10 to 20% H^{+}, or approximate ratios of 7:1 for Ca/Mg, 15:1 for Ca/K, and 3:1 for Mg/K. Without question, soils with this cation make-up would not present any problems for plant growth with respect to these nutrients. However, our question is, "will plants grow better if we adjust the cation ratios of the soil to these values?" A couple of key points need to be made about this approach:

- The method was proposed by scientists working in areas of the USA where there are very good soils with negligible nutrient element deficiencies. This ratio was suggested by Firman Bear because he noticed that (1) alfalfa (lucerne) took up 'luxury' amount of K, (2) K fertilizer was expensive, (3) Ca fertilizer was cheaper, and (4) if he increased exchangeable Ca to 65%, then the lucerne would take up less K. In other words, the proposed 'ideal' ratio was simply a method to reduce uptake of K in lucerne.

- We now understand that the majority of the exchangeable H^{+} that we measure in soils is an experimental artifact; it does not really exist. The exchangeable H^{+} that was measured resulted from an increase in surface charge density (CEC) as a result of using a high ionic strength saturating solution (commonly 1 M) (van Olphen 1977). With the development of more appropriate methods of measuring cation exchange capacity (e.g. Gillman and Sumpter 1986) exchangeable H^{+} is not found at measurable concentrations except in the most acid soils (pH<4.5).

Proof it doesn't work

The fact that the "ideal" cation exchange ratio idea received so much attention at the time is surprising, given that, at the same time, other researchers were reporting that it did not work (see Figure 1). Hunter and associates in New Jersey (Hunter 1949) could find no ideal Ca/Mg or Ca/K ratios for alfalfa (*Medicago sativa* L.), nor did Foy and Barber (1958) find any yield response in maize (*Zea mays* L.) to varying K/Mg ratios in Indiana. A comprehensive and elegant demonstration of the failure of the approach is presented by the glasshouse and field studies of McLean and co-workers (Eckert and McLean 1981; McLean et al. 1983), where Ca, Mg and K were varied relative to each other. They concluded that the ratio had essentially no impact on yields (e.g. Figure 2) except at extremely wide ratios where a deficiency of one element was caused by excesses of others. They emphasized the need for assuring that sufficient levels of each cation were present, rather than attempting adjustment to a non-existent ideal cation saturation ratio. Indeed, if you consider the mechanisms that plants use to take up nutrients, it makes sense that there is no such thing as an ideal base saturation ratio (Appendix 1). This is because plant roots are able to selectively remove some cations (e.g. potassium) from the soil solution.

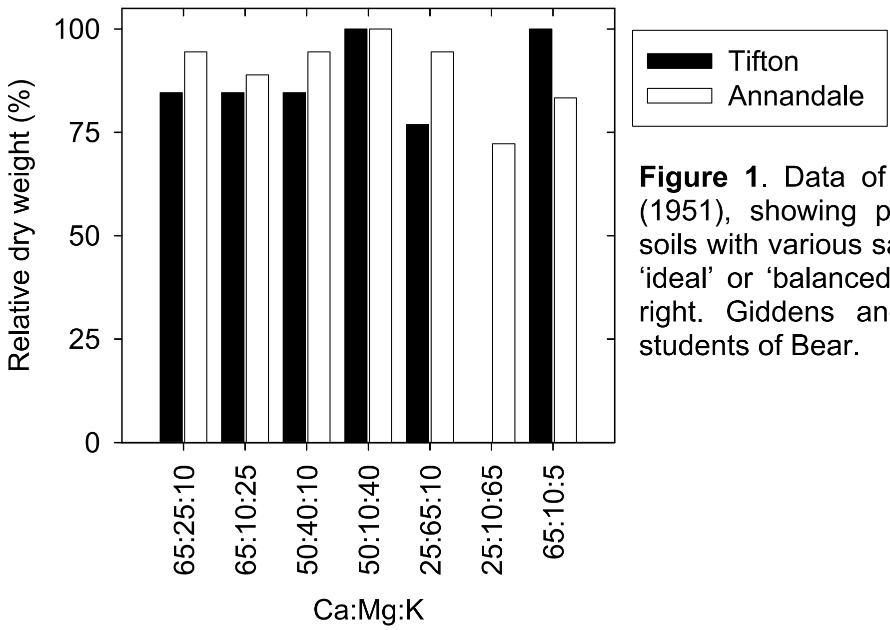

Figure 1. Data of Giddens and Toth (1951), showing plant growth in two soils with various saturation ratios. The 'ideal' or 'balanced' ratio is on the far right. Giddens and Toth were both students of Bear.

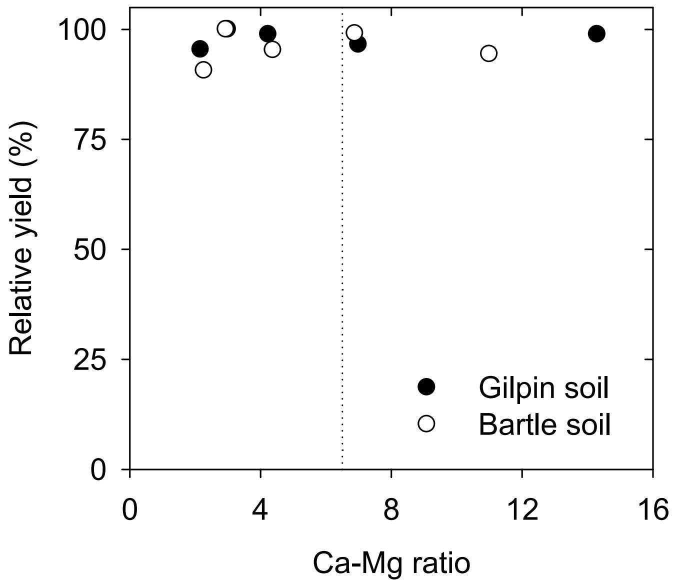

Figure 2. Data of McLean and Carbonell (1972) showing plant growth at various Ca-Mg ratios in two soils. McLean was a former student of Albrecht.

Nevertheless, the 'ideal' cation saturation ratio is still widely used today, largely because of its promotion by William Albrecht. However, the work conducted by Albrecht does not support this! Rather, it is likely that Albrecht has mis-applied the work of Firman Bear. In the book, 'The Albrecht Papers', it states that for a 'balanced soil', "65 % of that clay's capacity (needs to be) loaded with calcium, 15% with magnesium". According to Albrecht, he presented work in 1939 which proved that a 'balanced soil' must contain 65% Ca and 15% Mg. However, it is unclear how Albrecht concluded that this soil was 'balanced' as his own data from the 1930s and 1940s does not support this. Indeed, interpretation of Albrecht's data is difficult, because his experiments were often confounded by multiple factors. For example, in Figure 3, growth improves as Ca saturation increases, but this is most likely because the pH increased from approximately 4.5 to 7.0 as Ca saturation increased.

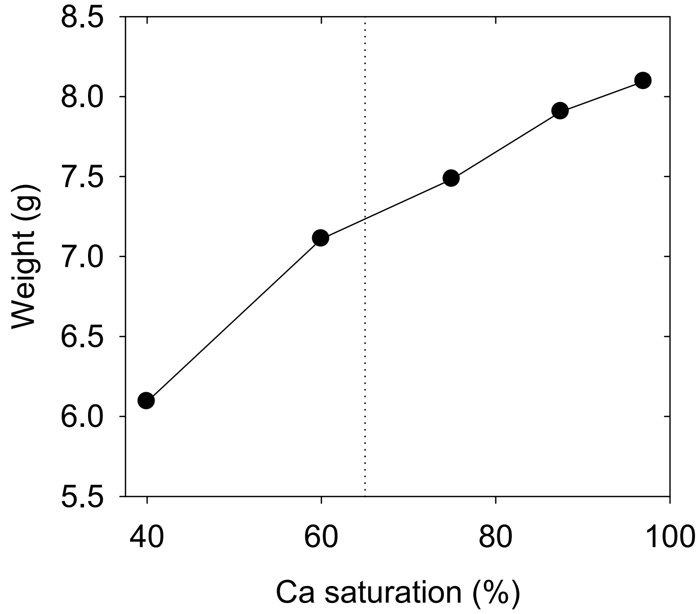

Figure 3. Data of Albrecht (1937), showing the growth of soybean at various Ca saturations. However, as the Ca saturation increases, pH also increases from approximately 4.5 to 7.0. The dotted line is 65% Ca, which Albrecht later stated was 'balanced'.

Cation saturation ratios and soil structure

Soil structure is a very important property of the soil. If soil structure declines, this can potentially cause crusting and hardsetting, a decrease in oxygen movement, increased erosion, a reduction in water infiltration, and poor plant growth. So what is soil structure, and what causes it? Individual soil particles are attracted to each other, and under certain conditions they can 'flocculate' to form larger aggregates. The process by which this occurs is well known, and we have many equations to describe this process. We know that Ca is a desirable cation that will promote aggregation (flocculation), whilst Na is undesirable and can cause the soil to disperse (lose its structure). However, if your soil does not have the 'ideal' saturation ratio, will it have poor structure?

For clayey soils, high Mg saturations have been found to result in poor structure (Figure 4). However, this soil structural decline did not occur until the Mg saturation was twice has high as the Ca saturation. In other words, even when the soil contained as much Mg as Ca (Ca:Mg ratio of 1:1, compared to the 'ideal' ratio of 6.5:1), soil structure was good. Thus, soil structure is maintained across a range of cation saturations. Indeed, we have many examples of this.

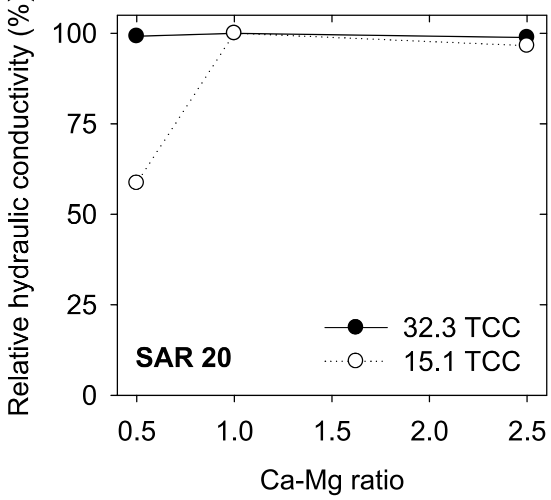

Figure 4. Data of Rengasamy et al. (1986), showing the influence of the Ca-Mg ratio on the rate at which water flowed through the soil. This was for an Australian soil containing considerable clay.

However, it is also worth noting that whilst the Na (and to a much lesser extent, Mg) are undesirable in clayey soils, sandy soils do not have structure and so the amount of Na and Mg in sandy soils does not influence soil structure. For sand and silt, the attractive forces required to bring the particles together to flocculate (and form structure) are too large, and these soils are unstructured. Hence, if you take a handful of sand, the sand particles are not all grouped together in a large aggregate, but they are all individual particles. Thus, for sandy soils, the saturation by Na and Mg is irrelevant (in terms of soil structure), because these soils do not have any structure anyway. A clear example of this is 'residue sand', a waste product of bauxite refineries. Even though residue sand is 100% saturated with Na, the hydraulic conductivity (the rate at which water moves through the soil) does not improve if you add Ca.

One of the reasons that the cation saturation ratio idea has persisted, is that, in very general terms, there is just enough "truth" in it to make it seem reasonable. Nevertheless, it is now well established (and has been for over 60 years) that the ratio of exchangeable calcium and magnesium in soil will not influence plant growth, except at extreme values seldom encountered in 'normal' soils. Additionally, soil structure is maintained across a range of saturation ratios, whilst in sandy soils, the cation saturation ratio is irrelevant in terms of soil structure.

Finally, and very importantly, if you are unsure as to whether a new product works or whether the interpretation of a soil test is correct, evaluate nutritional strategies yourself using trials before adopting them on a broad scale. If it doesn't improve plant growth, why use it?

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Appendix 1

Plant Potassium Uptake – An example of why there is no 'ideal' cation saturation ratio

Some people view the general finding that cation ratios do not matter, difficult to reconcile with their apparent success in predicting nutritional difficulties under extreme conditions. To understand this question, we need to consider the process of cation uptake by plants.

Let's look at potassium, as it is the cation plants require the greatest amounts of, and the cationic nutrient with the most specific uptake pathway. A key feature of potassium nutrition is the high rate and efficient means by which potassium is taken up and distributed throughout the plant. There are various potassium uptake systems, mainly specific (meaning they only work for potassium) channels in the plasmalemma (the outer membrane of plant cells). Two main groups of transporters can be identified; a high affinity group which are very selective for potassium and reach their maximum uptake rate at low soil solution potassium concentrations, and a low affinity group which are less selective and require much higher soil solution potassium concentrations to reach their highest uptake rate. Both types of uptake system work in conjunction with a plasmalemma proton (H^+) pump (Figure 5). The proton pump pushes H^+ out through the plasmalemma, creating an electrochemical gradient (more negative on the inside). This gradient then provides a driving force to push potassium into the cell, but it also provides the same driving force for other cations. The low-affinity transporters can be viewed as a gate which shows a preference for potassium—the gate will only open to permit a potassium ion to enter. However, this uptake approach will only work when there is a reasonable concentration of K^+ in the soil solution. At low solution concentrations the uptake process has to work against a strong concentration gradient. The soil solution may contain only 10 µM of potassium, while the cytoplasm (the semi-fluid contents of the cell) will contain around 80,000 µM K^+. This concentration gradient more than cancels out the electrochemical gradient (the inside of the cell is at -120 to -180 mV)—so potassium uptake is prevented. The plant can get around this problem by using its high affinity transporter, but this costs a lot more energy. When you consider that 25 to 50% of the energy flow in a root hair cell is used to drive the proton pump, to spend still further energy on nutrient uptake is something the plant would only do when it needs to.

