Perth Region NRM
Coordinating sustainable agricultural outcomes

Assessing soil quality and interpreting soil test results for citrus production in Western Australia

Introduction

Soil quality can be thought of as the soil's ability to support tree growth and the production of a crop of good yield and quality while maintaining long term sustainability. It includes the functions of soil such as the provision of a medium for tree growth, the retention and release of water, nutrient cycling and the regulation of biological populations. The assessment of soil quality should include the analysis of its chemical, physical and biological properties. By conducting a range of field and laboratory analytical tests, citrus growers can determine whether corrective action is required to alleviate any constraints to soil use or whether their practices are having any beneficial or deleterious impacts on soil quality. In established orchards, soil testing is undertaken regularly (i.e. annually or biennially) in order to provide information that is required for making decisions on the need for and application rate of inputs such as fertilisers and soil amendments (e.g. lime, gypsum and compost).

Regular soil monitoring over time using sound sampling and measurement strategies is important. There is no single descriptor of soil quality; instead a 'tool kit' of indicator tests is used. Results from these tests should be evaluated by comparing them with known benchmark (or optimum threshold) values and citrus performance criteria such as crop yield and fruit quality.

The field and laboratory measurements described in this publication have been selected on the basis of scientific merit and practicality (e.g. Peverill *et.al.* 1999). For some soil tests (e.g. biological properties), little information is available on benchmark values to aid data interpretation.

Reasons and purposes of soil testing

Methods used in soil analyses are intended to characterise the effect that the plant experiences due to a particular soil property. The most common use of soil testing in citrus orchards in Western Australia is to diagnose soil constraints to tree growth. The soil test results are then used to alter management practices; for example, to determine or adjust fertiliser programs or to ameliorate the soil by applying products such as lime and gypsum. Soil samples are often taken in poorer and better performing areas of a block of trees and the results then compared to identify the reasons for poor growth. Soil test results should be used in conjunction with visual symptoms on the trees, tissue analysis, crop yield and fruit size distribution before altering management (e.g. adjusting a fertiliser program).

Soil testing is also used prior to establishing an orchard to determine the capability of the land for fruit production. Generally, auger holes or soil pits are dug on a 100 metre grid over the potential site. The texture of each soil horizon is assessed as well as the depth of soil to any root-impeding layers. This information allows estimates of the readily available water (RAW) to be made (Newman 2012). This measurement is important as it allows the irrigation system to be designed so that soils with similar water holding capacities can be watered in the same way. Soil chemical measurements at this initial stage helps determine what pre-plant fertiliser applications and amendments are required. Areas with unfavourable soil conditions (such as shallow root restricting layers and high levels of salts) are usually excluded from planting. It is much easier to correct soil-related issues prior to planting when fertilisers and amendments can be incorporated into the soil. Chemical analysis of the irrigation water should also be conducted at this stage. Soil biological tests are now becoming available to measure living soil organisms and residues. However, for many tests, reliable benchmark values are not yet available.

Soil sampling and taking measurements

Soil characteristics can vary greatly across farms and some soil properties may change during the year. Separate soil samples are necessary for different soil types and areas that have had different fertiliser and soil management histories. The following points should be considered when sampling or taking measurements:

- The most appropriate time to sample or take measurements
- The most appropriate location to sample or take measurements
- The depth of the samples or measurements
- The number of samples or measurements required at each site

The appropriate sampling procedure will be discussed in the relevant sections below. Once samples have been collected (see Figures 1 and 2), it may be possible to bulk them to give a composite sample for analysis. Bulking should only be done when samples are taken from a uniform area with a similar management history.

Figure 1 Using an auger to collect soil samples in the field
(Photo: K. Pekin)

Figure 2 Using a soil pit in a citrus orchard to examine soil characteristics and root growth
(Photo: K. Lacey)

Soil test standards and how they are developed

Soil test standards (or guidelines) are used to assess and interpret the soil test results. For example, they provide the high and low critical levels of soil properties at which crop growth becomes affected and the optimum ranges that growers should aim for.

In some cases, soil test results may be categorised as low, moderate or high.

Soil test standards are usually developed by conducting field trials. For example, in determining optimum soil nutrient concentrations, researchers apply different fertiliser rates to the soil. Crop yields are measured and compared to a range of soil test values. A graph showing the generalised relationship between soil test value and crop yield can be produced (see Figure 3). Using this information, the crop's fertiliser requirements in future growing seasons can then be determined.

Soil test standards are usually specific to:

- Soil type
- Crop, variety and rootstock

In Western Australia there has been no research work done to develop soil test standards for the range of soil types used for citrus trees. Therefore, soil management recommendations are usually based on generic standards that have been developed in eastern Australia or overseas and their applicability should be carefully considered when interpreting soil test results.

By soil testing over an extended period of time and correlating the results with tissue (leaf) analysis, visual symptoms and crop performance, growers can develop benchmark soil test values for their own soil types, tree varieties and root stocks. This historical data set will provide a greater understanding of acceptable soil property values that will assist management decisions such as, how much fertiliser or soil amendment to apply.

