APPENDIX ONE

1.1 INTRODUCTION TO SOIL TESTING

Introduction

Soil testing can provide a great deal of useful information about a soil's physical and chemical characteristics. Knowledge of these characteristics offers improved decision-making with respect to fertiliser use, as well as lime and gypsum.

The value of a soil test depends on a number of quality factors. The three main factors are:

1. Sampling methods
2. Analytical methods
3. Interpretation.

Failure to acknowledge the importance of any of these factors can negate the value of soil testing to the point of making it useless, or worse, detrimental to soil fertility.

There are standard methods for both sampling and analysis. Fertiliser application rates are also somewhat standard, in that, for a given set of laboratory test results, two agronomists should come up with similar recommendations for both the type of fertiliser required, and the appropriate application rate.

Sampling is often the responsibility of the landholder. Analysis and, often, interpretation are the responsibility of the laboratory selected by the landholder. The problem for the layperson-landholder is: "How does one select a reputable laboratory?"

Labs vary in their ability to deliver sound results and also in their ability to interpret soil data and provide sound recommendations. The information presented in this guide provides an introduction to soil testing, covering the three main quality factors mentioned above. Information on plant testing is also provided. It is hoped that this information will allow the reader to ask the right questions of a laboratory, in order to assess its merits.

This document also includes a section on interpretation of soil test results, to allow the layperson to make sense of a soil test report.

Sampling Soil and Plant Material

Quality control - Standard Sampling Protocols

Quality control begins with collection of a representative sample. A laboratory should be able to provide sampling guidelines based on standard Australian protocols for current or proposed land-use. Re-sampling may be recommended by your laboratory, if the samples have been collected in such a way that results may be misleading (e.g. if sampling depth is non-standard).

If a laboratory is offering data interpretation, it should also provide a Paddock History Form for the landholder to complete. Interpretation of analytical data requires background information including rainfall and irrigation practices, and paddock history regarding previous crops and current paddock use, age, fertiliser history), as knowledge of and history is required for putting the results into context.

The sampling instructions outlined below are based on standard protocols recommended by the Victorian Department of Primary Industries. They cover agricultural and horticultural situations where basic soil parameters are being assessed with respect to plant nutrition. Sampling for other purposes such as contamination (e.g. pesticide residues), wastewater disposal, land evaluation or soil classification require different sampling strategies which are best carried out by experienced persons. Your local department of agriculture can often provide these services, or provide reputable contacts.

Soil Sampling Intensity and Sampling Depth

Soil samples submitted for analysis must be representative of the area concerned. Soil often varies considerably in chemical and physical composition over short distances, even in paddocks of apparently uniform soil. Representative soil sampling involves collection of soil cores from standard depths and from a sufficiently large number of spots.

The more spots that are sampled, the more representative is the final sample and the more reliable are the analytical results. To emphasise the importance of representative sampling, it is worth noting that the top 10cm of most paddocks contains about 1300 tonnes of soil/ha. About 500 grams of soil is submitted to a laboratory. Of this, only 1-10 grams of soil is used for any one analysis. That is, only 1-10 grams of soil is being relied upon to define the nutrient status of the whole paddock. Representative sampling is therefore critical to obtaining meaningful soil data. Table 1 provides recommended guidelines for representative sampling.

For a total farm fertiliser program, the ideal strategy would be to sample every paddock or block on your property. However, time and cost can make this prohibitive. An alternative is to select monitoring paddocks that are sampled at regular intervals. Monitoring blocks should reflect the major range of conditions present; e.g., poor vs. good growth, high vs. low stocking rate, Pinot vs. Chardonnay, sandy vs. clay soil, etc. A core sampler is preferred for sampling surface soils. A core sampler is essentially a piece of pipe that can be pushed into the soil to a specified depth, thus retrieving a uniform core from a specified depth – usually 10cm, but sometimes 15cm (see Table 1). For deeper, sub-soil sampling, an auger or

hydraulic sampler is really the only practical tool. It may sometimes be possible to collect samples from the side of an excavated soil pit

Collect soil cores in a bucket from the paddock, section or block using a grid or zigzag pattern. Alternatively, samples could be taken along a transect permanently marked by painted fence posts on two sides of a paddock. Soil cores should be taken from spots of average growth or from poorer spots if they are numerous. Avoid patches of very good growth, obvious dung or urine patches, stock camps or near trees, fence-lines or gateways; these areas often have higher nutrient concentration than average parts of the paddock. Do not sample paddocks, sections or blocks that have been fertilised or limed within the past six weeks; undissolved fertiliser may remain which can inflate soil test results. In horticultural situations, avoid sampling directly into soil where fertiliser has been banded.

The soil in the bucket should be mixed thoroughly and a sub-sample of about 300-500 grams should be forwarded to the Laboratory. If a large quantity of soil (e.g., more than 5 kg) has been collected, it first sub-sample using a process called quartering. Quartering involves spreading the material to an even level, dividing the sample into quarters, removing two diagonal quarters and remixing the remaining quarters. This procedure can be repeated as often as required to reduce the submitted sample size to about 300-500 grams.

Table 1 Recommended soil sampling depth and number of cores

Industry	Sampling depth	Number of cores
Pasture and cropping soils	0 to 10 cm, inclusive	30
Row crop soils, garden beds	0 to 15 cm, inclusive	20
Existing vineyard/orchard	0 to 15 cm, inclusive	20
Proposed orchard / vineyard	Collect samples from each main soil layer (horizon) down the soil profile. Horizon depths are usually associated with changes in clay content.	20 cores (surface)10 cores (sub-soil)

Soil Test or Plant Test?