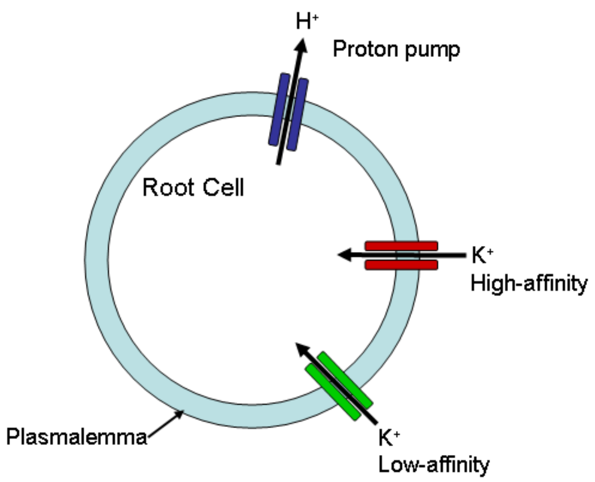


Figure 5
Schematic representation of a root hair cell showing the proton pump and potassium transporters.

The benefit that the plant derives from having these two mechanisms is that it can obtain its potassium requirement in the most efficient manner. As a result, the capacity of the plant to take up potassium is not directly related to potassium in solution. The uptake relationship for potassium in Figure 6 is strongly curved – the plant can obtain a lot of potassium despite low soil solution levels.

The presence of high concentrations of other cations in the soil solution (e.g. Na^+, Ca^{2+}, Mg^{2+}), can interfere with the potassium transporters. Thus, high concentrations of these other nutrients can reduce potassium uptake, especially by the low-affinity uptake system. However, the high-affinity uptake mechanism is so specific that interference by other cations is never so great as to produce a true deficiency of potassium in the plant. In very saline situations, uptake of sodium into the plant is sufficient to interfere with the plants use of potassium in the leaves, but it does not prevent potassium uptake from the soil.

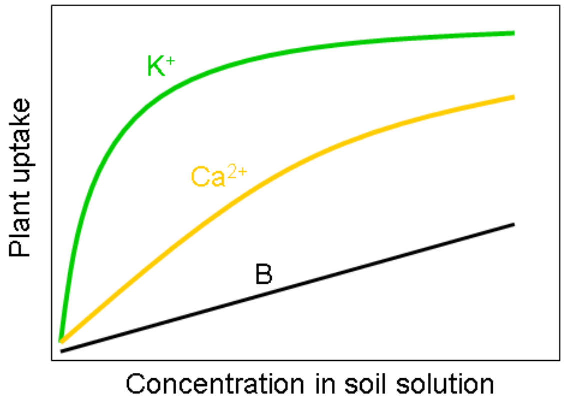


Figure 6. Schematic representation of the relationship between nutrient supply and uptake. The curved response for potassium reflects the plants specific uptake mechanisms for potassium, while the straight line response for boron indicates passive uptake (not actively controlled).

Session 2: SOIL PHYSICAL STRUCTURE

Soil Structure

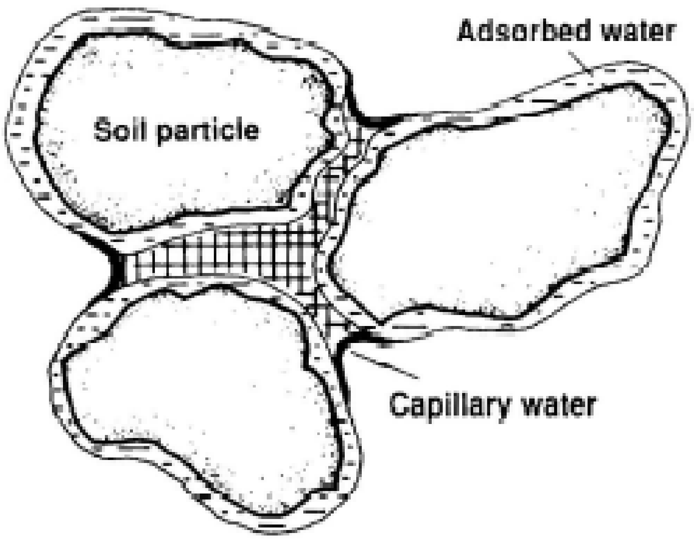
Dr Rob Loch
Principal Consultant, Landloch Pty Ltd, Harlaxton, Q'ld 4350.

Overview

Plants' needs from soil are relatively simple: water, air, and space for roots to grow. How well soils supply those needs is a function of both soil properties and soil management.

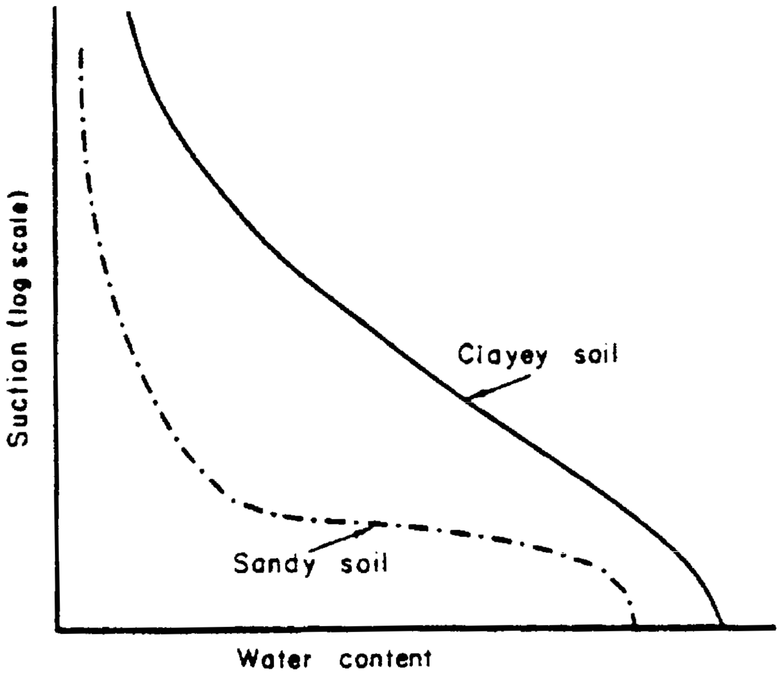
Soil water

Soil water is held in soil pores by capillary forces. The strength with which water is held by the pores depends on pore diameter and shape. It is simplest to consider this as the water being held under suction, with the suction increasing rapidly as pore diameter decreases. When soil dries out, water is removed first from the largest pores, where it is held with least suction.



Soil pores vary greatly in size, but as a general rule of thumb, pore size is approximately one-seventh the size of the particles between which it occurs. This means that soils with mainly fine particles will contain more fine pores (and less coarse pores) than soils with mainly coarse particles.

From the point of view of plant growth, pore size and the suction with which water is held are extremely important. Water held with low suction is relatively easy for a plant to extract from soil, whereas water held at high suction may even be impossible for a plant to take up. As the following graph shows, clay soils, with mainly fine pores, may hold a relatively high proportion of total soil water at higher suction, whereas a sandy soil may hold most of its water at relatively low suction.

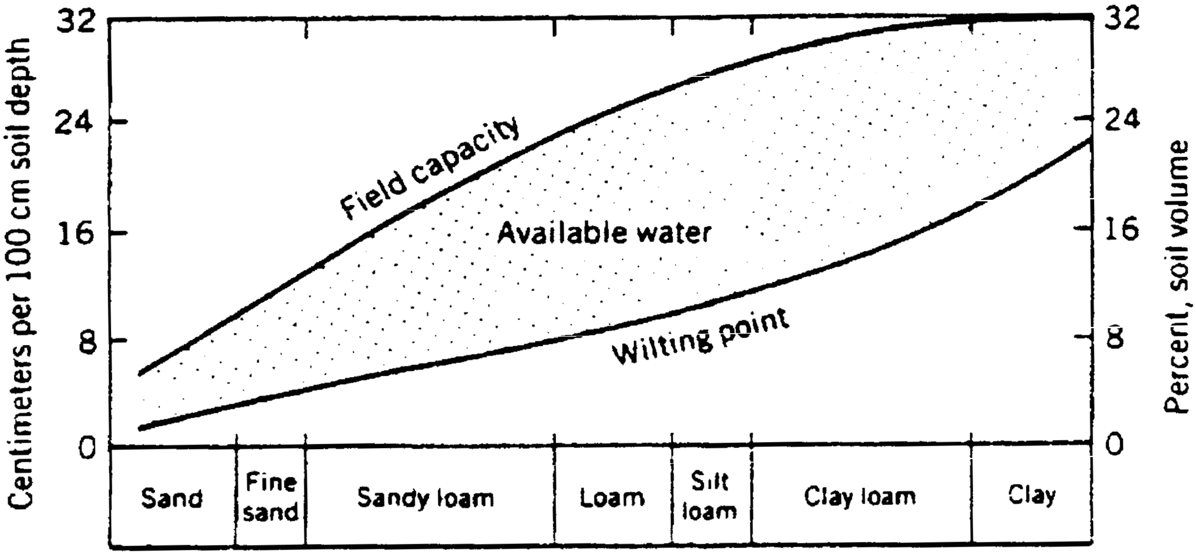


A range of terms are used to describe soil water and its availability to plants:

- Saturation (soil water suction of 0 kPa)
- Field Capacity (suctions of ~8-10 kPa; 33 kPa in dryland studies), considered to be the water content that a soil drains to rapidly after wetting, but not always as easily defined as the term suggests
- Refill point (crop, soil, & management dependent ~15-500 kPa)
- Permanent Wilting Point – plants not able to extract water from the soil (~1500 kPa)
- Oven-dried (~10^7 kPa)

Plant Available Water Capacity (PAWC) is the range between field capacity and wilting point, but for irrigation, ***readily available water*** (RAW) is more important, and is the water held between field capacity and the refill point.

Soil with low RAW will need frequent irrigation, whereas soils with higher RAW will need fewer, larger, irrigations. It should be noted that total soil water content is, in some respects, less meaningful to a plant than the suction with which it is held, and the quantity of water held in the available range (see figure below).

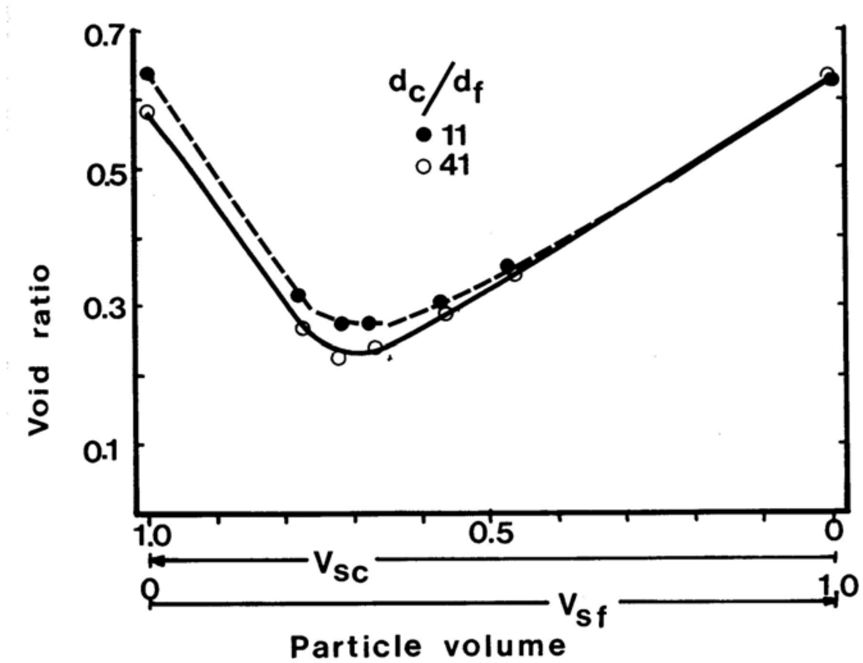


Soil texture

Soil texture has a range of important effects on soil properties, including pore size and water holding capacity (illustrated above). If we consider the void ratio of a soil, which is the volume of pores per unit volume of soil solids, then we find that the void ratio is high in sandy soils, but decreases as clay as added, as the clay packs into the large pores between sand grains. Eventually (as shown by the figure below), a point is reached at which maximum bulk density (minimum void ratio) is reached. If more clay is added, then a situation develops where sand particles are no longer in contact with each other, but simply “float” within clay particles. Effectively, there has been a change from a sand matrix to a clay matrix, and a number of soil properties change as well.

Aggregation in sand matrix soils will be greatly assisted by the addition of organic matter, but aggregation in clays will be less dependent on organic carbon. The point of maximum density – effectively at the texture of a light clay – also indicates the texture at which soils will compact to very high bulk densities.

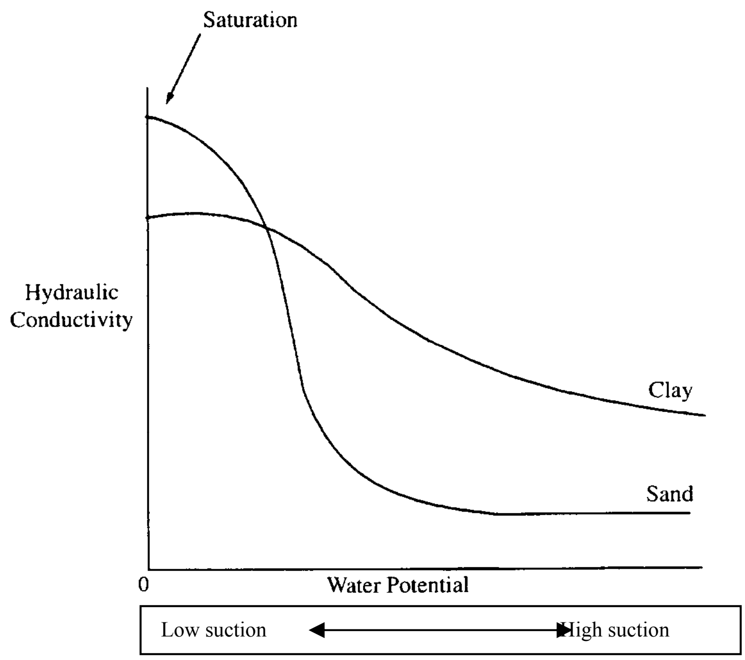
Addition of clay to a sand, therefore, will gradually reduce pore size, so that although more water is held, it will be held in finer pores at greater suction.