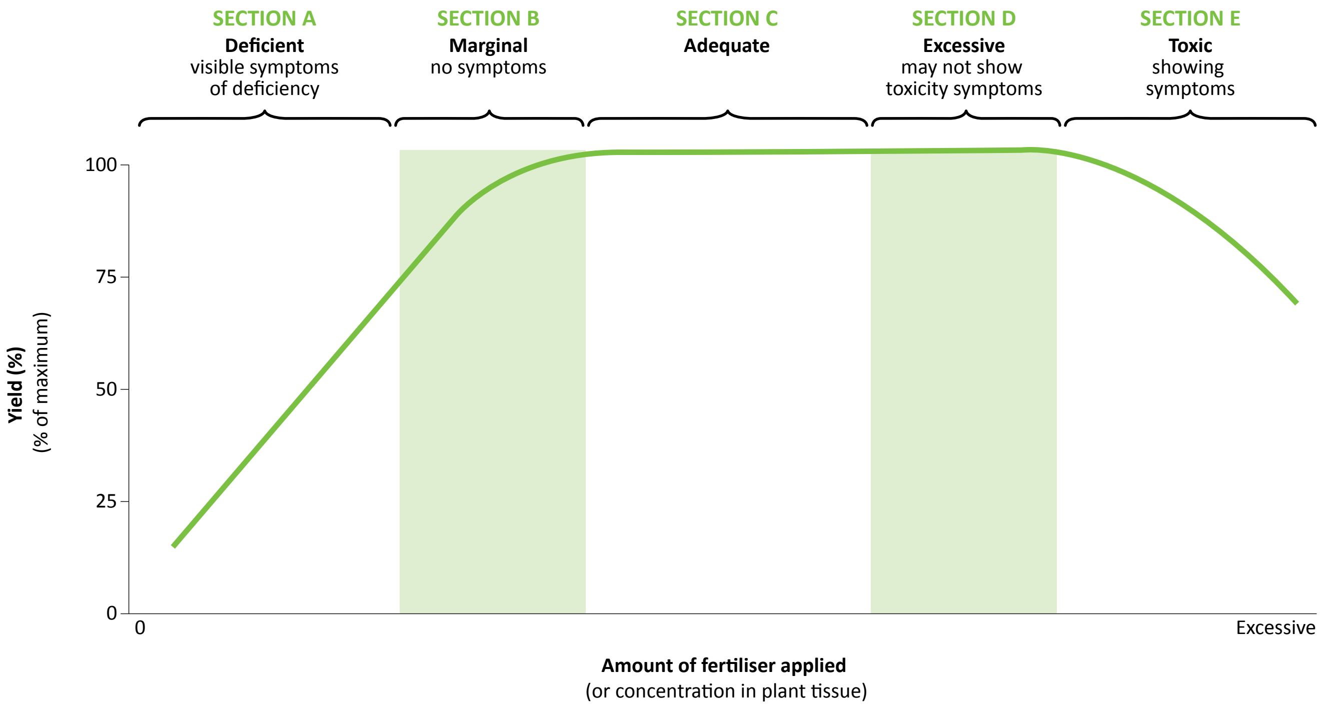

Figure 3 Generic crop response curve showing the effect of soil test value on yield
Source: Adapted from McLaughlin et al *(1999)*

Soil chemical properties

The primary function of soil in relation to chemical properties is to provide nutrients for plant and crop growth. In addition, the soil's chemical properties need to be suitable for nutrient uptake. Commercial laboratories offer a range of soil chemical tests such as pH, electrical conductivity, organic carbon, cation exchange capacity, exchangeable cations, sodicity and the availability of macro- and micro-nutrients.

pH

Soil pH is a measure of its acidity or alkalinity and is an important property because of its influence on the supply of nutrients (cations and anions) to plants, the chemical behaviour of toxic elements and the activity of micro-organisms. Figure 4 shows how the pH of the soil influences the availability of plant nutrients. The width of the band indicates the availability of each nutrient to plants. At a pH H_2O below 5.5 (acid) some elements such as phosphorus, calcium, magnesium and molybdenum become poorly available, while others such as aluminium may become available at toxic levels. At a pH H_2O above 8.0 (alkaline) the micro-nutrients (trace elements) manganese, zinc, iron and copper become poorly available. Farming practices which use ammonium-based fertilisers generally decrease the soil pH. Irrigation using alkaline groundwater on sands in the West Gingin area has resulted in the soil pH H_2O increasing to about 8.0.

Soil sampling for pH is normally conducted within the irrigation wetting pattern where the majority of the roots are located. The top 10 or 15cm of soil is typically sampled. Soil samples should also be taken from a depth of 15 to 40cm to identify whether subsoil acidification is affecting tree growth.

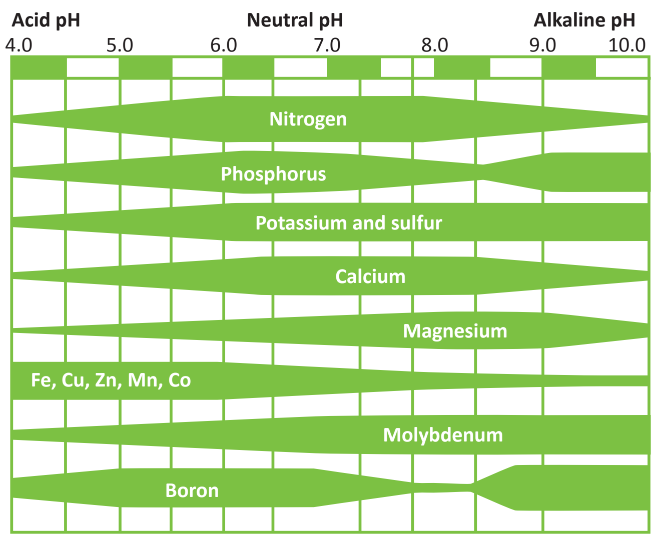

Figure 4 Diagram showing the effect of soil pH on nutrient availability

There are two standard laboratory tests; using water (pH H_2O) and using 0.01M calcium chloride (pH $CaCl_2$), both of which use a 1:5 soil to solution ratio (see Figure 5). Because these two methods give different values, pH test results should indicate the technique used. There is no simple conversion factor between the two measures. In non-saline soils, pH H_2O values are commonly between 0.6 and 0.8 units higher than pH $CaCl_2$ values. In saline soils, the difference between the two measures is about 1.2 units. The Inoculo soil pH testing kit, which uses a universal indicator and barium sulphate powder, can be used in the field to give a quick measurement but it is only accurate to half a pH unit. This testing kit gives an approximation of the pH H_2O method.