A typical suite of soil tests provides information on a number of areas that influence soil fertility. In combination with paddock history and current (or proposed) use, a typical soil test provides enough information for an agronomist to provide appropriated recommendations for lime, gypsum and fertiliser requirements. The four main areas influencing soil fertility, and the associated tests are:

- acidity (pH, aluminium, carbonates)
- salinity (electrical conductivity, soil texture)
- structure (exchangeable cations: calcium, magnesium, sodium, potassium; slaking, dispersion, organic matter)
- nutrients: including phosphorus, potassium, sulphur, magnesium

A soil test is also useful in perennial horticultural crops to monitor soil pH, salinity and structural aspects over time, but, for determining trace element requirements and monitoring crop nutrition, and for diagnosis of plant health problems, plant testing is recommended. Soil tests are generally a poor guide to determining trace element requirements.

The two main reasons for plant tissue analysis are diagnostic and routine monitoring. **Diagnostic** sampling is done to help establish reasons for poor growth. **Routine monitoring** is done to help assess the current fertiliser program and is normally done on a regular basis, even if the crop is looking healthy.

Plant tissue analysis can detect "hidden hunger". Although deficiency symptoms may not be present, plant nutrient levels may be below adequate, thus limiting production. Regular plant tissue testing can allow early detection of sub-optimal nutrient status, thus allowing timely adjustments to be made to fertiliser and trace element regimes. Thus, plant testing is a very useful monitoring tool. For existing perennial horticultural crops such as fruit trees and vines, plant analysis is considered to be the best guide for predicting fertiliser requirements. Plant testing is especially useful when it is carried out on an annual basis, in order to determine trends in fertility..

Plant Sampling Procedures

As for soil sampling, the principal objective of plant sampling is to collect representative samples. Published information relating to the desirable nutrient level in most crops is based on sampling at a specific growth stage and sampling a certain part of the plant. These guidelines form the basis for sampling instructions. Correct sampling methods must be adhered to if plant analysis is to be meaningful. Non-standard sampling, such as sampling at a different growth stage or from a different part of the plant will often give a different test result. A laboratory should be able to provide detailed sampling instructions for all common plant species.

For most species, the youngest mature leaf blades or their petioles (leaf stems) are sampled. Young plant parts are especially sensitive to nutrient supply, and are preferred to whole shoots, laterals or runners for analysis. Older leaves will have a different nutrient composition and should not be sampled.

The sample must also account for the natural variability of the crop or pasture. Therefore, as for soil, for which a composite sample is collected, consisting of a number of soil cores, many different plants must be sampled, typically around 100 leaves or petioles.

If soil contamination has occurred, the sample should be washed lightly with clean water, drained and patted dry with paper towelling before packaging. Paper bags are used to minimise sweating. The sample should be sent to the laboratory with minimal delay. Do not mail samples late in the week because plant material may deteriorate in the mail service during the weekend. Alternatively, samples can be dried before consignment in stainless steel ovens at 65^{o}C.

A minimum fresh sample weight of 100 g (or 10 g dry) is required to ensure that there is sufficient plant material for a comprehensive analysis. For small leaved plants, it may be

necessary to sample a greater number of plants than indicated by the standard sample instructions to get the desired weight.

Sampling Plants for Monitoring Purposes
Plant sampling for monitoring purposes is undertaken at a specified time of year. Typically, a small area or transect is usually selected, which is judged to be representative of the average crop condition in the field or orchard. Plants within this area are systematically sampled; this is most important for interpretive purposes. Leaves or sometimes leaf stems are collected from a specified part of the plant; timing and plant part varies depending on crop type. For example, for vines, a typical sampling procedure would comprise the selection of four rows within a block, in which the vines are all of the same age and variety, and growing on the same soil type. Petioles (the leaf stem, not the blade) are collected at 75% flowering, collecting the basal leaf opposite a bunch cluster (of grapes) from 100 vines.

Sampling Plants for Diagnostic Purposes (trouble-shooting)
For diagnostic (trouble shooting) purposes, sampling is best undertaken when the symptoms of the disorder are first observed. Sampling should be confined to the area of poor growth or production. Plant parts must be of the same physiological age.

Collection of two separate samples, from both good and poor areas (if present) costs twice as much, but provides data for a much better interpretation. For many ornamental plants, this is essential, due to the lack of published plant standards upon which to base an interpretation of the analytical data.

It is worthwhile to submit some additional examples of whole plants to the laboratory along with the leaf samples, just to enable agronomists at the laboratory to view the symptoms in relation to the whole plant. These whole plants need to be clearly marked “for viewing only”.

For interpretive purposes, include a detailed description of plant deficiency symptoms. Fertiliser and irrigation history and can be extremely useful for interpreting plant test results and identifying and recommending corrective action.

Sampling Plants for Stock Health Diagnostic Purposes
In a grazing enterprise there may be times when sampling is done more for the benefit of the grazing stock, rather than the pasture itself, for example, if you suspect copper deficiency in stock. In this situation a sample of the dietary intake of the stock (including grasses/clovers and weeds) can be analysed and compared with published standards for various classes of stock or for different stages of lactation. Several dairy stock feed companies promote analysis of herbage samples to enable them to custom-blend a feed mix, to compensate for deficiencies in the pasture at the time.

Sap Testing

Sap analysis could be considered for rapidly growing vegetable or field crops if reasonable standards (desirable sap levels) have been established for that crop.

Sampling Composts, Mulches and Potting Mixes

Collection of a representative sample for analysis, i.e., one which is representative of the entire compost heap should be carried out as follows. Cut a cross section through a

compost heap or windrow. Collect at least 20 x 500 mL, grab samples and mix together, thus providing a volume of 10 litres for submission to the laboratory. The quartering method should be employed for reducing sample size. This involves spreading the thoroughly mixed material on a clean surface. Quarter the sample. Discard opposite diagonals and remix. Repeat the procedure until the desired volume is attained.