Water movement in soils

Two forms of water flow are common:

- *Saturated flow* – all pores contributing
- *Unsaturated flow* - only a proportion of pores contributing (function of water content)



As the figure at the bottom of page 24 shows, hydraulic conductivity is highest at saturation, and then decreases as soil suction increases (water potential becomes more negative). The rate of decrease is very rapid for sandy soils, which mainly have coarse pores, whereas clay soils with more fine pores do not show such great decreases in conductivity at greater suctions.

For sandy soils, this means that only water held at relatively low suction is easily available to plants. Hydraulic conductivity can be too low for water to move to plant roots as rapidly as required once the sandy soil dries out a little. As well, capillary rise of salt will be much less effective in sandy soils than in clay soils. Once a sand begins to dry out, hydraulic conductivity often becomes too low to move water and salt to the surface in response to evaporation.

Infiltration and drainage are strongly affected by pore size, with the rate of water flow through a pore decreasing rapidly as pore size decreases. It is largely for this reason that constructed sports fields tend to have surfaces composed of coarse sandy material. The low water holding capacity typical of such materials is less of a drawback if irrigation is available and can be applied frequently.

Compaction

Compaction typically occurs when soils are wet. By compressing pores and increasing soil strength, root penetration can be reduced or prevented, water holding capacity can be reduced, and drainage may become poor.

Soils typically show an optimum water content for compaction. If too wet, compression is difficult, as the pores are full of water.

Compaction also tends to increase with soil clay content. Clay particles assist the shearing movements of particles that are part of the compaction process. The effect of clay in increasing susceptibility to compaction is another reason for the preference shown for relatively coarse surface layers on constructed playing fields.

Rooting depth

For a soil profile, the amount of water available to plants is a function of not only the difference between field capacity and wilting point, but also very strongly influenced by the depth of profile that is available for plant roots to exploit. A number of factors can limit rooting depth, including compaction, changes in texture with depth, and possibly, instability of clay if excess sodium is adsorbed to it.

In Conclusion

There is no such thing as perfect soil structure.

The challenge is to understand and manage the structure of the specific soils we have to work with, to obtain the specific results we want.

Manufactured Soil

Dennis E Baker
Environmental Soil Solutions Australia, Sunnybank, Q'ld.

Introduction

One of the key components of manufactured soil supplied in the landscape market place is good quality compost.

The quality of the compost used in soil manufacture can have both positive or, in the case of poor quality compost, negative effects on plant growth including turf.

Australian Standards (AS) apply for soils manufactured as "growing media". This is a safe guard to ensure that the media purchased with this certification will sustain healthy plant growth.

Some of the more important soil properties which effect growth (e.g. pH and nitrogen availability) will be discussed in this paper.

Manufactured Soils

Soils such as these, which are not natural soils, are generally a mixture of sand or sandy loam and compost, manures and similar inputs. These products are used for the landscape industry and are often called:

- Custom made soils
- Manufactured soils
- Blended root zone media

While the quality of top soil is vitality important for the plant establishment, the roots of turf and most plants will need to explore the existing sub-soils. Therefore the quality and condition of the underlying sub–soil needs to be assessed and sometimes ameliorated before the topdressing is applied.

Soil Media Testing Criteria

For an acceptable top soil a minimum standard of AS4419 (2003) is required. Sub-soils should at the very least pass tests for pH, salt content (EC) and exchangeable cations (calcium, magnesium, sodium and potassium).

Basic Soil Properties

The basic soil attributes which need to be assessed in order to ensure that a soil can maintain plant growth and vigour are the relevant:

- physical properties and
- chemical properties.

Soil physical properties of a soil which need to be assessed are:

- texture (estimate of sand, silt and clay)
- structure
- porosity
- plant available moisture and
- Bulk Density

From the suite of tests conducted on soil physical properties other important information such as:

- soil clay type and
- soil tendency to compact, can be assessed.

Soil chemical properties which affect a soils ability to sustain growth are:

- pH (acidity / alkalinity)
- EC (salt content)
- nutrient content (N, P and trace elements)
- cations and CEC (Cation Exchange Capacity, which impacts on the soil's ability to supply plants nutrients).

A full physical and chemical test based on AS 4419 and the sub-suite for the subsoil can give an accurate assessment of the ability of the growing media to establish and to sustain healthy plant growth.

Soil Amendments

Often soils require amendments to promote healthy plant growth. These amendments generally are:

- lime or dolomite to increase soil pH
- gypsum and lime to decrease soil dispersion and
- organic matter to increase soil water holding capacity and cation exchange to enhance fertilizer retention for plant growth.

Standards

The Australian standard which applies to manufactured soils is:

- AS 4419 (2003)

Other Standards :

- AS2223 and
- AS4419 1996 and 1998

NO LONGER APPLY.

Other Standards which do not apply to soils are as follows:

- AS3743 - for potting mix only and
- AS4454 - used for compost only.

Methods of Soil Analysis

The interpretation of the soil properties measured often depends on the method used to assess the property. For example, soil pH measured as one part soil in five parts water is different to soil pH in the same ratio of 0:01M $CaCl2$.

Methods applicable to soils, which are recommended for assessment of soil chemical properties, may be found in:

> Australian Laboratory Handbook of Soil and Water Chemical Methods (1992), G.E. Rayment and F. R. Higginson, Inkata Press, Melbourne.

How can good compost help?

Good quality compost ensures beneficial soil effects such as:

- water retention
- nutrient retention
- increased soil biology and
- soil sustainability.

Conversely, poor quality uncomposted organic material is broken down slowly by organisms in soil, uses up available soil nitrogen (Nitrogen Drawdown), causes nutrient imbalance and increases soil pH.

What makes good compost?

Good compost has the following properties:

- media pH < 7.8 and
- Nitrogen Drawdown Index (NDI)[2] of >0.2.preferably > 0.4

Improvements noted in soil mixes with good quality compost components are:

- increased water retention
- increased yield
- increased organic carbon
- adds fertiliser value as increased P and K and other nutrients and
- increased soil cation exchange.

Conclusion

All soils should be accompanied by a soil test certificate which demonstrates that they comply with Australian standards ranges for example:

- pH — 5.5 to 7.5
- EC — < 1.2 mS/cm
- phosphorus > 20mg/kg for general plantings

All media analyses should be supplied with soil-exchangeable cations measurements as well.

[2] Available as a laboratory test.

Soil Water Repellency

Dr Rachel Poulter
Department of Primary Industries and Fisheries, Redlands Research Station, Cleveland, Q'ld.

What is it?

A water-repellent soil (or hydrophobic soil) does not wet up spontaneously when a drop of water is placed upon the surface. It is common to see water pooling on the surface of dry soil rather than wetting it up. In turf, this translates into "dry patches" or localised dry spots—irregular shaped areas where the grass or other plants suffer from drought because the repellent soil below does not wet up uniformly following rain or irrigation. Much of the affected area remains dry between the "fingers" of higher infiltration.

If you think you have this problem then you are not alone. A recent survey of the Golf Course Superintendents Association of America found that 98% of golf course superintendents are using ameliorants for this problem. Papers addressing this issue in relation to turf health have been found from Australia (W.A., S.A. and Q'ld), the Netherlands, the United States and New Zealand.

Some notable quotes follow:

"It appears that water repellency is the norm rather than the exception, with the degree of water repellency variable." Wallis, M.G., Scotter, D.R. and Horne D.J. 1991.

"… water repellency is plant induced, and therefore probably more the rule than the exception in most field soils." Coen J. Ritsema 1996.

What causes it?

Soil water repellency is caused through the production of complex organic acids during the decomposition of organic matter. These complex organic acids are wax-like substances that form a coating over particles of soil.

Researchers claim that coarse textured sandy soils are more likely to become repellent as they have a relatively low surface area compared to finer materials. However, certain clay soils have been found to become repellent as the coatings have formed on aggregates of fine material.

The physical properties of water can be explained by the combination of two forces creating surface tension. Water has strong cohesive forces (attraction of water molecules to themselves) helping to hold water drops intact. It also has adhesive forces (attraction of water molecules to other substances) which cause the water to spread out and cling to other surfaces such as soil particles. The compounds causing repellency in soil are polar compounds with hydrophobic (water repellent) and hydrophilic (water attractant) ends. During dehydration the shape of the compound changes, so that the hydrophobic surface is exposed to the air/water in soil pores.

This then creates a hydrophobic layer preventing the spread of water over the soil particles.

When soil moisture is above a critical value (which is different for every soil), the water repellency effect is temporarily eliminated. When it falls below this critical value, the soil returns to a hydrophobic condition. The time taken for water to infiltrate increases for repellent soils. It takes as little as 3 to 6 % hydrophobic materials in the soil matrix to cause non-wetting problems.

What are the consequences?

- ***Drainage and leaching of nutrients***

Areas of weakness in the water repellent layer allows water to enter the soil in discreet areas or "fingers" forming zones of preferential flow. Preferential pathways through the soil, being small in area, lead to water infiltration deeper into the soil profile. Depending on the intensity of the rainfall or irrigation event, there is a potential for flow beyond the root zone. Water draining below the root zone is lost to the plant and could be considered wastage. Not only is water wasted, but any soluble fertilisers in the soil will also be carried out of the range of plant accessibility. Vertical solute leaching is approximately three times greater in "fingers".

- ***Runoff***

On sloping sites surface water runs off. There is also a loss of nutrients, and,potentially sediments, which may end up in surface streams and water ways with the potential to cause significant pollution. Nutrient and sediment losses are enhanced during summer storm events.

- ***Uneven distribution of applied chemicals***

This can include soluble fertilisers or the various pesticides, which again leads to non-uniformity in turf quality.

- ***Overall symptoms observed in turf = Localised Dry Spot (LDS)***

These are localised areas where the turf is experiencing water and nutrient stress . They appear as spots of varying size and shape where turf is wilted and/or brown. This equates to non-uniform turf of poor quality. It is more severe in summer when moisture stresses are more prevalent due to rapid drying of the soil profile.

The bottom line is that there are losses of water and nutrients which are economically wasteful and result in environmental degradation.

Are there preventative measures we can take?

No, not really! It is a consequence of the decomposition of organic materials, which are an essential component of a healthy soil. To entirely remove them from the system would not be good, however in a USGA or California green it is essential to control organic matter build up for reasons of maintaining adequate infiltration and drainage.

What treatment options do we have?

FIRST AND FOREMOST <u>- IDENTIFY THE PROBLEM!</u>

LDS is the symptom of a number of stresses such as soluble salts, fungal diseases, insect attack and uneven irrigation. Application of surfactants to non-hydrophobic soils does not increase infiltration.

Water repellency is identified through a simple water drop penetration test. This involves taking a profile core (about 1.5 – 2 cm diameter is sufficient) and allowing it to dry naturally for 1-2 weeks. A drop of water placed on the soil close to the thatch layer should be taken up by the soil in under 5 seconds in a non-hydrophobic soil. Use Table 1 as a guide. Check the level of repellency along the length of the core. This will provide an indication of the depth of water repellency and aid in the choice of treatment options. If only the thatch or soil-thatch interface is repellent, then management options that control the quantity of thatch may be all that is required. If the repellency continues into soil layers, then a surfactant will be needed.

Table 1. Level of severity of water repellency based on water drop penetration test results.

Water drop penetration time	Severity
< 5 seconds	No problems with water repellency
5 seconds–1 minute	Slightly repellent—treatment will help improve uniformity
1–10 minutes	Repellent—treatment required
> 10 minutes	Severely repellent—treatment essential

Management practices

There are several management options that provide a means of protecting turf from the effects of localised dry spot. These include:

- Raising the cutting height for mowing so that plants have greater top growth to enable root growth. Roots can then access water from deeper in the soil profile. However, the water repellency still remains, so the problem of leaching/runoff still exists.
- Removal or alteration of the coating—this requires large volumes of water and there is a question as to where the hydrophobic compounds end up.
- Increase the surface area of the soil by the addition of fine materials such as clays. This is not an option on most sandy sites, as it causes the bridging of particles and reduces infiltration significantly. Dispersible sodic clays (1:2 type clays) have been found to be more effective than Ca saturated clays. However, sodic clays have very poor structure so I wouldn’t recommend this practise.
- Biostimulants. There is some discussion on the use of biostimulants. These materials DO NOT affect the water repellency of the soil particles. The value may be in their action of enhancing root growth so that the plant can take up water from deeper in the profile. BUT, where the soil is hydrophobic, it is doubtful that the water can actually enter the soil to be stored deeper in the profile.
- The introduction of commercial mixes of microbes has been suggested. This is generally not appropriate as the repellent compound is a product of organic matter breakdown. There is no evidence that ‘new’ microbes will further breakdown these materials.
- Some anecdotal stories claim that the application of fungicides has reduced LDS. I would suggest that fungicides are actually acting against fungi whose symptoms match those of soil water repellancy. Fungi such as fairy rings can cause water repellency due to organic matter breakdown. In these situations it is important to treat with a fungicide **and** follow up with a treatment against water repellency.

Where the turf growth and quality is poor due to water repellency causing insufficient storage of water in the soil it is better to treat the cause and not the symptom.

- The overall goal then is to maximise input effectiveness in terms of irrigation or precipitation and minimise output losses through transpiration, evaporation, runoff, leaching and drainage.

- In practice, water repellency in higher profile turf sites is usually managed by periodically applying surfactants to the affected areas to improve water penetration. Surfactants, literally, are surface active agents (SURFace ACTive AgeNTS).

Are all surfactants the same? No!

Types of surfactants

- **Anionic Surfactants**

Anionic surfactants are negatively charged compounds which can have a deleterious impact on soil structure and are often harmful to plants (phytotoxic). These compounds are not used to manage soil water repellency.

- **Cationic Surfactants**

Cationic surfactants are positively charged and strongly adsorb to soil particles and have the potential to render soil particles water repellent. These compounds are biocides and are **not** used to manage soil water repellency.

- **Amphoteric Surfactants**

May be + or – charged. Not commonly used in agriculture.