Figure 5 Soil samples are sent to a laboratory to measure chemical properties such as pH
(Photo: Shutterstock)

Acidic soils can be ameliorated by applying lime and using nitrate-based fertilisers. Soil samples should be taken annually after lime application to determine the effectiveness of the lime in neutralising the acidity.

Salinity/Electrical conductivity (EC)

Soil salinity refers to the presence of soluble salts within the root zone. Tree growth, crop production and fruit quality can be affected through osmotic and/or ionic processes (see Figure 6). If the concentration of soluble salts is high enough, the tree's ability to take up water and nutrients may be reduced. In addition, there may also be direct toxicity effects due to high concentrations of chloride and sodium ions. There are large variations in the tolerance of citrus rootstocks to salinity. Table 1 shows the tolerance of orange trees to soil EC.

Soil salinity in Western Australian citrus orchards is usually caused by irrigating with saline water rather than rising saline ground watertables. Some properties in the Bindoon area have limited supplies of good quality irrigation water and growers are therefore forced to mix good quality water with poor quality (saline) water. Salt concentrations in the soil are highest on the soil surface and towards the edge of the irrigation wetted area. Irrigators should apply additional water (a leaching fraction) to push salt to the margins of the wetting area in order to reduce concentrations within the root zone. Soil samples should be taken from within the main wetted area and also at various depths to the bottom of the root zone to develop a greater understanding of where the salt is accumulating. Heavy winter rains will leach salt from the soil profile particularly on sandier soils. Sampling for soil salinity should be conducted during the irrigation season or prior to winter rains. Refer to 'Water salinity and plant irrigation' www.agric.wa.gov.au/fruit/water-salinity-and-plant-irrigation for further information.

Table 1 Tolerance of orange tree to soil salinity

Fruit	Salinity threshold (EC_e)	90% yield (EC_e)	75% yield (EC_e)	50% yield (EC_e)
Orange	1.7	2.3	3.3	4.8

Source: Maas and Hoffman (1977)

Electrical conductivity (EC) measurements, using either a saturated extract from soil paste (EC_e) or a 1:5 soil:water suspension ($EC_{1:5}$), provide an estimate of the total soluble salts. The saturated extract technique is the preferred method as it takes soil texture into account. However, it is less widely used than the soil:water suspension technique because it is more time-consuming and expensive to perform. If growers have salinity issues on their property, many soil EC measurements may be required to gain a full understanding of the extent of the problem. A portable EC meter can be bought and soil EC measurements conducted on the farm using the 1:5 soil:water method. Multiplier factors are available to convert EC_e to $EC_{1:5}$ and vice versa (Table 2). The standard unit for expressing EC measurement is deciSiemens per metre (dS/m) which is numerically the same as milliSiemens per centimetre (mS/cm).

Total soluble salts (TSS) is an expression of soil salinity that is still used by some laboratories. The standard unit for expressing TSS measurements is milligrams per litre (mg/L) which is numerically the same as parts per million (ppm). The following conversion equation can be applied:

TSS (mg/L) = 640 x EC1:5 (dS/m)

Table 2 Multipliers for converting EC1:5 (dS/m) to an approximate value of ECe (dS/m)

Soil texture	Multiply EC1:5 (dS/m) by this number
Sand, loamy sand, clayey sand	23
Sandy loam, fine sandy loam, light sandy clay loam	14
Loan, fine sandy loam, silt loam, sandy clay loam	9.5
Clay loam, silty clay loam, fine sandy clay loam, sandy clay, silty clay, light clay, light medium clay	8.6
Medium clay	7.5
Heavy clay	5.8

Source: NSW Department of Primary Industries www.dpi.nsw.gov.au/agriculture/resources/soils/salinity/general/measuring

Figure 6 A salt-affected citrus tree showing regrowth following partial defoliation
(Photo: N. Lantzke)

Soil salinity issues can be addressed by leaching salts from the root-zone through rainfall and/or applied irrigation and through the use of salt-excluding rootstocks. It is predicted that the rainfall in the south west of Western Australia will decrease by 20% in the next 60 years due to climate change. This is likely to result in higher concentrations of salt in both surface and groundwater supplies.

Soil sampling for nutrient availability

Macro and micro nutrients

A number of macro and micro nutrients are required for vegetative and reproductive growth. Soil nutrient testing aims to mimic the ability of roots to extract the nutrient under investigation from the soil. Often it is not the total amount of that nutrient that is measured but the portion that is readily available to the tree. Different laboratories often use different techniques and these produce different results. The method of analysis should be identified on the soil test report.

Tissue (leaf) analysis rather than soil analysis is considered to be more effective and more reliable in assessing the nutritional status of citrus trees as it shows the nutrient concentration in the tree rather than what is potentially available in the soil.

Soil test results for plant nutrients should be used as a guide only. To develop a fertiliser program they need to be used in conjunction with:

- Crop yield, fruit size distribution and proportion of class 1, 2 and reject fruit;
- Tissue analysis;
- Visual deficiency symptoms;
- Chemical analysis of irrigation water;
- District fertiliser recommendations; and
- An understanding of how each nutrient interacts and moves within the soil.

Soil chemistry is complicated with some elements either reducing the availability of other elements (antagonistic) or increasing the availability of other elements (synergistic) to the plant.

The most appropriate time to conduct soil sampling for plant nutrient analysis in citrus orchards is in winter. Soil sampling should not be conducted within a month of applying fertilisers as this is likely to give unusually high readings. Soil sampling may not need to be conducted every year if the trees are growing well and the fertiliser program has not been greatly altered.

An auger or soil sampling tube is used to take samples from the top 10 or 15cm. Leaf litter should be removed from the top of the soil prior to sampling. At least 15 samples should be taken at random from across the area to be sampled. Areas with different soil types and fertiliser histories should be sampled separately. In order to monitor changes in nutrient concentration over time, soil samples should be taken from the same location each year. This can be achieved by recording the rows and tree numbers where the samples have been taken. Soil samples for nutrient analysis should be taken from within the tree row towards the edge of the canopy and within the irrigation wetted area (especially if fertilisers are applied via the irrigation/fertigation system).