For bagged materials, collect at least three sub-samples per bag from at least 10 bags of a consignment. Use of a sharp-edged tubular corer will enable the top, middle and bottom section of each bag to be sampled.

Alternatively, 30 sub-samples can be obtained from every tenth or twentieth pot coming off the production line at potting up. The volume required for sample submission is 10 litres.

To sample potting media from planted pots, it is best to take 30 pots, remove plants, mix the potting media thoroughly, spread onto a clean surface and sub-sample by quartering down to a volume of about 10 litres.

Sampling Gypsum, Lime and Fertiliser

When sampling stockpiled or bagged material, sampling procedures should follow the principles outlined for potting media (see above). Particular care should be given to sampling of blended fertilisers because segregation of components may have occurred.

Sampling gypsum or lime from pit deposits will require adequate representation of the material currently being quarried from the pit face or working depth. Sub-samples should be taken from at least 30 spots to make up a composite sample. Extra and separate samples from different pit faces or working depths may be necessary. The composite sample should weigh 500-1000 grams.

Sampling Harvested Produce and Grains

Analysis of harvested produce is now a common pre-requisite prior to acceptance by Supermarket chains. For example potatoes are tested routinely for cadmium. For further information on sampling and analysis of fresh produce and grain for heavy metals and/or chemical residues, contact your local department of agriculture.

NOTE: Where **litigation** is likely, issues such as representative sampling, witnesses to sampling and chain of custody could be raised in court. These issues should be discussed with your laboratory.

Testing Frequency

The value of the crop, the cost of fertiliser being applied and annual nutrient removal influence the frequency of sampling for monitoring purposes. For example, beef/sheep paddocks only need to be re-tested every 5-7 years whereas vegetable blocks should be tested at least annually and ideally before each new crop.

Regular sampling for monitoring purposes allows trends in nutrient levels over time to be determined. Trends are a better guide to likely nutrient requirements than a one-off test. Regular monitoring also allows the grower/farmer/landholder to assess the effects of fertiliser decisions on nutrient levels, which enables regular fine-tuning.

The frequency of diagnostic sampling is entirely dependent on whether the crop is showing deficiency or toxicity symptoms, but a follow-up analysis 2-3 months following remediation is recommended.

Table 2 Guide to sample frequency for soil and plant tissue testing for monitoring purposes

Industry	Soil analysis	Plant analysis
Vegetables	Annually	Each Crop
Perennial horticulture	Pre-planting and then every 4-5 years	Annually
Cropping	Annually	Every 2-3 years
Beef/sheep	Every 3-4 years	Every 5-7 years
Dairy	Every 2-3 years	Every 5-7 years

Quality control - Sample Preparation – drying and grinding

Correct sample preparation is part of good quality control and involves thorough drying at a specified temperature and grinding to a specified fineness. The drying temperature varies depending on the nature of the material. For example, soil is dried at 40°C, while plant tissue is dried at 65°C. The type of grinder used may affect results. For example, heavy metal testing in soils is likely to be erroneous if the sample is ground in a metal mill, therefore a zirconium mill would be used. Your laboratory should be able to explain these issues, in order to assure its clients of its awareness of these issues, hence the integrity of the test results it provides. The following sections include brief outlines of sample preparation and analytical procedures for soil, plant tissue, potting media, mulch, compost, gypsum, lime and fertiliser.

Preparation of Soil prior to analysis

Samples are spread out in small cardboard boxes and dried in a fan-forced oven at 40°C for a minimum of one day. Partial drying of samples can lead to significant analytical errors, and a longer period of drying is sometimes required, especially for very wet soils. After drying, samples are ground to pass through a 2mm sieve. Some analyses require further fine grinding to 0.2 mm.

Preparation of Plant tissue prior to analysis

Plant material is dried in a fan-forced stainless steel oven at 65^{o}C for two days. Dried samples are then ground to a fineness of <1 mm for analysis. Fruit, vegetable or grain samples can also be analysed on an "as received basis". Analysis can be done on the whole sample, cored sample or peeled sample etc, depending on regulations or client requests. Moisture content can also recorded so results can be expressed on a wet weight or dry weight basis.

Preparation of Gypsum, Lime and Fertiliser prior to analysis

Gypsum, lime and fertiliser samples are air-dried overnight at 40°C. Gypsum is ground to pass through a 0.85mm sieve (20 mesh). Lime is ground to pass a 0.25mm sieve (60 mesh). Fertiliser is ground to pass a 0.50mm sieve (36 mesh). Prior to grinding the samples, a subs-ample is collected to enable sieving analysis to be undertaken if required by fertiliser regulations. Soil and fertiliser samples to be tested for mercury (volatile) are not dried. They are slurry-ground to a consistent paste using iced water. Plant samples for mercury are vitamised and frozen for future analysis.

Quality control - Equipment Calibration, Standards and Blanks

To ensure reliability of test results, SCL imposes stringent quality controls. Samples are usually tested on a batch basis and there may be over 50 samples in a batch. For each batch, laboratory equipment is first calibrated and a minimum of two standards (samples of known value) and two process blanks (samples of zero value) are included in each batch. A further quality control measure is the duplicate analysis of one customer sample with every batch. The results of these quality control samples help analysts to decide whether to accept or reject a batch of samples.

A good laboratory can also assess whether test results are typical for a given soil type or paddock history if a submitter provides adequate background to the sample. A sample may have passed the quality procedures outlined above, but a test result may still be queried. For example, an Olsen phosphorus level of 20 mg/kg in a virgin forest is an unusual result and the sampled may be re-analysed.