- **Non-ionic surfactant**

Non-ionic surfactants, as the name suggests, have no net charge although they are polar molecules. They generally have a low phytotoxicity and are the major class of surfactants used in soil applications.

They are detergent-like substances that reduce the surface tension of water allowing it to penetrate and wet the soil more easily. These compounds allow the water to 'spread out' by weakening the cohesive forces allowing adhesion to occur. The chemical make-up of these materials is ethylene oxide and propylene oxide units known as EO/PO block copolymers. These are essentially long chain polymers of varying complexity with a hydrophilic end and a hydrophobic end. The hydrophobic end binds to the coating on the soil particle while the hydrophilic end extends into the pore space allowing water to adhere to it.

- **Lubricants**

These are considered the 'new generation' in soil wetting agents. These materials contain several types of poly-oxyalkylene glycols. They tend to be more short lived and are less phytotoxic than EO/PO block copolymers and generally have good soil wetting properties.

- **Granular soil wetting agents**

These are some inert clay or organic material impregnated with surfactant. The type of surfactant varies with each product. The advantage of these is that they are easy to apply and have a low burn potential. Conversely they are generally expensive in terms of the quantity of surfactant applied per square metre of turf. The evenness of application is crucial to their effectiveness.

- **Synergistic compounds**

There is evidence to suggest that a combination of non-ionic surfactants and lubricants creates a response that is greater than the sum of the two. Materials are appearing on the market that are extremely effective in overcoming soil water repellency and improving soil water infiltration.

- **Environmentally friendly soil wetting agents:**

These are generally non-phenol types that are highly degradable. They are short lived in the soil.

- **Soil Humectants**

Soil humectants are compounds that attract and retain moisture. Skin moisturisers are based on the chemistry of these products as they attract water vapour back to the skin. They are large complex molecules that have many sites for water molecule attraction. Their large size, however, limits their transport in the soil. They tend to concentrate near the surface of the profile. They do have surfactant properties, but not to the same degree as true surfactants. Their burn potential is also very low.

- **Organic acid solubilising compounds**

These materials claim to dissolve and remove the hydrophobic compounds. The number of different compounds that these materials can remove is yet to be verified with adequate independent research.

How do we apply these materials?

Treat the ENTIRE area to create a more uniform infiltration pattern.

When irrigating after treatment, apply a sufficient quantity of water to wet the entire hydrophobic zone, not just the surface layer.

READ THE LABEL.

Avoid phytotoxicity by only applying surfactants at the recommended rate. Do not use higher rates in the hope of increasing the efficacy.

Some treatments may require irrigation after being applied to wash the compound off the leaves and prevent a phytotoxic response.

Ensure the treatment can actually penetrate the thatch layer—control the thatch through core aeration to 3 inches.

Injection systems may be useful for delivering surfactants to the root zone; particularly where the water drop penetration tests indicate that water repellency is occurring deeper in the soil profile.

What are the advantages in using soil surfactants?

- Turfgrass managers report an increase in moisture retention as a result of using surfactants. This may be due to the compound allowing wetting of finer pores which were previously "blocked" by hydrophobic substances.
- Irrigation efficiency is maximised.
- Output losses are minimised.
- Better uniformity and overall turf quality.

Acknowledgements
Stan Kostka, Aquatrols Corporation

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[3] Aquatrols Corporation, Cherry Hill, NJ
[4] Alterra, Wageningen, Netherlands
[5]University of Arkansas, Fayetteville, AR.

Session 3: LIFE IN THE SOIL

The Soil Organic Matter System—How It Works in Nature

Dr. Weijin Wang and Dr. Ram Dalal

Queensland Department of Natural Resources, Mines and Water, Brisbane

Summary

Soil organic matter (SOM) is a critical component of soil's biological, physical and chemical functions in the environment. It contains both living and non-living components. Living components are belowground fauna and roots and microbial biomass, and non-living components are active, slow and relatively resistant pools or humic and non-humic substances. The amount of organic matter in a soil at a given time is a function of rates of addition and decomposition of various SOM pools. Land use change from forestry to cropping and from pasture to cropping invariably leads to the loss of SOM due mainly to the decrease in the rates of addition but may also be due to increased rates of decomposition and erosion. Restoration measures include reduced or no-tillage, plant residue retention and nutrient management, ley farming, improved pastures, agroforestry and reforestation, and addition of organic manures and wastes. These management practices also lead to enhanced soil fertility, good structure, erosion control, rehabilitation of saline and sodic lands, and greenhouse gas mitigation.

The concepts: soil organic matter, humus and humic substances

Soil is a complex system of many components, consisting of numerous materials that physically, chemically and/or biologically interact with each other. The constituents of soil can be broadly classified into inorganic and organic fractions. The inorganic fraction includes materials of mineral nature such as sand, silt, clay and salts. The organic (carbon) fraction is composed of substances related to or derived from living or once-living sources such as plants or animals.

The organic materials in soil or on soil surface exist in many different forms such as living plants and insects and their unaltered or partially decayed remains, microorganisms (bacterial, fungi and actinomycetes), cells and tissues of organisms, root exudates, the microbial decomposition products of the above, and charcoal. Experts are divided as to what constitutes "soil organic matter" (SOM). Table 1 shows "included" and "excluded" elements from three different models.

Details regarding tests for soil organic matter are found in Appendix 1.

Table 1: Three Views of Soil Organic Matter

Reference	All fully decomposed organic matter (humus)[6]	Undecayed plant and animal products	Partial decomposition products (plant and animal)	Living Biomass (such as roots)
Baldock and Nelson (2000)	included	included	included	included
MacCarthy et al. (1990)	included	not included	not included	not included
Soil Science Society of America (1997)	included	not included	soil microbial biomass only	not included

Functions of soil organic matter

The known functions of organic matter are:

- Provides a reservoir of soil nutrients
- Improves the ability of a soil to maintain a stable pH
- Helps retain soil moisture and nutrients
- Can act as a plant growth stimulant
- Binds soil, improving its structure and infiltration
- Helps control some soil diseases
- Helps protect land from the effects of environmental extremes
- Complexes micronutrients and make them available to plants
- Retains contaminants such as heavy metals, herbicides and pesticides

[6] Humus consists of non-humic and humic substances. The non-humic substances make up about 30% of humus and are composed of well-defined classes of organic compounds, such as protein, carbohydrates, organic acids, lipids, pigments, lignin, cellulose and polyphenols etc. However it is technically difficult or impossible to isolate non-humic substances from humic substances and mineral materials because of their close association. Conventional chemical approaches are of little use due to the limit of their extracting ability and the possible changes in the chemistry of the humus during extraction.

Effects on biological and biochemical properties of soil

SOM is the source of carbon and energy for the makeup, growth and activities of fauna (e.g. earthworms) and microbes in soil. The organisms are the driving agents of organic carbon decomposition and nutrient transformations in soil. Soil fauna act as primary decomposers by ingesting plant materials and grazing on microbes. They also contribute to nutrient cycling by fragmenting surface plant residues and incorporating the fragments into the soil profile. Soil microbes are considered to play a major role in the decomposition of the organic materials, the formation and turnover of humus, and the release of metabolic products including enzymes, carbon dioxide, and nitrogen (N), phosphorus (P) and sulphur (S) contained in the organic substrates.

SOM provides a considerable reservoir of plant nutrients, particularly N, S and P. In most soils, more than 95% of the N exists in the organic pool. The organic N can be released into soil for plant uptake through microbial decomposition. On the other hand, the inorganic N (mainly ammonium and nitrate) can also be immobilised into SOM for storage through microbial assimilation. SOM normally has a C/N ratio ranging from 10 to 16, while the plant residues can have much higher C/N ratios. In general, soils with lower C/N ratios in SOM more readily release mineral N, whereas organic materials with higher C/N ratios tend to promote immobilisation of mineral N into the organic phase.

It has been found that humic substances can stimulate plant growth (Chen and Aviad, 1990). The major observed effects include enhancing seed germination, root initiation and elongation, shoot growth and productivity. The quality and quantity of SOM can also influence the incidence of plant pathogens in soil. Some biologically active compounds such as antibiotics and polyphenols may reduce the vulnerability of plants to the attack by pathogens (Stevenson, 1994)

Effects on chemical properties of soil

The organic molecules in soil, particularly humus, contain many negatively charged sites in their structure. Thus SOM can substantially increase the ability of soils to retain positively charged nutrients such as calcium (Ca^{2+}), magnesium (Mg^{2+}), and potassium (K^{+}), which further influence soil physical properties and nutrient supplying capacity. This feature of SOM is especially important for nutrient retention in sandy soils or where the clay fraction has a low charge density, such as kaolinite. SOM benefits soil fertility and health by (i) increasing the availability of P in soil that would otherwise be tied up with iron (Fe^{3+}), aluminium (Al^{3+}) or Ca^{2+} and their oxides; (ii) enhancing the availability to plants of trace elements that would otherwise exist as insoluble salts or oxides; and (iii) helping reduce high concentrations of toxic metals (such as cadmium (C_d^{2+}), lead (P_b^{2+}), mercury (Hg^{2+}) and Al^{3+}).

SOM can significantly increase the acid/alkali buffer capacity of soil. According to the findings of Cutin et al. (1996), obtained with 59 agricultural soils, the SOM fraction accounted for approximately two-thirds of the soil pH buffering capacity, despite the fact that soils generally contained several times more clay than SOM. The effects of application of organic material on soil pH vary with the quantity and quality of the material added, soil properties and the environmental conditions. Usually, amendment of organic materials tends to buffer soil pH values.

Effects on physical properties of soil

SOM plays an important role in the binding together of mineral particles, the formation of aggregates, and the maintenance of soil structural stability. It is considered that humified organic compounds and plant root exudates are the key agents in the formation of small aggregates. Fine roots, fungal hyphae and plant residues are important in the formation and stabilisation of large aggregates (> 2 mm) (Baldock and Nelson, 2000).

As a result of the beneficial effects on soil structure and pore size distribution, SOM enhances water-holding capacity, aeration, infiltration and tilth of soil. When SOM is lost, soils tend to deteriorate in the structure and become hard, compact and cloddy. Also, plant residues on the soil surface can improve the infiltration of water into soil and reduce the rate of evaporation.

Effects on land use sustainability

Management of SOM is considered the most important factor affecting land use sustainability. Because of its important biological, chemical and physical functions, managing for SOM can improve productivity and environmental quality, and can increase the buffering capacity of land to the negative impacts of natural phenomena such as drought, flood and disease. As SOM enhances soil structure, water-holding capacity and infiltration, maximising SOM content can generally increase the ability of soil to resist erosion, and thus protect water quality, the landscape and wild life habitat. Furthermore, increasing SOM content can reduce atmospheric carbon dioxide concentration and contribute to the mitigation of global warming.

Factors affecting soil organic matter levels

The SOM level represents the balance of organic matter inputs and outputs in the soil system. Therefore, any factor that affects the amount of plant biomass returned to soil and the decomposition rate of SOM will have impact on the equilibrium level of SOM. In some cases, losses by erosion or leaching may also be a significant factor. Figure 1 illustrates the inputs and outputs of SOM.

Soil texture has a significant effect on SOM decomposition rate. Under similar vegetation and climate conditions, SOM content usually increases with increasing clay content. Clay protects SOM from decomposition through mechanisms such as adsorption, encapsulation and entrapment. In addition, multivalent cations (e.g. Ca, Fe^{3+} and Al) can also stabilise fresh or humified organic substances.

Vegetation type and species affect the quantity and quality of plant residue input. Woody debris has higher content of lignin and higher C/N ratio than grassy residues and is more resistant to decomposition. Changes in SOM concentration are often observed following vegetation change (Dalal and Chan, 2001).

Temperature and moisture affect both plant biomass productivity and SOM decomposition. In a rainfed system, SOM usually increases with increasing precipitation. The decomposition rate of SOM normally doubles when temperature increases by 10 ^{o}C, which often exceeds the positive effects of temperature on biomass production. It has been often observed that SOM decreases with increasing temperature (Dalal and Chan, 2001).

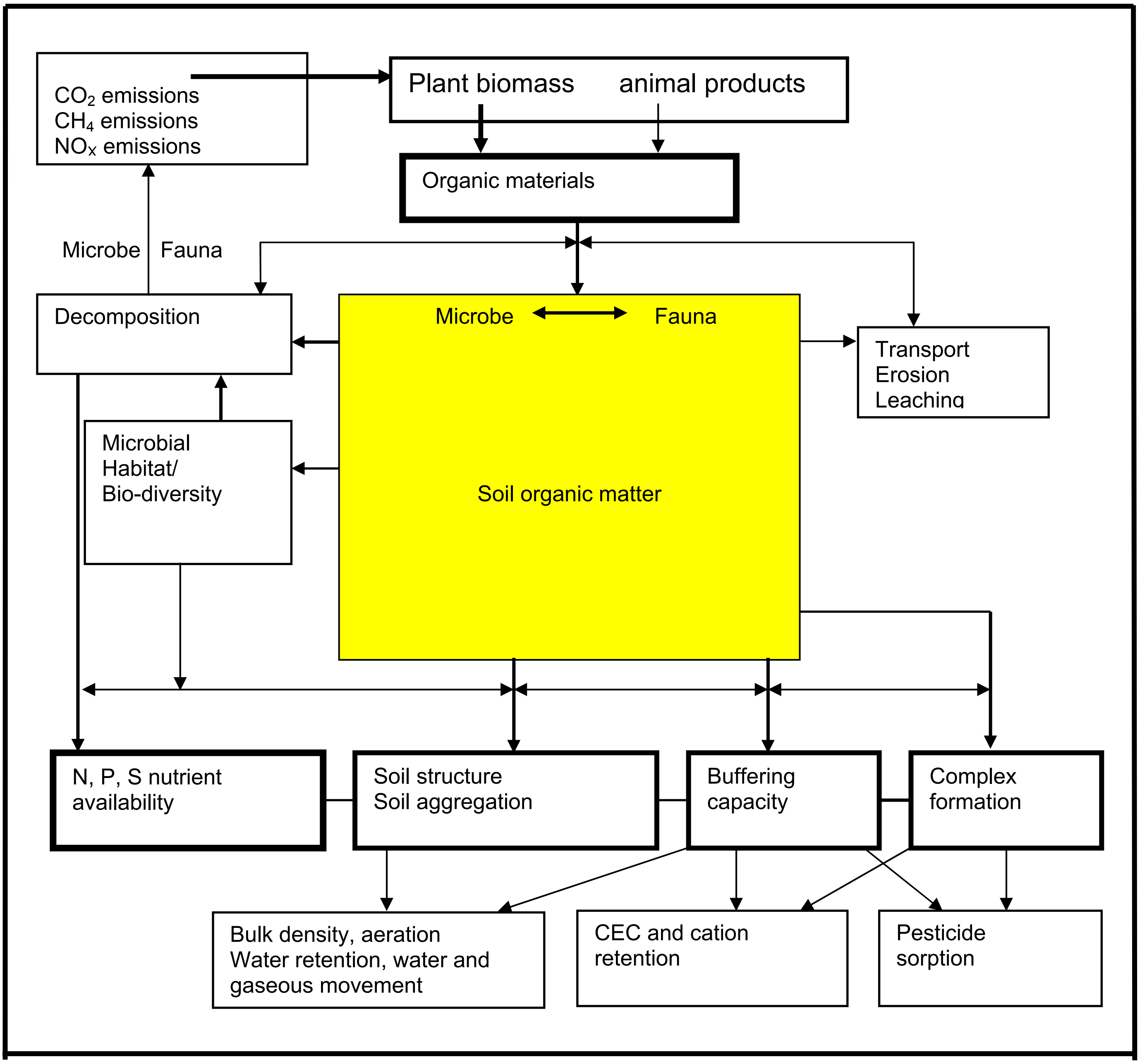

Figure 1. Biological, physical and chemical functions of organic matter in soil (from Dalal and Chan 2001).