One of the issues with soil sampling is that trees get nutrients from deep within the soil profile. This is particularly true for sandy soils with underlying clay subsoils. When taking samples from lower soil depths, care is required to ensure that topsoil does not fall into the hole and contaminate the sample.

Phosphorus and phosphorus buffering

Measuring the soil concentration of available phosphorus (P) is a reliable method for determining the phosphorus requirement of crops. Soil test standards for phosphorus have been developed for horticultural crops grown in Western Australian soils (e.g. McPharlin 2001). However, while there has been no such trial work for citrus grown in Western Australia, generic phosphorus standards are of some use. It is recommended that these soil test standards be used in conjunction with a measure of the soil's ability to either leach or 'fix' phosphate (i.e. the phosphorus retention index, PRI or phosphorus buffering index, PBI). For example, critical soil test values will be lower for low PRI soils such as pale sands and will be higher on heavier textured soils that contain larger amounts of iron and aluminium oxides. Growers should correlate their leaf analysis results with soil P levels to determine acceptable soil test concentrations for that particular soil type.

A number of analytical methods are used to determine plant available phosphorus; these include Colwell, Olsen and Bray tests, where each test will give a different result.

Nitrogen

The use of soil tests alone to determine nitrogen (N) requirements has met with only limited success throughout Australia (Strong and Mason 1999). Nitrogen concentrations in the soil are transient and nitrogen availability relates to climatic conditions. This makes soil test results inconsistent and therefore difficult to interpret reliably.

Micro nutrients (trace elements)

Micro nutrient soil tests that have been examined in Western Australia usually show little relationship between the soil test result and plant uptake of the nutrient (Brennan 1995). Tissue testing is the only reliable way to determine if micro-nutrients such as copper, manganese, zinc, magnesium, iron, and boron are limiting production.

Nutrients in groundwater

The groundwater that is used for irrigation may contain nutrients that can, in some cases, contribute a significant proportion of a tree's nutritional requirements. These nutrients either occur naturally in the groundwater or, particularly in the case of nitrogen, have accumulated through leaching. This source of nutrients should therefore be taken into account when developing a fertiliser program.

Cation exchange capacity

The cation exchange capacity (CEC) of a soil represents the capacity of the soil to hold and exchange positively charged cations. Soils with a low value (CEC <5) generally have a low fertility status and a low resistance to changes in soil chemistry caused by land management practices. Sandy soils and acid soils often have a low CEC, while clay soils generally have a high CEC. The type of clay mineral also has a strong influence on CEC (Table 3). The standard unit for expressing CEC and individual exchangeable cation measurements is centimole per kilogram of soil (cmol[+]/kg) which is numerically the same as milliequivalents per 100 grams of soil (meq/100g).

The CEC is a single value and therefore does not indicate which cation(s) predominate. The five most abundant exchangeable cations in soils are sodium (Na^+), calcium (Ca^{2+}), magnesium (Mg^{2+}), potassium (K^+) and, in strongly acidic soils, aluminium (Al^{3+})

Sodicity

Sodic soils are characterised by a disproportionately high concentration of sodium in their cation exchange complex. When in contact with water, a sodic soil will generally swell and disperse into small clay particles. As the soil dries, the clay particles block the soil pores resulting in poor water infiltration, decreased available water capacity, hard setting and drainage/aeration issues (see Figure 7). These physical soil conditions generally have an adverse effect on tree growth and productivity. They can be ameliorated by applying gypsum and by reducing the frequency and severity of tillage operations, avoiding over-irrigation and increasing soil organic matter levels through the use of cover crops and mulches.

The sodicity of a soil is assessed in the laboratory and is expressed as either the exchangeable sodium percentage (ESP) or the sodium adsorption ratio (SAR) (Table 4). ESP is the amount of Na^+ adsorbed on to soil particle surfaces as a proportion of the CEC. SAR is the relative concentration of Na^+ to Ca^{2+} and Mg^{2+} in the soil solution and is determined using either a saturation extract (SAR_e) or a 1:5 soil:water extract ($SAR_{1:5}$). The soil:water extract method is cheaper but less accurate.

Table 3 Cation exchange capacity for soil textures and soil colloids

Soil	CEC meq/100 g
Sands	1–5
Fine sandy loams	5–10
Loams and silt loams	5–15
Clay loams	15–30
Clays	over 30
Sesquioxides	0–3
Kaolinite	3–15
Illite	25–40
Montmorillonite	60–100
Humus	100–300

Source: Adapted from Donahue et al *(1977)*

Figure 7 The dispersion of clay particles results in crusted/ sealed soil surface which limits the infiltration of water and the emergence of plants
(Photo: T. Proffitt)

The extent of sodicity in the citrus producing regions of Western Australia has not been studied. There are areas of soils within the Harvey district that are prone to waterlogging and maybe affected by sodicity. Some citrus orchards in the Bindoon area are irrigated with marginally saline water and the sodium may result in sodicity problems. More extensive soil testing and trial applications of gypsum in citrus orchards are required to determine if sodicity is a significant problem.

Soil physical properties

Measures of soil physical properties are not routinely performed by laboratories and require specialised equipment which makes it difficult for orchardists to perform the measurements themselves. Due to the nature of these properties, it may take many years before changes are detectable.

Texture

Soil texture (the proportion of sand, silt and clay) is an inherent property of soil and changes little with land use or management practice. It can be measured qualitatively in the field (see Figure 8 or refer to DAFWA 2012) or quantitatively in the laboratory.