Quality control - Participation in Quality Assurance Programs

Most reputable laboratories within Australia also participate in regular inter-laboratory proficiency programs, such as the ASPAC Program (Australian Soil and Plant Analysis Council). ASPAC issues participating laboratories with homogeneous samples. Laboratories can submit test results for a range of basic parameters such as pH, Olsen P, exchangeable cations, etc. Results are collated and each laboratory receives the mean, median and range of results of all the participating laboratories, for comparison to their own results. If the individual laboratory's result for a particular analyte (e.g., Olsen phosphorus), falls within the acceptable range of variation, ASPAC will award the laboratory with proficiency accreditation for that analyte.

Large variations in test results between laboratories suggest not all laboratories are equally competent. Even for simple tests such as pH (water), the range between labs is as wide as 5.0 - 6.4, for the same soil. Such a difference in soil pH results will have an obvious impact on lime recommendations, i.e., provision of quality interpretation is impossible if a laboratory is unable to produce quality results.

Common Soil Analyses - Methodology

Soil Analyses - Chemical

Electrical Conductivity, Chloride, pH and Aluminium

Electrical Conductivity (EC)
Soil samples are shaken for one hour with distilled water at a ratio of 1:5 soil:water. EC is recorded in deci-Siemens/metre (dS/m) at 250C using a digital conductivity meter. EC is a measure of all soluble salts in the soil; which includes chlorides, nitrates, sulphates, phosphates, carbonates etc.

Chloride Determination
A fresh 1:5 soil/water suspension is shaken for one hour. The chloride level is determined by potentiometric titration of the soil suspension against a standard solution of silver nitrate. Chloride is reported as % sodium chloride (NaCl) w/w or chloride (mg/kg).

pH
Soil pH is a measure of the level of soil acidity or alkalinity. The pH in water (pHw) is determined using the same soil suspension as used for the EC measurement.

The pH in 0.01 Molar calcium chloride (pHc) is determined after the addition of 1.0 mL of 1.0 M calcium chloride to the 100ml of soil suspension followed by stirring of the sample.

Exchangeable Aluminium
High concentrations of exchangeable aluminium are often associated with low soil pH. Aluminium is extracted from the soil with 1.0 M potassium chloride at a 1:5 soil/extractant ratio. The extract is analysed for aluminium by a colorimetric method using a catechol violet reagent which reacts with aluminium to give a coloured complex. Exchangeable aluminium levels can also be obtained by the Gillman and Sumpter method for exchangeable cations (see below).

Plant- Available Estimates of Nutrients

Available Phosphorus (P)
There are many methods for measuring available phosphorus (P). Two very commonly used methods are the Olsen and Colwell phosphorus methods. Results for both methods are reported in mg/kg.

Olsen phosphorus is extracted from the soil with 0.5 M sodium bicarbonate (pH 8.5) at a 1:20 soil/extractant ratio for 30 minutes and centrifuged. The phosphate in the filtrate is reduced by ascorbic acid to form the blue molybdophosphate complex with ammonium molybdate. The concentration of phosphorus is determined calorimetrically using an autoanalyser.

Cowell phosphorus is also extracted from the soil using 0.5 M sodium bicarbonate (pH 8.5) but the extraction involves a 1:100 soil/extractant ratio and shaking for 16 hours. Colour development and subsequent measurement is the same as used for Olsen P.

Available Potassium (K)
An estimate of available potassium is most commonly done from the analysis of exchangeable potassium. Alternatively potassium can be extracted by the more traditional Skene or Colwell methods. Skene potassium is extracted from the soil with 0.05 M hydrochloric acid at a 1:20 soil/extractant ratio. The suspension is shaken for one hour and allowed to settle overnight. The extracted potassium is measured using an atomic absorption spectrophotometer (A.A.S) and reported in mg/kg.

Available Sulphur (S)
Inorganic sulphate is extracted form the soil by calcium dihydrogen phosphate (pH 4.0) and charcoal at a 1:4 soil/extractant ratio. The extracted sulphur is measured directly using ICP and reported in mg/kg. The method is referred to as CPC sulphur.

Available Nitrogen (N) : Nitrate (NO_3) and Ammonium (NH_4)
The sample is extracted with 1M KCL at a soil:solution ratio of 1:10 for one hour. The supernatant solution is then analysed for nitrate and ammonium simultaneously using an auto-analyser.

Available Trace Elements: Copper, Zinc, Manganese and Iron
The method involves equilibration of air dried soil with the extracting solution (ratio 1:2) for two hours at a pH of 7.3. The extracting solution contains the chelating agent DTPA. The trace elements are measured using ICP and are reported in mg/kg.

Boron
For boron determination, the sample is refluxed for tem minutes at 100°c with 0.01 M $CaCl_2$ at a soil:solution ratio of 1:2. The sample is filtered while hot and allowed to coll. The boron in solution is then determined by ICPAES.

Exchangeable Cations (Calcium, Magnesium, Potassium and Sodium)

The three most common methods for cation analysis are described below. Soil pH, and salinity can influence which cation method should ideally be used, however the lower cost of the ammonium acetate method means it is the most common method requested.

Tucker Method
The Tucker method is suited to alkaline soils, or those containing appreciable quantities of sodium salts. The sample is washed initially with ethanediol/methylated spirits to remove soluble salts. Exchangeable cations are extracted from the soil with am ammonium chloride solution. The cations calcium, magnesium, potassium and sodium are analysed using Atomic Absorption Spectroscopy (AAS)

Gillman and Sumpter Method
The Gillman method is suited to acid soil conditions. The samples are extracted with a 0.1M barium chloride/0.1M ammonium chloride extracting solution using a soil extractant ratio of 1:10. The diluted extract is analysed for calcium, magnesium, potassium, sodium and aluminium using inductively coupled plasma spectrometry (I.C.P). The aluminium extracted by this method can be expressed as a percentage to enable comparison with published data on aluminium tolerance.