Farming practices, such as tillage, stubble management, rotation, fertiliser application, irrigation and fallow management can considerably influence the accumulation and decomposition of SOM. The effects of the farming practices may interact with each other and be further effected by soil and climate conditions. In a cereal cropping/fallow system in SE Queensland, Wang et al. (2004) found that no-till, stubble retention, and N fertiliser application had no significant effect on SOM if practised alone but increased SOM level by 0.2 to 0.4% when practised together. Cultivation of a soil that previously supported native vegetation or pasture generally leads to reduced level of soil organic carbon (SOC) (Dalal and Mayer, 1986). This is due to reduced plant carbon inputs and a faster SOM decomposition. The organic matter level of a cultivated soil eventually attains a steady state, when rate of formation of new SOC from organic residues (plant and crop residues, roots and root exudates, organic wastes, manures and green manures) equals rate of SOM decomposition. However, if soil and crop management practices change, a new equilibrium level, either higher or lower, will be reached over a long period.

The complexity of the SOM cycle means that it is not practical to define a standard level suitable for all soils. Buckman and Braddy (1969) stated that SOM should be maintained to achieve maximum economic yields, where the soil maintains a suitable physical condition, satisfactory biochemical activities and an adequate availability of nutrients. Sikora et al (1996) suggest that as long as SOM changes little with time, and the system is productive and resilient, the SOM content may be considered optimum.

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Appendix 1

Determination of soil organic matter content

SOM is usually determined using air-dried soil samples which have been sieved to < 2 mm and fine-ground to < 0.25 mm. Therefore the SOM content determined in analytical laboratories generally encompass all organic substances passed through the sieve such as plant and animal residues, living or dead microorganisms, charcoal, and humus.

A variety of techniques are available for determination of SOM content, each with advantages and disadvantages. One of the methods involved pre-treating the soil sample with a mixture of HCl and HF to remove the hydrated minerals and carbonate, following by ignition at high temperature. The SOM content of the sample is then directly estimated from the weight loss on ignition. This method is tedious and can be erroneous for some soils due to weight loss of inorganic materials during ignition (Soon and Abboud, 1991).

SOM content is usually calculated indirectly from the concentration of soil organic carbon (SOC). Carbon (C) is the skeleton element in the structure of all organic compounds and was assumed to make up 58% of SOM. Thus a factor of 1.724 has been used to convert SOC into SOM. However, it has been found that this conversion factor can vary from 1.724 to 2.02 for different surface soils (Nelson and Sommers, 1982; Siri Prieto et al., 2002). Because of inaccuracies associated with determination of SOM, either by the direct weight loss methods or through the indirect SOC determination/conversion methods, SOC instead of SOM concentration is often reported in the literature.

A number of methods have been proposed for determining SOC content. The most widely used techniques nowadays are the dichromate oxidation techniques and the dry-combustion techniques. In the dichromate oxidation methods, an excess of dichromate solution is mixed with concentrated sulphuric acid in the presence of finely ground soil sample. The amount of dichromate consumed during the oxidation of SOC is determined by titration with ferrous ammonium sulphate, which is then used to calculate SOC content. If the oxidation reaction relies only on the heat generated from the dilution of sulphuric acid, such as the method of Walkley and Black (1934), complete oxidation of SOC cannot be achieved, and thus a correction factor must be used for calculating the results. Because the organic C in different soils, or even in different depths of a soil profile, is not always oxidised to the same degree, the correction factor is soil specific, generally in the range of 1.20 to 1.40 (Nelson and Sommers, 1982; Soon and Abboud, 1991). Where external heat is used to accelerate the oxidation (Mebius, 1960 ; Soon and Abboud, 1991), correction of the results is not needed as the complete oxidation of SOC can usually be achieved. The dichromate oxidation methods can result in overestimation of SOC for samples containing Cl^- or Fe^{2+}, and lead to underestimation where MnO_2 is present.

Automated dry combustion instruments (e.g. LECO series) are increasingly used in modern laboratories for determining SOC contents. These automated analysers convert all C in the soil sample to carbon dioxide and quantify carbon dioxide evolution with an infrared detector. For soils containing carbonate, pre-treatment with weak acid (such as sulphurous acid) should be performed to remove the inorganic C from the sample. Alternatively, the inorganic C content should be determined separately and subtracted from the total C to calculate SOC content. The automated combustion analysers are very effective and normally give satisfactory results, provided caution is exercised to the possible interference from carbonate. In addition, some automated instruments can analyse total C, N and S simultaneously.

References

References included in this appendix are listed on pages 52–53.

Microbial Amendments and Microbe-friendly Additives

Tony Pattison
Department of Primary Industries and Fisheries, South Johnstone Research Station, South Johnstone, Qld, 4859.

Introduction

Before we can understand the role of amendments and additives to the soil and their part in a healthy soil, we need to understand what is in the soil and role of some of the organisms in the soil. By knowing something about soil biology we can get a greater appreciation of the constraints and challenges presented by the use of amendments and additives to the soil. This article is not meant to be prescriptive or a definitive assessment of soil biological activity, but is a general overview and discussion on soil biology and biological activities in the soil.

What is in soil?

Soil is made up of four broad categories: minerals (~45%), air (~25%), water (~25%) and organic matter (~5%). The proportion of these elements is variable between soils, but it is the organic fraction that is the most variable between soil management systems. The organic matter component of the soil makes it a vital living system. The organic component of the soil is composed of the residues of dead plants and animals and living organisms that consume organic matter and other soil organisms. Most of the biological activity in the soil occurs in the top 10 cm where there is continual exchange of air and plant residues. We often do not realise the amount of life and what type of organisms exist in soil, because we do not see their activities. We also do not understand the diversity of organisms present in the soil and their function. A popularised experiment in Norway describes how two scientists took a gram of soil from outside their laboratory and found between four and five thousand separate species of bacteria. They then drove a few kilometres to the coast and took another gram of soil and found 5,000 different species of bacteria. The author questioned "if two pinches of soil in Norway contained over 9,000 separate species of bacteria, how many different species of bacteria may exist in soil?" (Bryson 2003).

To begin to understand the function of soil organisms it is sometimes easier to divide them into groups and try and understand the functions of some of the organisms in the group before looking at the whole soil biological ecosystem. Soil organisms are typically classified according to size—divided into microflora, microfauna, mesofauna and macrofauna (Figure 1, Table 1).

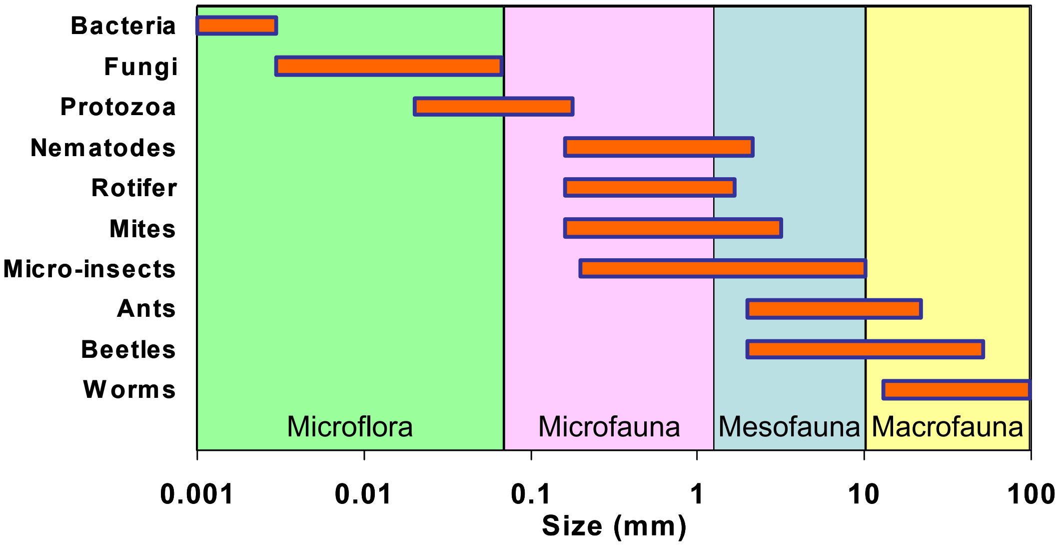
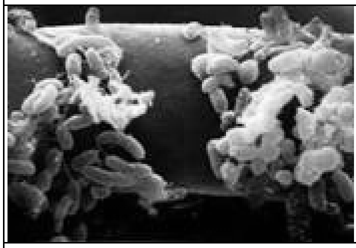
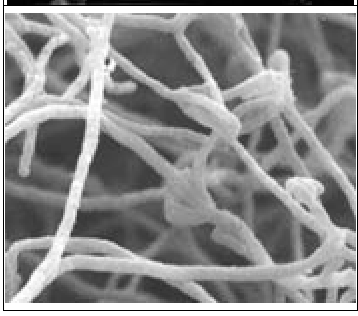
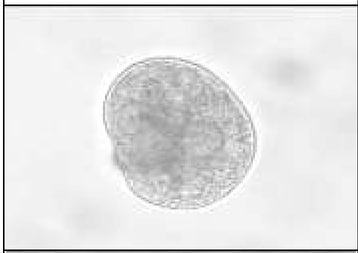
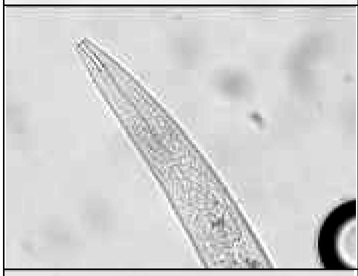
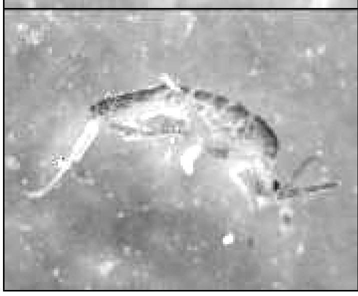
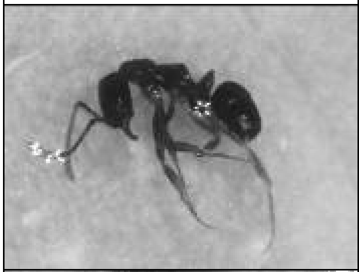


Figure 1: Size classification of some example organisms found in the soil.

Table 1: Examples of some soil organisms and their roles in the soil.

Microflora	Soil microflora is made up of the microscopic component of soil life. These a organisms are primarily responsible for breaking down organic matter in the soil
	**Bacteria** Bacteria are less than 5 µm in size and can only be seen using a microscope. There are as many as 1 to 100 million bacteria per gram of soil. They have a wide range of functions in the soil and are the main agents for breaking down organic material and recycling nutrients in the soil.
	**Fungi and filamentous bacteria** Fungi and filamentous bacteria are usually slower growing than bacteria and not quite as numerous with usually less than 1 million colony forming units per gram of soil. However, there may be as much as 6 metre of filament per gram of soil. This group of organisms decompose organic matter more resistant to decomposition by bacteria and can withstand a greater range of environmental conditions.

Microfauna	Microfauna are primarily involved in the recycling of nutrients and the release of nutrients for further biological transformations in the soil.
	**Protozoa** Protozoa feed by engulfing other organisms in the soil such as bacteria and fungi. Their numbers in the soil range from 10 to 1 million per gram. Protozoa have a high turnover and their feeding on soil microflora helps to refresh the microflora population.
	**Nematodes** Nematodes have been described as the "vacuum cleaners of the soil". Their numbers in the soil range from 2 to 200 per gram of soil. Nematodes can feed on bacteria, fungi, roots or are predators of other nematodes and protozoa. Nematodes are very important in recycling nutrients within the soil.
	**Other microfauna** Other microfauna exist such as rotifers (pictured) and tartigrades. Their role is similar to nematodes and protozoa—feeding on the soil microflora and recycling nutrients. However, these organisms are not quite as numerous in the soil.
Mesofauna	Mesofauna are primarily responsible for regulating and distributing microorganisms in the soil. They may also fragment organic matter in the soil, making it easier for microorgansims to decompose.
	**Mites** Mites in the soil can feed on fungi, decomposing organic matter or they may be predatory on smaller microorganisms. Mites vary in size from less than 1 mm to 6 mm. There may be as many as 15 mites in 1 gram of soil.
	**Insects** There is a wide range of small insects, such as collembolan (pictured). Their size varies from 1-10 mm and numbers are typically around 5 per gram of soil. Small soil insects can feed directly on decaying organic matter, soil microflora (bacteria and fungi) or on soil microfauna.