Citrus growers should have a good understanding of the variation in soil texture across their orchard. Soil texture has a large influence on the amount of readily available water (RAW) a soil can hold. RAW values and rooting depth should be used to determine the length and frequency of irrigation cycles. The sands used for citrus production on the Swan Coastal Plain and in the West Midlands region have very low water holding capacities and excessive irrigation is not only a

Table 4 Interpreting soil sodicity (ESP, SAR_e and $SAR_{1:5}$) results in relation to soil structural stability

Degree of sodicity	ESP (%)[1]	SAR_e[2]	$SAR_{1:5}$[3]	Effect on soil structural stability
Non-sodic	<6	<6	<3	Generally stable
Marginally sodic	6–15	6–15	3–7	Aggregates susceptible to dispersion when wet
Strongly sodic	>15	>15	>7	Dispersion occurs spontaneously by rainfall and/or irrigation

[1] Exchangeable Sodium Percentage; [2] Sodium Adsorption Ratio determined using a saturation extract; [3] Sodium Adsorption Ratio determined using a 1:5 soil:water extract
Source: Adapted from Nicholas (2004)

Figure 8 Assessing soil texture by hand in the field
(Photo: K. Pekin)

waste of water but also results in a loss of soluble nutrients. Soil texture also has a large influence on a soil's ability to hold and supply nutrients for tree growth. Table 3 shows the cation exchange capacity for different soil textures. Sandy soils have a poor ability to retain cations, and on these soils, nutrients such as nitrogen and potassium need to be applied in small quantities at regular intervals.

The texture of sandy soils can be increased by the addition of clay prior to orchard establishment. Fruit growers in the West Midlands region have amended poor sandy areas of their properties with clay to change the texture to a loamy sand. A scraping machine was used to remove soil from a nearby clay deposit. This was then incorporated to a depth of 25cm. Typically, 200 to 400 tonnes of clay per hectare is required and therefore, to be cost-effective, a clay pit needs to be located on or near the property.

Soil structure and aggregate stability

Soil structure has profound effects on water infiltration, available water capacity, drainage, aeration and root penetration. These effects are partly due to the arrangement of aggregates of sand, silt and clay and the pores between them and partly due to the stability of the aggregates when immersed in water.

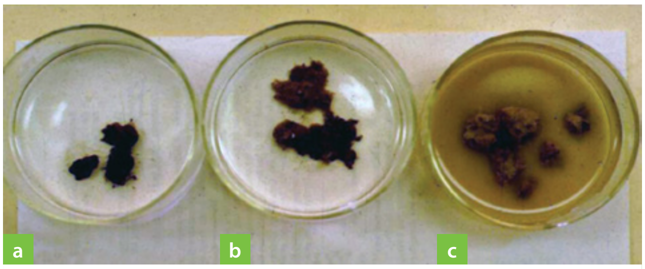

Figure 9 Assessing aggregate stability in the laboratory (a) aggregates remain stable (b) aggregates swell and slake (c) aggregates swell, slake and disperse
(Photo: DEPI, Victoria)

Aggregate stability can be measured in the field or laboratory using the slaking/dispersion test (see Figure 9 and Table 5) or, less commonly, in the laboratory using the wet sieving technique (Table 6). Soils which slake readily (i.e. aggregates separate into micro-aggregates) and/or disperse readily (i.e. micro-aggregates separate into single particles) indicate a weak structure that is easily degraded by raindrop impact and mechanical disturbance. This in turn impacts on the availability of water to the tree, the availability of oxygen for respiration at the soil-root interface and the functionality of the root system. Aggregate stability can be improved by increasing the organic matter content of the soil and by applying gypsum (calcium sulphate; $CaSO_4$).

Table 5 Interpreting soil aggregate stability results derived from the dispersion test

Degree of dispersion[1]	Emerson aggregate class	ASWAT[2] score
High (complete dispersion)	1	>12
High to moderate (partial dispersion)	2	9–12
Moderate to slight (complete or partial dispersion after remoulding)	3	1–8
Negligible (well-aggregated, with no dispersion after remoulding)	4	0

[1] Dispersion may be suppressed in saline soils; [2] Aggregate Stability to Water
Source: Adapted from Hazelton and Murphy (2007)

Table 6 Interpreting soil aggregate stability results derived from the wet sieving technique

Aggregate stability rating	% stable aggregates (1–2mm)
Very low	<10
Low	10–20
Moderate	20–30
High	>30

Source: Adapted from Hazelton and Murphy (2007)