Ammonium Acetate Method
Exchangeable cations are extracted from the soil with a 0.1 Molar solution of ammonium acetate. The cations, calcium, magnesium, potassium and sodium are analysed using I.C.P. The ammonium acetate method may be used on either acid or alkaline soil, provided the samples are not extremely acid or alkaline. The method is typically performed without a pre-wash to remove soluble salts

Carbon and Nitrogen

Oxidisable Organic Carbon
Easily oxidisable organic carbon is measured by a modified Walkley-Black method. Soil samples are oxidised by chromic acid in the presence of excess sulphuric acid without external heat being applied. The solution is allowed to settle and the green chromous colour is measured using a UV spectrophotometer. Organic carbon is reported as a %. Organic matter levels can be calculated from organic carbon analysis by using a conversion factor of 1.72.

Walkley and Black and other wet chemical methods are suitable for soil with up to 24% organic carbon (about 40% organic matter). For higher levels, organic matter is estimated via loss on ignition at 550^{o}C.

Total Carbon and Total Nitrogen
Total carbon and total nitrogen is measured by the Leco method which involves combustion followed by infra-red analysis. This method measures all forms of carbon in the soil, including those forms not easily oxidised such as charcoal, lignin and carbonates. Where charcoal and carbonate content are low, both the organic carbon determination and total carbon determination give a very similar result, and hence the same conversion factor is used to estimate organic matter levels.

Soil Analyses - Physical

Soil Description
Descriptions are routinely carried out on prepared samples only. Soils are described with respect to their colour, texture and free carbonate content. The description is subjective, but documented methods are followed to minimise variation between operators.

Colour is described (on dried soils) in terms of hue (type), value (lightness) and chroma (intensity) according to the Munsell Colour System.

Texture is described after re-wetting dried and ground soils. It involves working moisture into dried soils to form a ball, then ribboning the ball to determine whether the soil is a sandy loam, clay loam, light clay, heavy clay, etc.

Gravel is a visual estimation (on a volume basis) of the amount of soil material not passing through a 2mm sieve expressed as a percentage of the total sample.

Carbonate content (free lime) is described by dropping a small quantity of soil into dilute hydrochloric acid (10% v/v) and recording the degree of effervescence, if any, due to the liberation of carbon dioxide.

Aggregate Slaking and Clay Dispersion
The method used is that of Loveday and Pyle (1973). Natural and remoulded soil aggregates are gently dropped into distilled water and a visual description of the degree of aggregate slaking and clay dispersion is made after two hours and 20 hours have elapsed.

Other common soil physical tests that may be offered by a laboratory include determination of clay, silt, fine sand, coarse sand fractions, moisture retention, bulk density, soil structure, plasticity limits, and hydraulic conductivity.

Common Plant Analyses - Methodology

Total Nitrogen
Nitrogen is determined by oxidation using a Leco induction furnace procedure.

Nitrate Nitrogen
The dried and ground plant sample is extracted with water (1:100 sample:solution ratio) for one hour. The filtered solution is then analysed colorimetrically.

Phosphorus, Potassium, Calcium, Magnesium, Sodium, Sulphur, Manganese, Copper, Zinc, Boron and Iron
Plant material is digested in acid, diluted with distilled water and then the above elements are determined by ICP-ES.

X-ray analysis can also be used as an alternative to analyse a similar range of nutrients, after plant material has been pressed into a disc. Analysis by X-ray includes chloride determination but does not include boron.

Molybdenum, cobalt, cadmium, lead and other heavy metals
Plant material is digested as above and the digest is run on ICP-MS.

Fertiliser, Lime and Gypsum Analysis

Fertiliser analysis

Total nitrogen
Nitrogen is determined by oxidation using a Leco induction furnace procedure.

Kjeldahl nitrogen
For fertiliser samples with a very low level of nitrogen, eg worm casting liquid, the Kjeldahl nitrogen method is preferred as it is has a lower detection limit.

A sample of fertiliser is boiled in concentrated sulphuric acid to convert the nitrogen of the nitrogenous substances into ammonia. The ammonia is determined by distillation and titration with standard sulphuric acid. The method does not measure nitrate in fertilisers.

Alternatively, for ammonium nitrogen, a crushed sample of fertiliser is boiled with hydrochloric acid and diluted to volume. The digest is analysed colorimetrically by the "phenol blue" method. Reading at 620nm, the nitrogen concentration is calculated from absorbance readings.

Total Phosphorus, potassium, calcium, magnesium, sulphur, sodium
The method involves a double acid digest followed by ICP-MS

Gypsum analysis

The method involves a double acid digest followed by ICP-MS analysis for calcium, sulphur and sodium. The percentage gypsum (calcium sulphate dihydrate) is calculated from the sulphur percentage.

Lime analysis

The liming material is dissolved in acid and the excess acid is titrated with sodium hydroxide. The end point titre permits the calculation of the percentage neutralising value (NV).

The analysis for calcium and magnesium involves a double acid digest followed by ICP-MS analysis. The calcium and magnesium are expressed as calcium carbonate and oxide percentages.

A sieve test is performed separately on the sample. Sieving permits the calculation of the effective neutralising value (ENV).

Interpretation of Analytical Data

Establishing a rating for a soil or plant test result

A test result on its own is meaningless. Test results start to take on some meaning if a rating (e.g. low, high etc) can be applied, with justification. Ideally ratings should be established by field trials where some measure of crop performance (normally yield) is related to different test results (soil or plant) in a replicated scientifically run trial. These trials are costly, but such trials help establish the ideal test range for a particular analyte. Consider, soil pH, for example: the ideal soil pH varies for different crops. Differences in soil types also mean that desirable ranges for test results are sometimes soil type dependent (e.g. potassium).

Diagnostic work, involving the analysis of many samples from good, average and poor crops have established desirable ranges for a range of soil analytes, for various plants, growing on a range of different soil types (e.g. sands vs. clays).