Macrofauna	These are the larger animals in the soil and easily seen with the naked eye. Not all macrofauna are permanent residents in the soil, but may complete only part of their life cycle below ground. The macrofauna are described as “soil engineers” as they are able to move soil particles.
	**Ants** There is a large range of ants that live in the soil. The larger animals that live in the soil have the capacity to rearrange soil particles creating channels in the soil. Ants can range in size from 1-25 mm.
	**Beetles** There can be a range of beetles and their larvae that live in the soil. They typically live on plant material or may be predatory on other soil animals. They range in size from 0.5 to 10 mm.
	**Earthworms** Earthworms feed on organic matter in the soil and are important in moving organic matter to lower soil depths. Earthworms range in size from 5-25 cm and their numbers vary in soils from 30-300 per m^2. The tunnelling and worm castings due to worm activity are important in maintaining soil structure.

Role of microorganisms in the soil

Nutrient recycling

There are a lot of nutrients contained with organic matter. However, much of these are unavailable to plants until they under go transformation mostly by soil microbes. This process is known as *mineralisation*. Without the activities of microorganisms on organic matter the surface of the world would be covered to the depth of several meters in undecomposed organic matter. However, very few organisms possess the ability to entirely decompose organic matter by themselves. Instead there are a chain of events as the organic matter passes between organisms in the soil that lead to the decomposition of the organic matter. For example larger organisms can shred organic matter into smaller pieces, increasing the surface area that bacteria and fungi are able colonise to start microbial decomposition. This connectivity of organisms and flow of nutrients between organisms is known as the *soil food web*.

Soil management has a big impact on the flow of nutrients and the turnover of organic matter in the soil. The management of inputs into the soil will influence the biology and availability of nutrients to soil organisms. Long term changes in soil biology take place when management practices occur over a long time or dramatic disturbances occur to the soil environment.

Maintaining soil structure

The formation and maintenance of good soil structure has a strong dependence on soil biological activities. The mucus covering of the organisms in the soil mix with soil particles, sticking them together to form soil aggregates. Fungi in the soil not only produce mucus which sticks the soil together, but the hyphae act like a net, helping to bind soil particles.

The formation of soil aggregates helps the movement of air and water into the soil, which not only supports better plant growth but a more diverse range of soil organisms. Soils with better binding of the particles, or *aggregate stability,* are more stable when exposed to water and tillage.

Suppression of plant diseases

Disease suppression is a natural condition which can be disrupted by agricultural activities, which often allow soil pathogens and pests to become dominant. Some soils with high amounts of organic matter and biological diversity are able to suppress pests and diseases. That is, the pests and diseases may be present in the soil but they rarely become problematic. Suppressive soils are thought to be the result of *predator-prey* relationships occurring as part of the interactions between organisms in the soil food web.

Soil detoxification

The organisms in the soil act as *biofilters*, decomposing many of the pollutants and pesticides added to the soil. The organisms in the soil are able to use some pesticides applied to the soil as a food substrate. This is referred to as *biodegradation*. Other organisms are able to tie up pollutants such as heavy metals, stopping them from being recycled in the soil ecosystem and ending up in the food chain.

Measuring soil biological activity

There are three broad categories that we are interested in when we want to measure the biology of soils:

1. Size or biological activity,
2. Diversity and
3. Function.

Biological activity

Biological activity only gives an estimation of the size of the biological component in the soil. It cannot tell us how many different types of organisms are present or what their functions are. Soil biological activity can be measured either directly or indirectly. The direct measurements of biological activity can look at the organisms still in the soil or may use various methods of trying to extract them from the soil.

Direct investigations of organisms in the soil is difficult due to the opaque properties of soil. The extraction of organisms from the soil does not always remove all the organisms and some methods are biased towards certain groups. It is estimated that only 1% of soil microflora can be cultured on nutrient media. However, new techniques are being developed that overcome some of these problems, but they are experimental and tend to be expensive.

Indirect measurements of biological activity rely on measuring chemical substrates produced by organisms in the soil. The respiration of living organisms produces carbon dioxide (CO_2). The production of CO_2 can be used as one measure of biological activity (Figure 2). Similarly, the amount of carbon contained in the bodies of microorganisms (biomass C) is another method of measuring the size of the biological component of soils (Figure 2). A study by Shi *et al.* (2006) found greater microbial activity (up to 3 times greater) in older turf grasses compared to younger turf grasses or neighbouring forest (Figure 2).

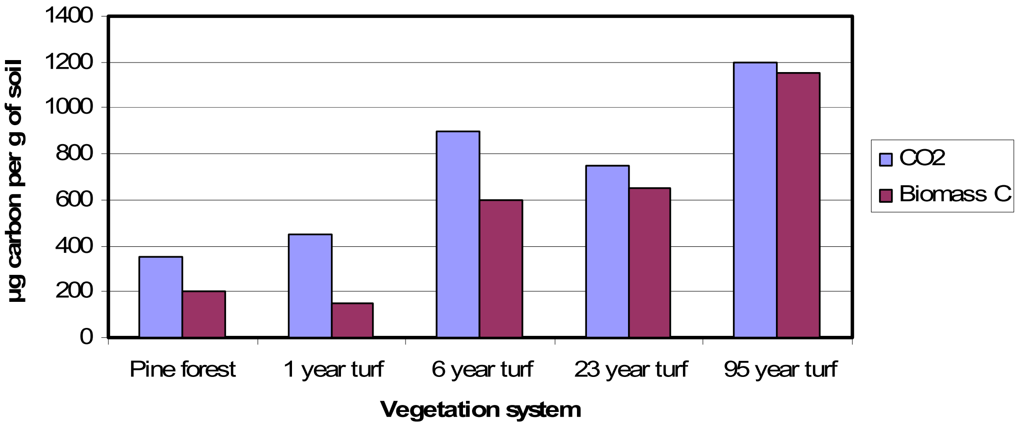


Figure 2: Microbial activity measured by respiration and biomass carbon in four turf grasses of different ages compared to neighbouring forest (Shi *et al.* 2006).

The activity of organisms in the soil requires enzymes to break down organic matter. The amount or activity of the enzymes in soil can give an estimation of the biological activity. The enzymes in the soil can be measured directly or a substrate added to the soil and its decomposition gives an indication of biological activity.

Biological diversity

Biological diversity is the number of different types of organisms present in the soil. The soil is a diverse environment and we can only estimate the true extent. It is estimated that less than 5% of the species in the soil have been described (Bardgett *et al* 2005). It is recognised that different organisms have different roles in the soil or perform a similar function slightly differently. Therefore, a soil that has greater biological diversity has greater resilience to stress and changes, which could be termed as *biological buffering*. A diverse soil ecosystem has a wider range of functions with more interactions among soil organisms. This means there are more organisms in the soil that perform various processes and are able to take over roles of other organisms if a particular group is inhibited by stress. Soil management decisions have the ability to change growth factors, substrate quality or substrate concentration in the soil, which can change the organisms that dominate the biological soil community.

Biological function

The function that different organisms in the soil perform is much more difficult to determine. Some estimates of functions can be made by soil ecological studies. Estimates of the diversity of functions in the soil can be made by the addition of different carbon sources to the soil and measuring their decomposition. In soils with greater functional diversity, the carbon sources will decompose at a similar rate and relatively quickly. However, in soils that have little functional diversity, one or two carbon sources may decompose much quicker than others.

Indicator groups of organisms can be used as *surrogate* indicators of soil functions. For example, soil nematodes are being used more widely as ecological indicators because they feed on a diverse range of substrates and perform different roles in the soil food web (Figure 3).

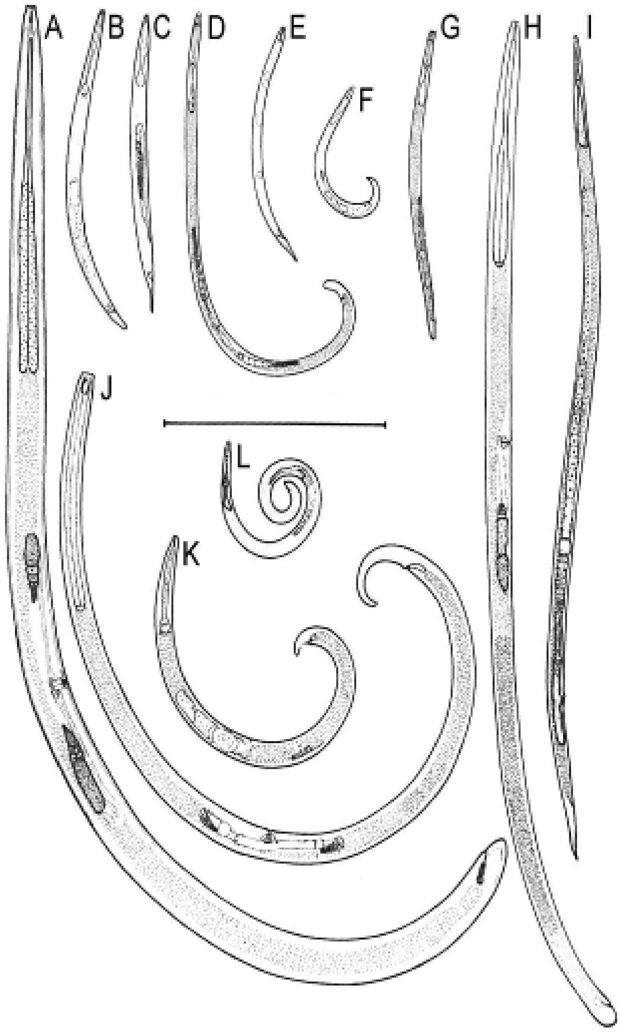


Figure 3: Diversity of size in 12 genera of nematodes recovered from soil. Drawings are at uniform magnification; **A**: *Aporcelaimus* (Dorylaimida; omnivorous), **B**: *Cephalobus* (Rhabditida; bacterial-feeding), **C**: *Rhabditis* (Rhabditida; bacterial-feeding), **D**: *Tylenchorhynchus* (Tylenchida; plant-feeding), **E**: *Heterodera* second stage (Tylenchida; plant-feeding), **F**: *Paratylenchus* (Tylenchida; plant-feeding), **G**: *Pratylenchus* (Tylenchida; plant-feeding), **H**: *Pungentus* (Dorylainida; plant-associated), **I**: *Ditylenchus* (Tylenchida; species variously plant-feeding or fungal-feeding), **J**: *Mononchus* (Mononchida; typically predacious but some have been cultured on bacteria), **K**: *Anaplectus* (Chromadorida; bacterial-feeding), **L**: *Helicotylenchus* (Tylenchida; plant-feeding). Scale line 500 µm = 0.5 mm.(Yeates and Pattison 2006).

Application of microbial inoculants to soil

Discussion so far has highlighted that the soil environment is diverse, well buffered and difficult to modify. Short term changes may be induced by the addition of amendments to the soil. However, microbial organisms applied as inoculants are more likely to be affected by the soil environment than any other agricultural practice. Each microbial agent has specific temperature, moisture and pH requirements for growth and colonisation of the soil. It is very difficult to generalise about the requirements that favour the proliferation of microbial agents. There are few studies that track the survival of microbial inoculants. However, one study investigated the addition of bacteria to the soil and found a 10 fold reduction in the population of that bacteria in the soil after 4 days, 100 000 fold reduction after 50 days and after 90 days the bacteria was undetectable in the soil (Esnard *et al*, 1998) (Figure 4).

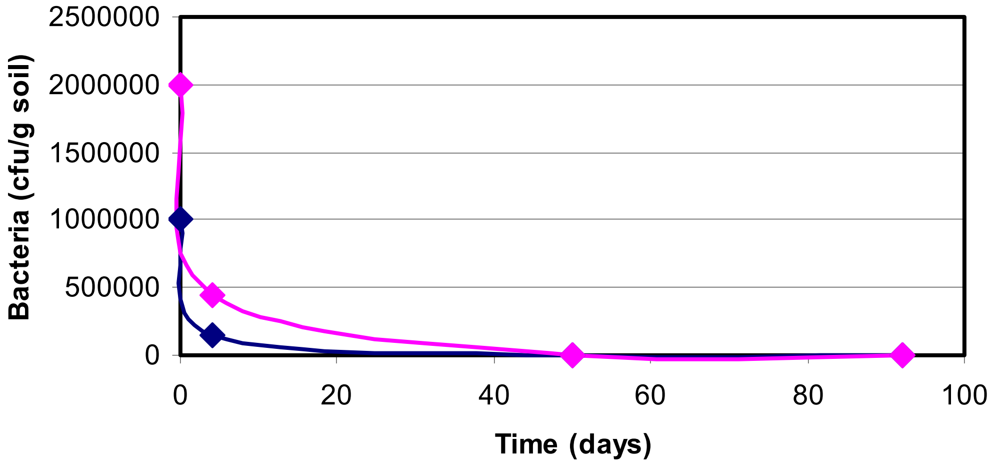


Figure 4: Recovery of bacteria added to soil at two rates over 92 days. (Esnard *et al*, 1998).

There are three general methods that have been used to change the microbial status of the soil. These are:

1. *Inundation* or *microbial pesticide* application—the microbial agent is introduced in large numbers, but fails to persist in the soil so frequent applications are needed (Figure 4).
2. *Introduction* or *mass release*—the microbial agent is normally absent, but it can spread and establish itself in soil to provide long term control.
3. *Natural control*—microbial agents have increased in the soil and their manipulation is confined to preserving or enhancing the conditions that favour their activity.

Introduced microbial agents must compete with the indigenous microflora for scarce energy resources. When adding microbial inoculants to the soil it is important to understand what is trying to be achieved. The addition of microbial inoculants often makes the soil manager feel good, without producing the desired outcome(s). Therefore, some criteria for determining the success of the microbial inoculant need to be set before the inoculant is applied. This will allow an objective comparison with untreated areas (see page 65, Growing the Soil Biology).