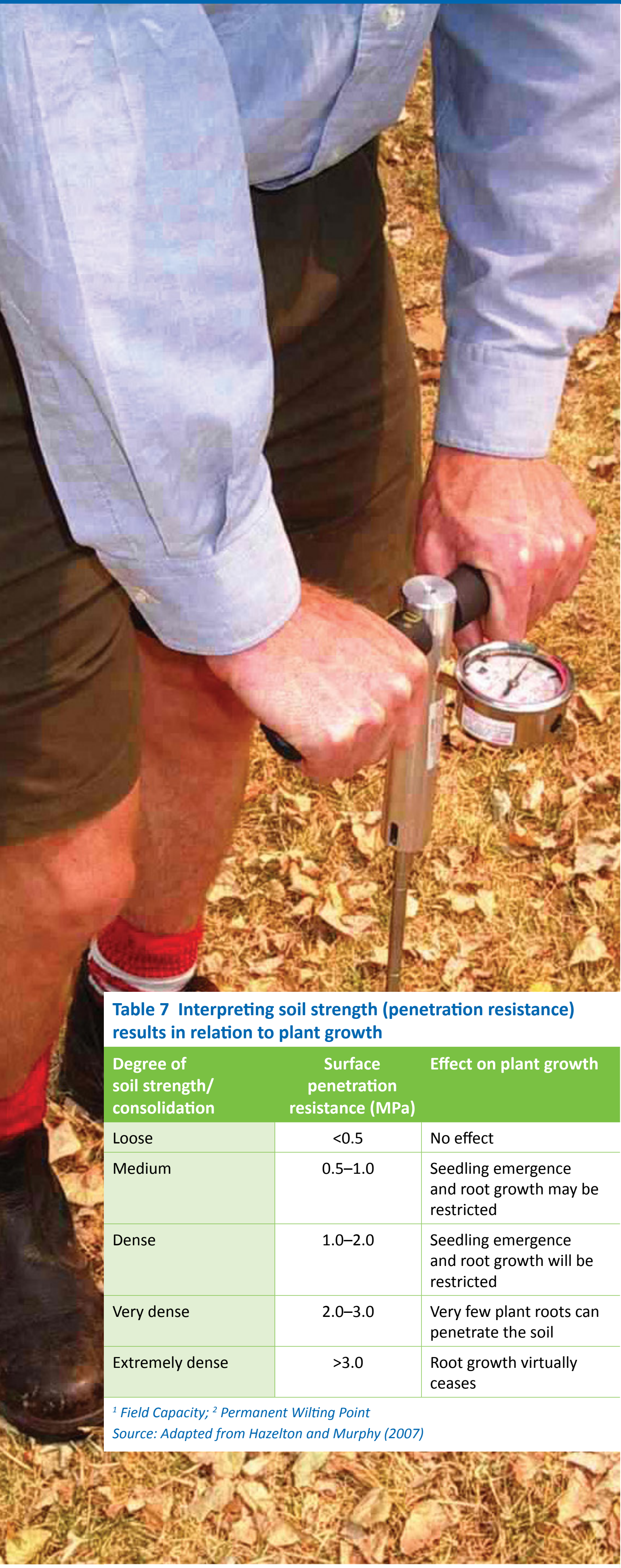

Table 7 Interpreting soil strength (penetration resistance) results in relation to plant growth

Degree of soil strength/ consolidation	Surface penetration resistance (MPa)	Effect on plant growth
Loose	<0.5	No effect
Medium	0.5–1.0	Seedling emergence and root growth may be restricted
Dense	1.0–2.0	Seedling emergence and root growth will be restricted
Very dense	2.0–3.0	Very few plant roots can penetrate the soil
Extremely dense	>3.0	Root growth virtually ceases

[1] Field Capacity; [2] Permanent Wilting Point

Source: Adapted from Hazelton and Murphy (2007)

Figure 10 Assessing soil strength in the field with a penetrometer

(Photo: R.E. White)

Strength

Soil strength determines the resistance of soil to breaking or deformation and is usually measured in the field quantitatively using a penetrometer (see Figure 10 and Table 7) or semi-quantitatively by hand and foot (Table 8). Penetrometers cannot be used accurately in gravelly soils. A soil with high strength (e.g. due to compaction, see Figure 11) is likely to limit the volume of soil that can be accessed by plant roots, as well as by soil flora and fauna. Since the results are highly dependent on soil water content, measurements should be taken and results compared at the same water content (preferably field capacity). The standard unit for expressing soil strength measurement is mega-pascal (MPa).

Digging a soil pit adjacent to a tree in the orchard is a good method for determining whether soil strength is limiting root growth either vertically or horizontally. Subsoil compaction may occur in orchards due to cultivation or the continuous use of vehicles within the mid-row area (see Figure 11). If compaction does occur, tree root growth into the midrow is likely to reduce the tree's ability to access water and nutrients.

Table 8 Interpreting soil strength (hand or foot breaking) results in relation to soil behaviour

Degree of soil strength/ consolidation	Ranking	Amount of force required to break/ deform a 20mm diameter piece of soil
Loose	0	None required
Very weak	1	Almost none required
Weak	2	A small but significant amount required
Firm	3	A moderate or firm amount required
Very firm	4	A strong amount required but within the power of thumb and forefinger
Strong	5	Insufficient force can be exerted using thumb and forefinger. An effect can be realised when placed underfoot on a hard flat surface
Very strong	6	Crushes underfoot using full body weight applied slowly
Rigid	7	Cannot be crushed underfoot using full body weight applied slowly

Source: Adapted from McDonald et al *(1998)*

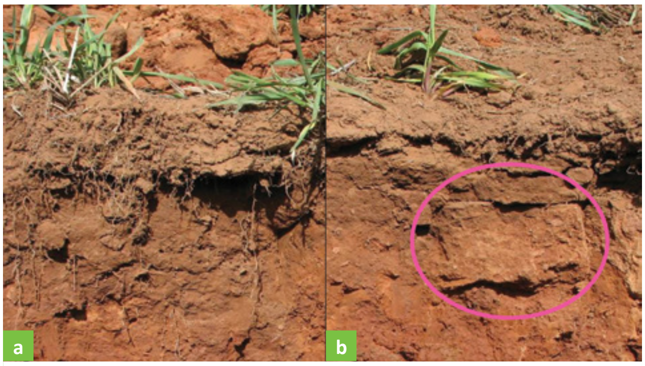

Figure 11 (a) No evidence of sub soil compaction and good root exploration, (b) compacted soil (note the brick-like unit in the upper subsoil) is often the result of using vehicles in wet soil conditions

(Photos: DEPI, Victoria)

Soil biological properties

There is a growing interest by orchardists in understanding the role of organic matter and living organisms in soils and how these properties can be used to improve citrus production in Western Australia. Increasing the organic matter content and biological activity of a soil can improve its structure, nutrient availability, water holding capacity and may also result in a suppression of some diseases (Donovan, unpublished). However, the results are often inconsistent and vary with environmental factors such as temperature and moisture content, soil types and management systems.

There is a lack of information on how orchard management practices, such as the use of fertilisers, herbicides and pesticides, affect soil biology. Research is needed to better understand the impact of such practices on soil biological properties. Indicators of soil biological health are required so that growers can assess whether altered management practices (e.g. a reduction in chemical use or the addition of composts) have made a measurable change in crop yield, fruit quality or orchard sustainability. As with chemical and physical soil tests, it is likely that a number of indicators will be required to gain a complete picture.