Sometimes, where no specific published information is available it is necessary to rely upon established data for a similar species. For example, analytical data for white clover may be used as a guide as to strawberry clover. Sometimes there is no published work at all for a plant species or near relatives. This is so for many ornamental plants. For diagnostic purposes, the lack of published standards can be overcome to some extent by submitting two plant samples (poor and good); which provides baseline data for comparative purposes. Sending in good and poor samples is beneficial even if published standards do exist.

Determining a rating of low, marginal etc is just the starting point in the interpretation process. Knowledge of soil types, target yields, deficiency symptoms, nutrient removal data for crops, fertiliser types and characteristics, mode of application, and detailed block/paddock history are all required in making a good interpretation of test results.

Interpretation of soil chemical data

Salinity

Effects of salt on plant growth

There are two main salt effects on plant growth. The first is an osmotic effect. All salts whether they are from gypsum, fertiliser, lime, sodium chloride etc can impact on plant growth if at high enough levels. Salt has a strong affinity for water and hence water is held more tightly in saline soils and as a result plants may suffer water stress more easily in such soils. This effect salt has on water uptake is called an osmotic effect.

Apart from osmotic effects, sodium and chloride can also cause direct toxic effects and hence are considered the most harmful salts. Symptoms of sodium and chloride damage to plants include the burning of leaf margins, dying tips and defoliation.

Plant species vary considerably in their tolerance to salinity. Most field trials used to establish salt tolerant guidelines were based on sodium chloride as being the dominant salt in the trial. However in the field, particularly on many intensive dairy/horticultural blocks, high

salinity levels may be due to fertiliser residues such as gypsum, urea, NPK fertilisers etc and not due to sodium chloride.

Interpretation of Total Soluble Salt levels (TSS)

As a more general guide to soil salinity the EC value can be expressed as Total Soluble Salts (TSS). This is particularly useful where the proposed cropping future is unknown.

Table 3 Interpretation of total soluble salts

Total Soluble Salts (%)	Description	Interpretation
<0.05	low and harmless	harmless for all plant species
0.05-0.08	slightly higher than normal	may cause growth reduction in salt sensitive species in lighter textured soils (sands, sandy loams)
0.09-0.16	higher than normal	likely to cause growth reduction in salt sensitive species. and may cause growth reduction in moderately salt tolerant species in lighter textured soils
0.17-0.24	unfavourable	expected to cause growth reduction in salt sensitive and moderately salt tolerant species
0.25-0.33	high and harmful	may cause growth reduction in salt tolerant species in lighter textured soils
>0.33	very high and harmful	harmful to all but very salt tolerant species

Electrical Conductivity –Saturated Paste Extract (ECe)

The same amount of salinity will have a greater detrimental effect on plants growing in a sandy soil compared to a clay. Published data on the salt tolerance of plants commonly refers to the electrical conductivity of the saturation extract (ECe) and not EC. Obtaining the saturation extract ECe in the laboratory is time consuming and hence not practical for the rapid estimation of the salinity of large numbers of samples. For this reason the EC of a 1:5 soil/water suspension is used and may be converted to approximate ECe value by multiplying by appropriate factors for different soil textures. For example, a heavy clay that has an EC value of 0.6 dS/m would have an ECe value approximating 3.6 dS/m. The conversion of EC to ECe is an estimate only and it is likely that the actual conversion factors would be soil type dependent.

Table 4 Factors for converting EC values to ECe values based on soil texture

Soil Texture	Multiplication Factor
Sands, loamy sands	13
Sandy loams, fine sandy loams	11
Loams, very fine sandy loams, silty loams, sandy clay loams	10
Clay loams, silty clay loams, very fine sandy clay loams, fine sandy clay loams, sandy clays, silty clays, light clays	9
Light medium clays	8
Medium clays	7
Heavy clays	6

Interpretation of ECe results

Table 5 should be used as a guide only. Salt tolerance within a plant species can vary depending on rootstocks, cultivars, and growth stage, with germination and seedling stages generally less tolerant than later growth stages, although sensitivity may increase again at flowering. Note that the table lists salinity levels at which no yield reduction is expected. The impact of increasing soil salinity on crop yields is highly variable. Some crops may show a yield reduction of 20% if the ECe level increases by one unit whereas for other crops the yield reduction may be negligible. Also, many saline soils are poorly drained. Although many salt tolerant plants are tolerant of some waterlogging this is not always the case, hence some salt tolerant plants may grow poorly in saline soils if drainage is also very poor.

Table 5 Salt Tolerance of Agricultural Crops: maximum ECe for no yield reduction

Sensitive		Moderately Tolerant		Tolerant	
(ECe 0-1.9 dS/m)		(ECe 2.0-3.9 dS/m)		(ECe >3.9 dS/m)	
Field Crops					
Faba Beans	1.6	Canola	2.8	Sorghum	6.8
Linseed, Maize	1.7	Rice	3.0	Soybean	5.0
				Safflower	5.3
				Wheat	6.0
				Sorghum	6.8
				Barley	8.0
Pasture, Turf and Fodder Crops					
White clover	1.5	Lucerne	2.1	Phalaris	4.6
Subterannean clover,	1.5	Sudan Grass	2.8	Birdsfoot Trefoil	5.0
Persian clover	1.5				
Strawberry clover	1.7	Vetch	3.0	Perennial Ryegrass	5.6
Bent Grass	1.7	Kikuyu	3.0	Couch Grass	6.9
				Tall Wheat Grass	7.5
Vegetable Crops					
Beans, Carrots	1.0	Spinach,	2.0	Beetroot	4.0
Peas, Watermelon		Cantaloupe	2.2	Zucchini/Squash	4.7
Onion	1.2	Broadbeans	2.3	Sugar beet	7.0
Lettuce	1.3	Cucumber, Tomato	2.5		
Potato	1.7	Broccoli	2.8		
Cabbage, Cauliflower, Celery	1.8				
Fruit Crops					
Strawberry	1.0	Fig, Grape	2.7		
Avocado	1.3	(Thompson spp)			
Grape (own rooted)	1.5	Olive, Pomegranate			
Plum/Pear	1.5				
Lemon, Orange	1.7				
Grapefruit	1.8				