Successful introduction of microbial inoculants often depends on the addition of organic matter to enable the microbe to overcome competition. The organic amendment is added to the soil as an energy source to aid the establishment of microbial agents added simultaneously. It then becomes difficult to determine if the microbial agent or the organic matter added has the greatest impact on soil properties. The energy source considered essential for the successful introduction of microbial agents will have marked effects on the soil biology and these effects vary with the soil amendments.

Large amounts of organic matter can be added to the soil to enhance indigenous soil organisms. However, soil biology can be slow to respond and is dependent upon the distribution of the organic matter through the soil. The addition of amendments have many side effects that cannot be attributed solely to changes in soil biology. Soil amendments may result in changes in soil structure and plant nutrition. However, changes in the soil biology from the addition of amendments to promote indigenous organisms tend to have longer lasting effects than the addition of foreign microbial inoculants.

Application of organic amendments

The application of organic amendments has a greater potential of altering soil properties than the addition of microbial inoculants. Organic amendments may not only alter the biological characteristics of the soil, but change the physical and chemical properties in the soil. However, large quantities of material are needed to change soil properties (Figure 4). The application of between 10-25 tonnes per ha of compost were needed to significantly increase the yields of potatoes (Figure 5, Stephen Harper, DPI&F unpublished data). However, the application of more than 30 tonnes per ha of compost began to reduce potato yields (Figure 5).

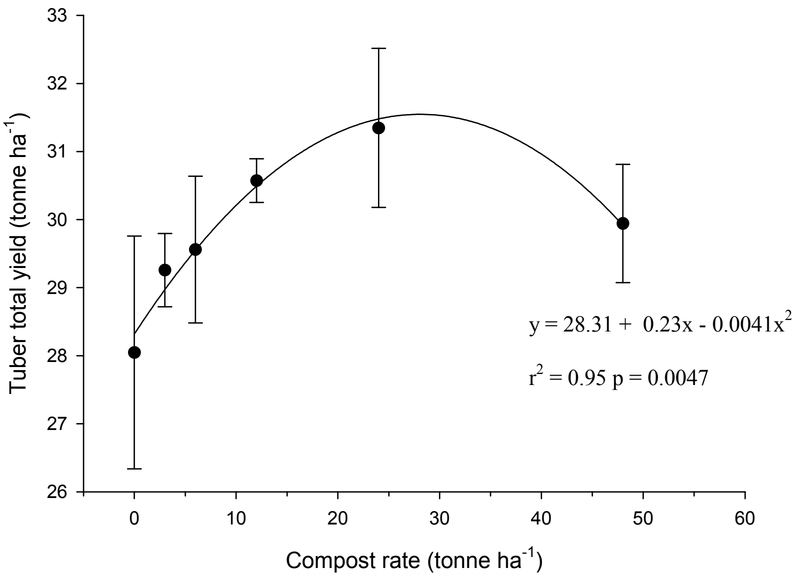


Figure 5: Response curve of potato yields to increasing compost applications (Stephen Harper, DPI&F unpublished data).

Not all organic matter decomposes at the same speed. The rate of the decomposition is reliant on:

- The chemical properties of the organic matter—the C/N ratio and the type of carbon contained within the organic matter,
- The activity of microorgainsms—the number and types of organisms present,
- Temperature and
- Moisture.

The more complex the organic amendment, the more organisms are required to decompose it and release nutrients (Figure 6). Valenzuela-Solano and Crohn (2006) found that grass clippings had nearly completely decomposed after one year, whereas redwood shreddings had only lost 20% of their biomass in the same time (Figure 6).

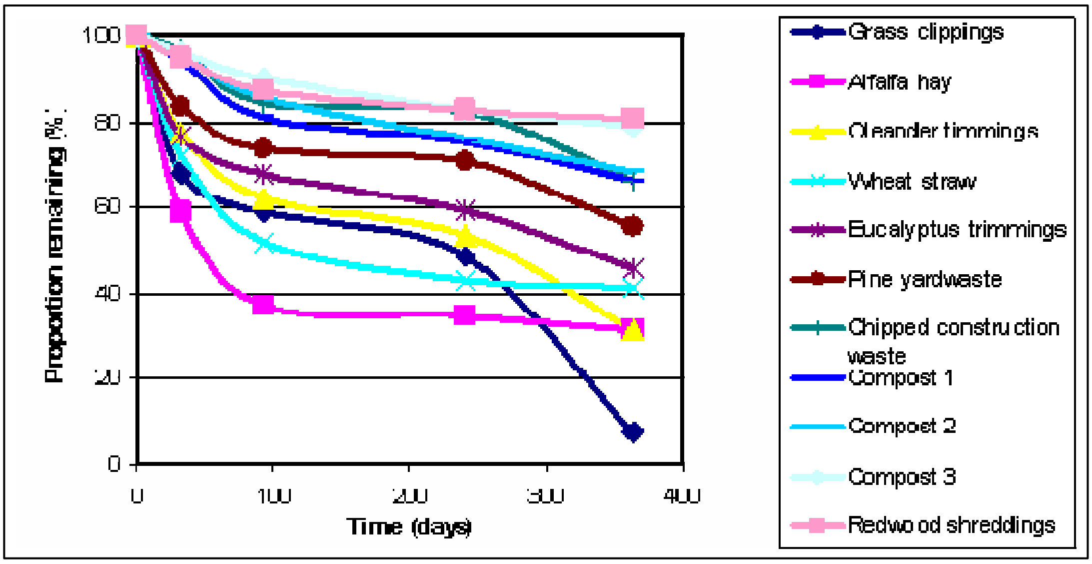


Figure 6: Proportion of mulch remaining applied to the soil surface in a one year experiment.

Complex or resistant organic matter requires more time to decompose and to release nutrients, and will require different groups of microorganisms compared to less complex, nutrient-rich organic matter. The decomposition of organic matter, especially mixtures such as composts, and their effects on soil biology are largely dependent on the supply source used. Similarly, the placement of the amendment will also have a big impact on the rate of decomposition and soil biology. Amendments incorporated into the soil tend to decompose faster and stimulate bacterial activity, whereas those left on the soil surface decompose slower and tend to stimulate fungal activity in the soil.

Different amendments have different impacts on the biology in the soil. In banana soil which had different amendments applied, there was a dramatic variability in the proportion of different feeding groups of nematodes. There were less plant parasitic nematodes and more omnivorous and bacterial-feeding nematodes in soils amended with grass hay or banana trash (Figure 7). The application of biosolids and alfalfa to the soil increased the proportion of bacterial-feeding nematodes (Figure 7).

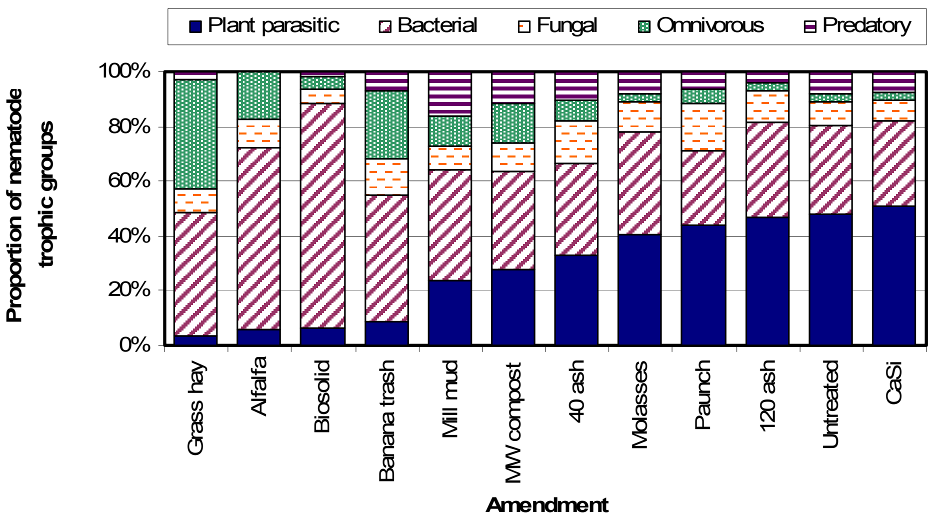


Figure 7: Effects of soil amendments on nematode feeding (trophic) groups in soil.

Influence of plants on soil biology

The influence of plants growing on the soil surface exerts a very strong influence on the organisms in the soil. There is a phenomenon is known as *above-ground-below-ground feedback*. This occurs because atmospheric carbon (CO_2) fixed by plants is decomposed by a select group of organisms in the soil which regulate the availability and supply of nutrients required for plant growth. The growth of *monocultures* (single species) is selecting organisms in the soil that are suited to surviving around the roots and decomposing residues associated with that plant species. A mixture of plant species requires a more diverse soil biological community to deal with the roots and residues of the different plants growing on the soil surface. This was highlighted in a survey comparing banana monocultures to neighbouring mixed plant communities, either forest or pastures. The monoculture had a greater proportion of plant-parasites (75%) in the soil, whereas the mixed plant species had a more even distribution of the different feeding types of nematodes (Figure 8).

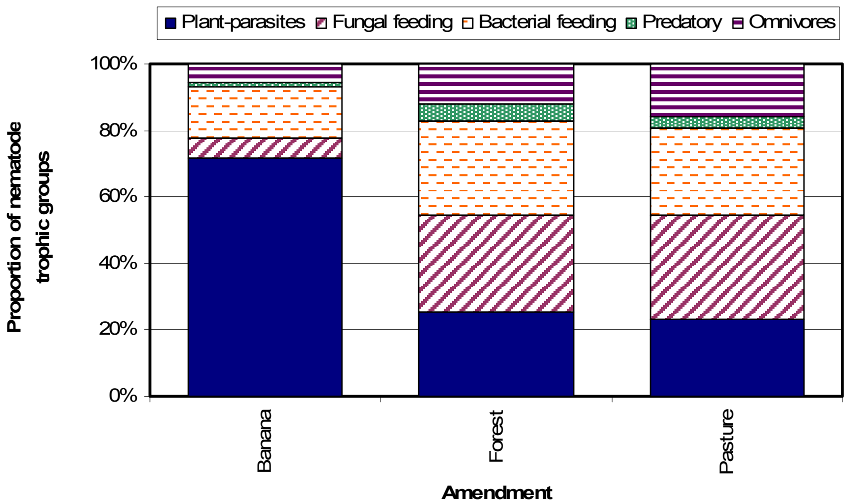


Figure 8: Effects of different plant communities on the proportion of nematode feeding (trophic) groups.

Growing the soil biology

With a greater understanding of the types of organisms in the soil and the roles they perform, we can start to develop strategies to make the most of the soil biology. However, before any type of biological farming can take place, there needs to be clear objectives about what is trying to be achieved. Some of the important questions that need to be answered include:

1. What do I want to achieve by changing the soil biology?—greater productivity, increased sustainability, disease suppression etc.
2. What organisms should I try to promote in the soil?—fungi, bacteria, earthworms etc.
3. What amendments would best help me achieve the objective and how much do I need? For example: amendments high in carbon applied to the soil surface stimulate fungal decomposition, whereas amendments high in nitrogen incorporated into the soil stimulate bacterial decomposition.
4. How do I know if the amendments are working and achieving the desired effect? There needs to be an established method of assessment and comparison with untreated areas.

The measurement of soil biology is difficult, but the plants growing on the soil surface can act as *bioindicators* of the function of soil health. Because plants integrate the biological, chemical and physical aspects of soil they are often the easiest determinant of changes occurring below the ground. However, it is then difficult to establish *what* has caused the change. This is why it is important to keep areas untreated, as a reference point to see differences.

Degradation of the soil takes place over a long time. Similarly, the restoration of a soil environment is a slow process and large quantities of material are required to bring about changes. Continual monitoring of the soil may help to find trends in soil indicators that can help to prevent soil degradation. An improvement in soil biology is only the start to a healthy soil—it is not the solution to unhealthy soils.

Conclusion

Life in the soil is a small but very important component of the soil system. The biology in soils is responsible for recycling nutrients, maintaining soil structure, suppressing diseases and removing toxins from the environment. For the biology of the soil to function properly and sustain healthy plant growth, organisms in the soil are dependent on one another to form a soil food web. There is an large number of organisms and diversity of different organisms existing in the soil—ranging from microscopic microflora to macrofauna the size of earthworms.

The composition of the soil biological community is well buffered against changes in the absence of large disturbances. Practices that bring about long term changes in the biological composition of the soil are large scale management changes—such as changes in plant community composition or the addition of large amounts of amendments. The effects on soil biology resulting from the addition of amendments are dependent on the source of the amendment and the quantity applied. To understand what effects amendments have on soil biology requires a structured process of assessing and comparing changes in soil and plant properties. A holistic view of how soils function to sustain plant growth is required to make the most of the life existing in soils.

Acknowledgements

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Soil-Borne Turfgrass Diseases

Kaylene Bransgrove

Department of Primary Industries and Fisheries,Redlands Research Station, Cleveland.

Introduction

Soil-borne turfgrass diseases affect all warm-season grasses and cause major losses of turf quality. They are caused primarily by fungi and there are few examples of true disease resistance in turfgrass. All turf applications are affected, from home lawns to golf greens, although the incidence and severity of disease is usually higher in highly managed applications. Examples include golfing and bowling greens where the turf is cut low and frequently. Both incidence and disease severity are influenced by plant health, site factors like shading and sometimes directly by mowing height. At times environmental factors like shading, water logging or heat stress can cause severe turf injury and stress and are misdiagnosed as diseases.

Commonly used warm-season turfgrass species are *Axonopus compressus* and *A. fissifolius* (broad and narrow leaf carpetgrass respectively), *Cynodon dactylon* and *C. dactylon* x *C. transvaalensis* (green and hybrid green couches respectively), *Dactyloctenium australe* (sweet smothergrass), *Digitaria didactyla* (blue couch), *Paspalum vaginatum* (seashore paspalum), *Pennisetum clandestinum* (kikuyu), *Stenotaphrum secundatum* (St. Augustinegrass) and *Zoysia* spp. (Zoysiagrass).