Soil biological properties encompass living soil organisms (micro-flora, meso-fauna and macro-fauna) and residues (dead material making up soil organic matter) living on and in the soil (see Figure 12). Soil organisms have an impact on plant production systems through the modification of the physical, chemical and biological environment. They can be grouped according to their main functions; (i) the micro-food web organisms (e.g. bacteria and fungi), (ii) the litter transformers (e.g. micro-, meso- and macro-fauna) that assist in the decomposition of organic matter, and (iii) the habitat creators/modifiers (e.g. earthworms, ants and termites).

Soil biological tests relate primarily to measurements of the amount, activity and diversity of soil organisms and their related biochemical processes. However, because they are difficult to measure and quantify, benchmark values are not as readily available as for physical and chemical soil tests. Where information is available, it has generally been derived from broad-acre agriculture rather than from horticultural research.

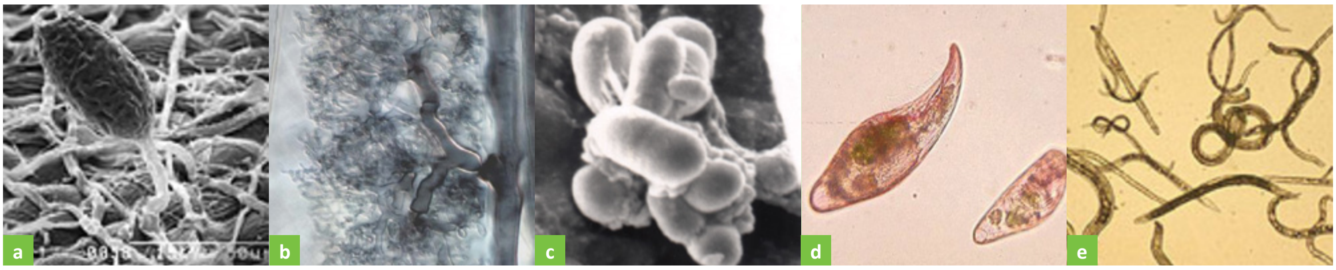

Figure 12 The diversity of soil organisms found in soils can be extremely high. (a) Fungi (b) Arbuscular mycorrhizae (c) Bacteria (d) Protozoa (e) Nematodes
(Photos: DEPI, Victoria)

Figure 13 Mulch is often applied to the tree line to increase soil organic carbon and reduce soil temperature and water loss through evaporation
(Photo: N. Lantzke)

Organic matter/carbon

Organic matter (OM) is usually expressed in the form of organic carbon (OC). OC is readily available as a carbon and energy source and is important because of its association with nutrients and the beneficial contributions it makes to soil properties. OM levels are usually determined by measuring the amount of OC present in the soil, and then multiplying this value by 1.72.

Soil organic matter can be partitioned into an active component (labile organic matter) which includes soil microorganisms, and a more stable component that is resistant to decomposition (humus). The labile component readily decomposes to release nutrients and is important in binding soil particles together and maintaining soil structure. The labile fraction has been shown to be a good indicator of key soil chemical and physical properties (Bot and Benites 2005). The humus fraction contributes mainly to the nutrient holding capacity of the soil. Table 3 shows that humus has a CEC of between 100 and 300 meq/100g.

The rate of accumulation and decomposition of organic matter is determined by inputs from plants and animal residues, temperature, moisture, cultivation and soil texture. Warm, moist conditions and frequent cultivation favour the decomposition of soil organic matter. It is difficult to build up soil organic matter on sandy soils because of their low clay content. Clay particles bind with organic matter to help protect it from decomposition. An investigation of soil properties in Western Australian citrus orchards (Lantzke unpublished data) showed that on the sands of the Swan Coastal Plain none of the orchards sampled had organic carbon levels above 1% despite efforts by the growers to increase organic carbon levels by cover cropping and mulching.

A number of laboratory tests are used to measure OC, with the majority focusing on the total amount present rather than the labile forms. OM and OC values are generally expressed as either a % or as g/100g of soil. OC values for different textures are usually interpreted with respect to soil condition (or quality) since interpretive criteria that are meaningful to tree performance are not readily available (Table 9).

Soil micro-flora

Soils contain a diverse range of micro-flora (archaea, bacteria and fungi). At present, the ecological function of many species within this group of soil organisms is unknown and hence benchmark values have yet to be established. Where benchmark values do exist, they are primarily for soil pathogens.

Table 9 Interpreting soil organic carbon (OC) results in relation to soil condition/quality

OC rating	Level of OC % (g/100 g)	Effect on soil condition/quality
Very low	<0.4	Degraded or severely eroded topsoil Deep coarse grained sands
Low	0.4–1.0	Poor structural condition and stability or sandy soils
Moderate	1.0–1.8	Moderate structural stability, condition, pH buffering, nutrient levels, water holding capacity
High	1.8–3.0	Good structural condition and stability, high pH buffering capacity, high nutrient levels, high water holding capacity
Very high	>3.0	Dark colour, large amount of organic material, soil often associated with undisturbed woodland/forested areas

Source: Adapted from Hazelton and Murphy (2007)

Figure 14 Cover crops are often grown in the mid row to increase the soil organic matter content in citrus orchards
(Photo: N. Lantzke)

One group of organisms with a known ecological function is the arbuscular mycorrhizal fungi (AMF). AMF have been shown to be beneficial through their symbiotic relationship with plant root systems, including citrus. Their presence can result in increased plant uptake of phosphorus via the fungal hyphae which extend out into the soil. The level of AMF infection may be a good indicator of soil biological health in low input orchards, but may not be of universal use for horticulture.

Soil fauna

Soil fauna are categorised into three size classes based on body width; micro-fauna (<100µm; e.g. protozoa), meso-fauna (100µm to 2mm; e.g. nematodes, mites, springtails) and macro-fauna (>2mm; e.g. earthworms, ants). As for micro-flora, benchmark values exist for only a few groups due to difficulties associated with sampling, isolation and identification.