Interpretation of chloride salts

Chloride is commonly the major constituent of the Total Soluble Salts (TSS) present in a soil – and the most harmful. Where chloride is only a minor constituent of TSS, the remainder of the TSS probably consists of salts derived from the recent use of gypsum, fertiliser, etc and as such, is less likely to cause salt damage. Testing for chloride salt is often worthwhile when EC levels are over 0.20 dS/m to provide a better interpretation of test results. Soil levels of phosphorus, potassium and sulphur can also be used as a guide as to whether salt is present as chloride or from fertiliser or gypsum use.

It is possible that two soils both with an ECe level of 4.0 dS/m may have quite different effects on plant growth due to the type of salt present and not just the quantity. Where fertiliser and gypsum salts are known to be present in high levels it is likely that plant will tolerate ECe levels higher than that indicated in Table 5..

Plant tissue analysis of sodium and chloride can be used to assess uptake of harmful salts.

Table 6 Descriptive terms of chloride ranges (expressed as % NaCl)

	Sands to sandy loams	Clay loams	Clays
Low	<0.02	<0.03	<0.05
Slightly saline:	0.02-0.07	0.03-0.10	0.05-0.15
Moderately saline:	0.08-0.20	0.11-0.30	0.16-0.40
Highly saline:	>0.20	>0.30	>0.40

Soil pH

Soil pH is a measure of acidity and alkalinity. The measurement of pH is carried out by two methods. The water method (pHw)is the more traditional method and is therefore the method that is more easily interpreted. The pHw method more readily reflects current soil conditions than the calcium chloride method. For example it will give a decreased pH if there is an increase in soil salinity. The calcium chloride method (pHc) gives a significantly lower reading (generally 0.7 – 0.8 of a pH unit) than pHw, but is less subject to seasonal changes. It is a useful measure for long-term monitoring of soil pH. Soils with pHw below 4.5 or above 9.5 are rare, which is fortunate, since most plants do not tolerate such extremes. For pHw between 5.5 and 8.0, nutrient availability and microbial activity are generally adequate for plant growth. However, some plant species prefer a more specific pH range. Knowledge of soil pH down the soil profile is useful, especially for deep-rooted crops.

Table 7 Descriptive terms of pH ranges measured in water

Extremely acid	<4.5	Slightly alkaline	7.1-7.9
Very strongly acid	4.5-4.9	Moderately alkaline	8.0-8.5
Strongly acid	5.0-5.5	Strongly alkaline	8.6-9.0
Moderately acid	5.6-6.0	Very strongly alkaline	9.1-9.5
Slightly acid	6.1-6.9	Extremely alkaline	>9.5
Neutral	7.0		

Increasing soil pH

Soil pH can be increased by application of liming material. (see section on types of liming material). Liming soils to increase soil pH is common practise in much of South Eastern Australia. Lime is relatively insoluble and ideally it should be worked in prior to sowing/planting a crop. For existing long term perennial crops and pasture, where working the soil is not practical or planned for the near future, broadcast lime may be the only option, but it may take several years before a change in pH is observed in the root zone. As a guide, lime moves 1cm per year.

Deciding whether to lime
The following factors are generally used in deciding if lime is recommended or not:

- Current and target soil pH
- Aluminium levels
- Soil acidification rate if known
- Acid tolerance of crop
- Sub-soil pH if known
- Soil structure
- Whether the lime can be worked in
- Whether the crop is annual or perennial
- Value of crop
- Any factors that may limit lime response, eg poor pasture composition or salinity

Estimating lime requirements
The following factors are used in determining lime requirements:

- Current soil pH
- Target soil pH (will be influenced by plant species and likely acidification rates)
- Depth of soil to be ameliorated (more lime is required to change soil pH in the top 30 cm cf. to 10 cm)
- pH buffering capacity (see below)
- Lime quality/ENV (more lime is required, if lime is of low quality)

The pH buffering capacity is the ability of a soil to withstand pH change. A pH buffering capacity test enables a more accurate estimation of lime requirement and should be considered prior to planting any perennial crop on acid soils. Generally the higher the clay and organic matter content of a soil the higher the pH buffering capacity and hence the higher the rate of lime required to increase soil pH.

Exchangeable Aluminium (in mg/kg)
The level of exchangeable aluminium is soil pH and soil type dependent. The lower the soil pH the higher the level of exchangeable aluminium. Levels of over 250 mgr/kg are not unusual in clay loams and clays where soil pH(w) is under 5.5. Exchangeable aluminium is not analysed where the soil pH(w) is over 6.4 as it is safe to assume exchangeable aluminium is below detection limits at this pH.

High levels of exchangeable aluminium can be toxic to acid sensitive plants. Liming the soil will increase soil pH and lower exchangeable aluminium levels.

Soil testing for exchangeable aluminium is particularly useful in order to determine soil suitability for lucerne establishment and persistence. Surface and subsurface soil samples are required for lucerne. Lucerne may be affected at exchangeable aluminium levels as low as 15 mg/kg.