Major Root and Crown Diseases

Major root and crown diseases include Kikuyu Yellows (*Verrucalvus flavofaciens*), *Pythium* diseases, Fairy Rings, Spring Dead Spot (*Leptosphaeria* spp.), *Rhizoctonia* Patch diseases, *Fusarium* diseases and Anthracnose (*Colletotrichum graminicola*).

Spring Dead Spot and Anthracnose are not strictly soil borne diseases, their spores survive in plant material and, anthracnose particularly, can also be a foliar disease and disseminated aerially. They do however cause severe root, stolon and crown rots and large patch deaths. They have been included in this summary for that reason. The causal agents of Kikuyu Yellows, *Pythium*, *Fusarium* and *Rhizoctonia* diseases can survive in the soil itself and are considered soil-borne diseases.

Kikuyu Yellows

Kikuyu yellows is caused by the oomycete *Verrucalvus flavofaciens* and is the primary disease of turf and pasture types of kikuyu. The causal agent infects the root system and causes severe root rot and root and plant death. As an oomycete the pathogen thrives in the presence of high soil moisture. Disease symptoms are consistent and are expressed as a yellowing which becomes circular as the affected area expands. The centre of the circle dies and as kikuyu does not regrow in the centre, the patch is colonised by other grasses and broadleaf weed species. This can create an uneven, non-uniform surface. The disease usually appears in spring, progressing through summer and autumn. It is often more noticeable in dry weather. While there are no chemical controls for the disease, it can be masked to a degree by nitrogen fertiliser application.

Pythium *Diseases*
Pythium is another oomycete, or water mould, and is favoured by high soil moisture. A number of *Pythium* species cause turf diseases.

Damping Off
This is usually a seedling disease, but can be seen on adult turf. Affected seedlings are water soaked, stunted, become wilted and withered and die. The disease is promoted by warm, humid conditions in conjunction with wet soil.

Root and Crown Rot
The roots and crowns are affected. Root and crown rot can be a problem where excessive moisture is kept in the soil profile due to inadequate drainage.

Pythium Blight
This is a leaf infection that creates water-soaked looking patches—leaves in the patch may 'stick' together and white mycelium (fungal strands) may be seen in the morning or in periods of high humidity. The infection and destruction process can be very fast (such as overnight).

Fairy Rings
Fairy Rings are caused by numerous fungal species; a common few are *Lycoperdon* spp., *Marasmius* spp. and *Tricholoma* spp. Symptoms take three forms: no symptoms on turf but the presence of mushrooms, greening of the turf and turf death. All symptoms are in rings that enlarge from year to year. Rings can coalesce and form larger rings, scalloped rings or arcs.

Leptosphaeria *Spring Dead Spot*
There are two species of *Leptosphaeria* that cause spring dead spot, but in Australia *Leptosphaeria narmari* is the predominant species. Green couch, St Augustinegrass, Broad Leaf Carpetgrass and Kikuyu are known to be affected. The roots and rhizomes become discoloured and rotten and sunken. On the grass sward, circular patches may be noted in autumn and through winter and spring, or only in spring as turf moves out of winter dormancy. The incidence of the disease may be elevated by high nitrogen application.

Rhizoctonia *Patch Diseases*
The diseases most commonly known as "brown patch" and "large patch" are caused by a range of fungi in the *Rhizoctonia* group including *R. solani*. The diseases have been documented in most warm-season grass genera and are prevalent in warm, humid conditions in spring through to autumn. Incidence may also be elevated by high nitrogen applications. Patches of turf usually become light green in colour, then yellow, before degenerating into a brown discoloured area. Individual plants may have a dark purplish border and rot at the base of the leaf sheaths and/or stems.

Fusarium *Diseases*
Winter Fusarium is caused by the fungus *Microdochium nivale*. It was identified for many years as a *Fusarium* species, hence the usage of the name *Fusarium*. It is primarily a cool season and winter disease, and a pathogen of cool season turf, however it has been recorded on warm-season grasses. It is often characterised by an orange/brown colour in the patch and patch borders.

Anthracnose
Included in this summary because of its ability to cause severe crown rot, anthracnose, caused by *Colletotrichum graminicola*, is prevalent in cool, wet conditions and is primarily a disease of cool season grasses. Whilst it can cause severe damage to turf, it is considered a weak pathogen, found where the grass is under pressure from another (usually environmental) factor.

Control

Cultural control for most of these diseases is all about ensuring soil moisture is adequate but not high or excessive. In some soils drainage needs to be improved, while for others, where good drainage is inherent, good irrigation management practices are need to be employed.

Many diseases are also facilitated by high rates of applied nitrogen, often because nitrogen facilitates fast growth rates, producing plentiful amounts of young, easily infected tissue. Where it is possible, fertilise more frequently with less fertiliser to promote steady growth rates.

There is a range of chemicals registered for the control of diseases in turf, some being registered for use against several diseases. Local chemical re-sellers can provide up-to-date information on current chemical registrations and chemical recommendations.

Soil as a System

Tony Pattison
Department of Primary Industries and Fisheries, South Johnstone Research Station, South Johnstone, Qld, 4859.

Soil health management requires a holistic view of the soil and the understanding that soil health is made up of physical, chemical and biological soil properties working together (see Figure 1 on page 2, What is a Healthy Soil?). A change in one soil property interacts with other soil properties, creating a change in the soil environment. Most soils are resilient to change and changes occur slowly so they often go unnoticed. However, over a long period of time, or with severely degrading practices, soil properties will change leading to problems with production and impacting on the surrounding environment. Following degradation, soil properties take a long time to be restored. Therefore, to sustain healthy plant growth, soil managers need to develop practices that form a healthy soil system.

It is important to realise what impact management decisions will have on soil health. The improvement of soil health follows some basic principles (Figure 1 below). Management practices that increase the diversity of plant and root systems, and the types of plant residue that are returned to the soil, increase the diversity of organisms in the soil. Increased biological diversity helps to build a healthier soil that is better at sustaining plant growth. There are other benefits with increased biological diversity, such as improved nutrient recycling, improved soil stability and disease suppression.

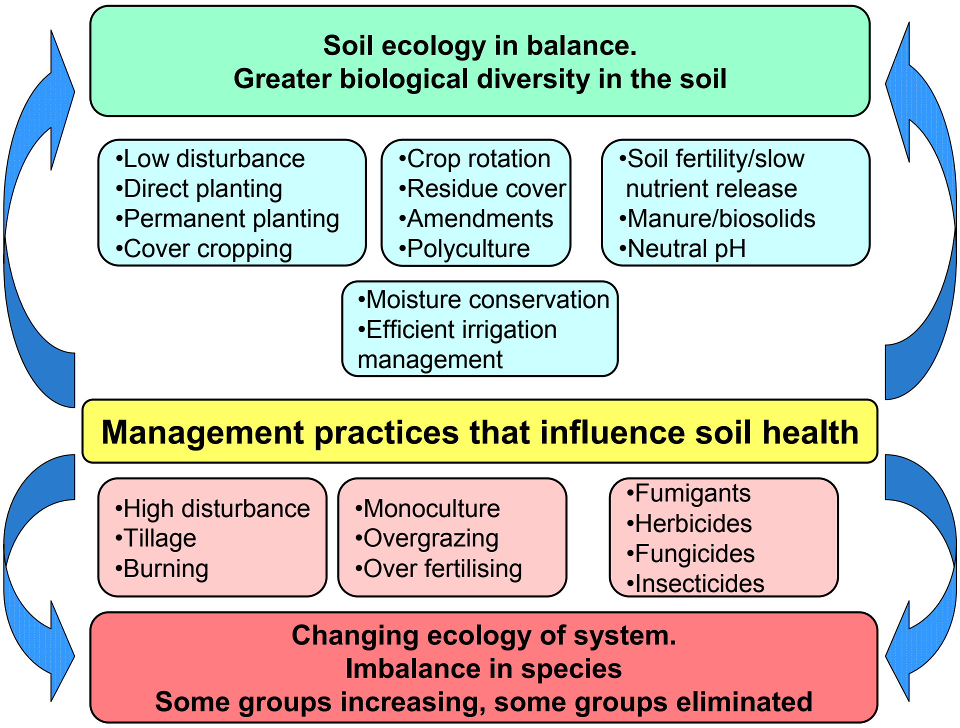

Figure 1: Management effects on soil biology and soil health (Kennedy *et al.* 2004).

Management practices that use a lot of inputs and impose large disturbances on the soil environment, such as fertilisers, tillage and pesticides and a reliance on monocultures (single plant species) tend to decrease the diversity of organisms in the soil. The continual removal of plant residues degrades the organic matter levels in the soil, which reduces microbial activity and diversity, reducing the health of the soil. Practices that degrade the health of the soil make an agricultural system less sustainable, which impacts on the viability of the farming operation and on the surrounding environment.

Organic matter management plays an important part in developing healthy soil systems. Because organic matter is made up of a mixture of compounds, it performs a number of different roles in the soil. However, organic matter is continually being lost from soil as either CO_2 or as particles (Figure 2). The activities of organisms in the soil require the carbon in organic matter as an energy source. This activity causes carbon to be lost as CO_2 to the atmosphere. However, soil management decisions can accelerate the losses of organic matter from the soil. Practices such as burning, erosion and over fertilisation all speed up organic matter loss. Any system for managing soil health requires carbon to be sequestered or saved in the soil as humus or microbial biomass. Therefore, the addition of carbon as organic matter must be greater than losses as CO_2 or as lost organic particles. However, the process of sequestering carbon may take many years.

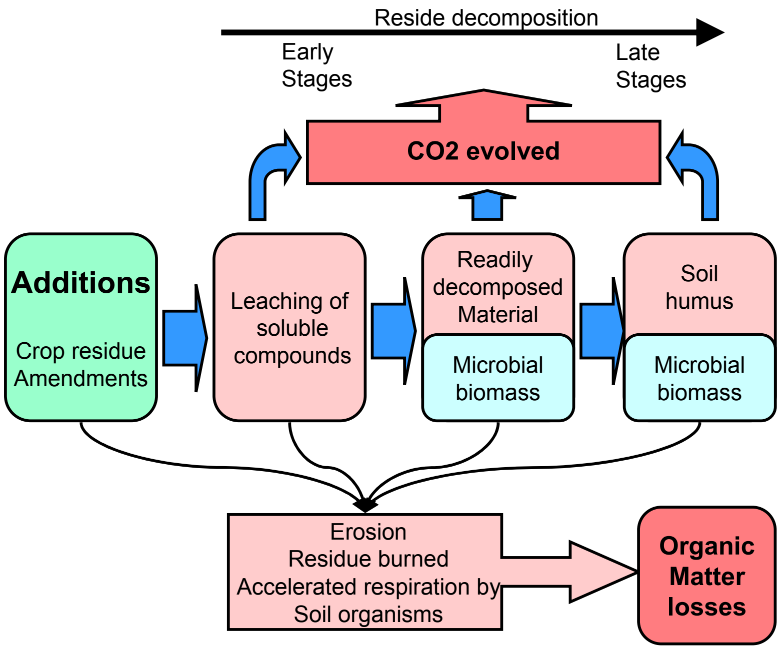

Figure 2: Stages of decomposition and losses of organic matter following additions to the soil (Kennedy *et al.* 2004).

Soil health management is not a one off treatment, but a process of continually improving and refining management practices. The improvement of soil health through the development of good soil management systems requires a strategic process of planning, implementing, monitoring and reviewing to check if the changes implemented have worked (Figure 3).

- The planning process requires some definite aims and defined methods of addressing soil problems and what can be realistically achieved.
- The "doing" process is the implementation of practices that may vary from what was traditionally done before.
- The "checking" is the monitoring that allows measurements to be obtained to allow comparisons between new practices and old practices. These do not have to be sophisticated or expensive tests, but can be done with simple on-farm tools.

- The “reviewing” of the practice changes allows a better understanding of what has worked, what has not worked and why. It is also the next stage in the continual improvement cycle and provides information for the next planning stage.

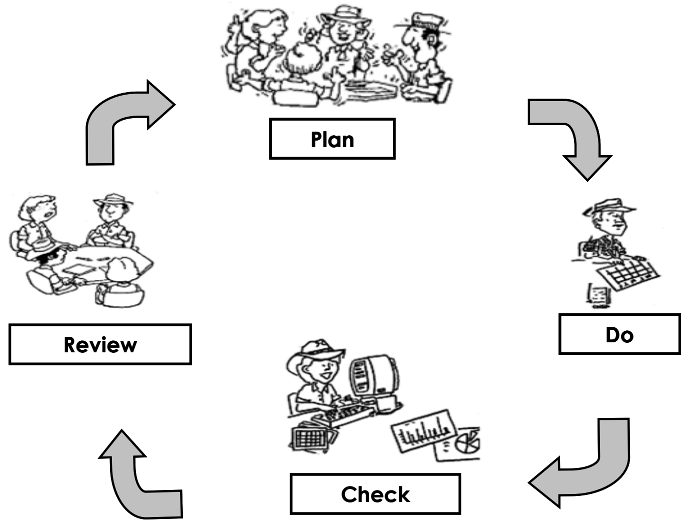

Figure 3: Continual improvement process for implementing better systems for managing soil health.

Agricultural practices can have a positive or a negative effect on the health of the soil. It is important to understand how management decisions impact on long-term soil and plant health. Soil health management requires a awareness of how physical, chemical and biological soil properties work together to sustain plant growth. Decision making for the management of soil systems is a balancing act, integrating these three soil properties with plant productivity, while ensuring environmental sustainability.

The management of soil organic matter is an important part of developing healthy soils. An understanding of how carbon contained within organic matter is continually lost from the soil and what practices can sequester soil carbon is fundamental to building healthy soils.

Any decisions about developing a “healthier soil system” should be structured with the aim of continually improving soil management and not relying on “one off” treatments with the expectations that this will fix all soil and production problems. The benefits from healthy soil practices may not occur immediately, and will not solve all the production problems, but will eventually result in sustained productivity and environmental protection.

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