Macro-fauna, such as earthworms, are relatively easy to sample and isolate and have been used as indicators of soil quality. In vineyards for example, earthworm populations have been shown to decrease in response to increased tillage operations and high concentrations of copper in the soil. Where mulch and compost additions have been used, earthworm populations have been shown to increase. However, earthworm populations are not considered to be a good soil quality indicator test since they are not ubiquitous and are liable to respond to changes in soil moisture and inputs such as organic matter.

Within the meso-fauna size class, nematode soil tests have been used the most frequently because information exists about their taxonomy and feeding roles. Although the time and expertise required for assessment of nematodes communities is high, benchmark values have been established and are used where there are potential soil and tree health issues. There are numerous soil-inhabiting nematode species and not all of them are harmful to plants. However, some are plant-parasitic, feeding on and damaging roots, including those of citrus trees. These activities reduce the tree's ability to take up water and nutrients from the soil. Root damage can also lead to the entry of disease-causing pathogens.

Soil microbial biomass

Soil microbial biomass (SMB) is defined as the living component of soil organic matter, excluding plant roots and macro-fauna. It is a measure of the total size of the microbial population but not its composition or functional potential. SMB is considered to be a more sensitive indicator of change in soil quality than measures of organic carbon. At present, benchmark values are not available.

There are two laboratory techniques used for measuring SMB; the substrate induced respiration technique (SIR) and the chloroform fumigation extraction technique (CFE). SIR values can be converted to CFE values by multiplying by 30. The standard unit for expressing SMB is milligrams of carbon per kilogram of soil (mg C/kg) which is numerically the same as micrograms of carbon per gram of soil (µg C/g). The wide spatial variability in SMB, along with their sensitivity to moisture and temperature, means that a representative sampling strategy has to be adopted and that samples have to be taken at the same time of year.

Considerations

- Soil analyses can provide valuable information to optimise overall orchard performance, particularly when combined with tissue analysis.
- Soils are inherently variable which means that the correct sampling/measurement strategy needs to be adopted. Be aware of factors that may impact on the values obtained and the repeatability and interpretability of the measurements (e.g. location of sampling in relation to the irrigated area and the time of sampling).
- For some soil properties, little information is available on benchmark values to aid data interpretation. This is particularly the case for biological properties.
- Benchmark values may vary with soil type and with tree variety and rootstock.
- By soil testing over an extended period of time and correlating the results with leaf analysis, visual symptoms and crop performance, growers can develop benchmark soil test values for their soil, tree varieties, rootstocks and management practices.
- Avoid variation in results arising from different analytical techniques; use the same accredited laboratories at the National Association of Testing Authorities (NATA) or the Australasian Soil and Plant Analysis Council (ASPAC).
- Unless you test, it's just a guess!

References

1. Brennan (1995). Soil testing for copper and zinc. Department of Agriculture Western Australia. Farmnote 56/95.
2. Bot, A. and Benites, J. (2005) The importance of soil organic matter — Key to drought resistant soil and sustained food production. FAO Soils Bulletin 80. Rome, Italy.
3. DAFWA (2012). Determining soil texture types. Department of Agriculture and Food Western Australia. Farmnote 508. http://archive.agric.wa.gov.au/PC_94911.html?s=1525642938
4. Donahue, R.L., Miller R.W. and Shickluna J.C. (1977). Soils: an introduction to soils and plant growth. 4th Edition. Inglewood Cliffs, New Jersey 07632: Prentice-Hall. pp.115–116.
5. Donovan, N. (unpublished). Review of literature. Sustainability and Soil Health in Citrus ProductioSystems. NSW Agriculture Elizabeth Macarthur Agricultural Institute, PMB 8 Camden NSW 2570.
6. Hazelton, P. and Murphy, B. (2007). Interpreting soil test results. What do all the numbers mean? CSIRO Publishing, Melbourne, Australia.
7. Maas, E.V. and Hoffman, G.J. (1977). Crop salt tolerance – current assessment. Proceedings of the American Society Civil Engineering. Journal of the Irrigation and Drainage Division 103(IR2): 115–134.
8. McDonald, R.C., Isbell, R.F., Speight, J.G., Walker, J. and Hopkins, M.S. (1998). Australian soil and land survey field handbook. 2nd Edition. CSIRO Publishing, Melbourne, Australia.
9. McLaughlin M.J., Reuter D.J. and Rayment G.E. (1999). Soil testing — principles and concepts in 'Soil Analysis — an interpretation manual' (eds. Peverill, K.I., Sparrow, L.A. and Reuter D.J.). CSIRO Publishing, Melbourne, Australia.
10. McPharlin, I. (2001). Phosphorus fertiliser management of potatoes on sands. Western Australian Department of Agriculture. Farmnote 107.
11. Newman, H. (2012). Calculating readily available water. Department of Agriculture and Food Western Australia. Farmnote 543. http://archive.agric.wa.gov.au/PC_95247.html?s=1525642938.
12. Nicholas, P. (2004). Soil, irrigation and nutrition. Grape Production Series No. 2. South Australian Research and Development Institute. Adelaide, Australia.
13. Peverill, K.I., Sparrow, L.A. and Reuter D.J. (1999). Soil Analysis — an interpretation manual. CSIRO Publishing, Melbourne, Australia.
14. Strong, W.M. and Mason, M.G. (1999). Nitrogen In 'Soil Analysis and interpretation manual.' pp 171–185. CSIRO Publishing, Melbourne.

Publication reference

Lantzke, N.C. and Proffitt, T. (2015). Assessing soil quality and interpreting soil test results for citrus production.

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ACKNOWLEDGEMENTS This fact sheet has been developed by Perth Region Natural Resource Management for citrus producers growing fruit in the South West region of Australia. Funding for this publication has been provided through the Australian Government's Department of Agriculture, Carbon Farming Futures Fund (Action on the Ground program). Perth Region NRM acknowledges the input of Neil Lantzke and Tony Proffitt who researched and wrote this publication.

Published February 2015