Decreasing soil pH
Application of elemental sulphur to lower soil pH is not considered as an option for broadacre agriculture

Table 8 Preferred pHw ranges for some agricultural crops

Field Crops		Fruit Crops		Vegetable Crops	
Barley	6.0-8.0	Apple	6.0-7.0	Bean	5.5-7.5
Wheat	5.5-8.5	Pear	6.5-7.5	Beetroot	7.0-8.0
Oats	4.5-8.0	Peach	6.0-7.5	Broccoli	6.5-7.5
Triticale	4.5-8.5	Nectarine	5.5-7.5	Brussels Sprouts	6.5-7.5
Ryecorn	5.0-7.5	Almond	6.0-7.5	Cabbage	6.5-7.5
Rice	5.0-6.5	Cherry	6.5-7.5	Carrot	6.5-7.5
Canola	5.5-7.5	Plum	6.5-7.5	Cauliflower	6.5-7.5
Sunflowers	6.0-8.0	Apricot	5.5-6.5	Celery	6.0-7.0
Linseed	5.0-7.0	Citrus	6.0-7.5	Cucumber	5.5-7.0
Lupins	5.0-7.0	Grape	5.5-8.5	Garlic	6.0-8.0
Soybeans	6.0-7.0	Walnut	6.0-8.0	Lettuce	6.5-7.5
Peas	6.0-7.5	Olive	6.0-8.5	Onion	6.0-7.0
Vetch	5.0-7.0	Raspberry	6.0-6.5	Parsnip	6.5-7.5
Maize	5.5-7.5	Strawberry	6.5-7.5	Peas	6.0-7.5
Millet	5.0-6.5	Melon	7.0-8.0	Potato	5.5-6.5
		Watermelon	5.0-5.5	Pumpkin	5.5-7.0
		Cantaloupe	6.0-6.5	Spinach	7.0-8.0
		Passionfruit	6.0-8.0	Sweet Corn	5.5-7.5
				Tomato	6.0-7.0
				Turnip	5.5-7.0

Pastures		Cut Flowers	
Clovers	5.5-7.0	Waratah	5.0-6.5
Medics	6.5-8.5	Protea	4.5-6.0
Lucerne	6.0-8.0	Carnation/Chrysanthemum/Tulip	6.0-7.0
Ryegrass	5.5-7.0	Rose/Freesias	6.0-7.5
Phalaris	6.0-8.0	Daffodil	6.0-6.5
Cocksfoot	5.0-7.5	Gladiolus	6.0-8.0
Fescue	5.0-7.0	Tulip	6.0-7.0
Bent Grass	5.0-6.0	Liliums	5.5-7.0
Couch Grass	6.0-7.0	Freesia	6.0-7.5
		Gypsophila	6.0-7.5

Soil fertility

Base Status (calcium, magnesium, potassium, sodium)

The balance of exchangeable cations is normally considered from the perspective of soil structure (sodicity and Exchangeable Sodium Percentage (ESP). However, overall cation content (the sum of calcium, magnesium, potassium, and sodium) can also provide an indication of the inherent fertility of a soil. For example, sandstone / shale soils and to a lesser degree, alluvial soils, would be expected to be poorly supplied with nutrients. They are also more prone to nutrient leaching, and will require better nutrient management than volcanic basalts. On the other hand, basalts may require large inputs of fertiliser because they have a high capacity to "fix" nutrients, rendering them unavailable for plant uptake. Soils may be described as:

- Dystrophic (base status < 5 meq/100 g), i.e. poor inherent fertility.
- Mesotrophic (base status 5-15 meq/100 g), i.e. moderate inherent fertility.
- Eutrophrophic (base status >15 meq/100 g), i.e. high inherent fertility, but a potential to fix nutrients.

Base status is normally determined on the top 20 cm of subsoil clay, but this is not always appropriate. For example, alluvial soils are gradational and may not have a true clay horizon. Also, where the topsoil is particularly deep (more than 50cm), it may take young plants several months to access subsoil nutrient reserves. It is therefore important to consider base status from 30-40cm onwards.

The cation balance is also important for plant nutrition, particularly the balance of calcium to magnesium and potassium. Plant uptake of calcium may be restricted by high potassium and/or magnesium concentrations and/or by excessive fertiliser application. Conversely, where potassium or magnesium is very low, application of calcium in fertiliser, gypsum or lime means that amelioration of soil with calcium-based products may need to be accompanied by applications of potassium and magnesium.

Available Potassium (K)

Soil potassium is often low in Australian soil (where rainfall is more than 700mm) and K-fertiliser is commonly applied, together with phosporus (once phosphorus reserves have been improved to at least a marginal level for plant growth). As for phosphorus, only a small fraction of the total K in the soil is available for plant uptake. Soil K tests are used to predict the likelihood of a response to applied fertiliser potassium. Whether available potassium is measured by the Skene or Cowell methods or estimated from the exchangeable potassium result, the actual result obtained should be similar and hence interpretation is similar. On alkaline soils, the Colwell K is marginally to significantly higher than the Skene value. Even though the tables below are a useful guide in a pre-planting situation, the need for potassium fertiliser for existing horticultural crops, should be determined on the basis of leaf analysis. The ranges presented for available potassium levels in the tables below are a useful guide, but they refer to only 0-10cm soil samples. Deep-rooted species may be able to access subsoil reserves of potassium. Also, some the test is not valid for all soil types, for example soils of the Riverine plains and low soil test results. For such soils, potassium test strips and leaf analysis should be used as a guide to potassium-fertiliser response.

Table 9 Guide to available potassium (mg/kg) for pastures and crops

	Sands	Sandy Loams	Clay Loams	Clays
Low	<50	<80	<110	<120
Marginal	50-100	80-120	110-160	120-180
Moderate	101-150	121-200	161-250	181-300
High	>150	>200	>250	>300

Table 10 Guide to available potassium (mg/kg) ratings for general horticulture

	Sands	Sandy Loams	Clay Loams	Clays
Low	<80	<110	<140	<150
Marginal	80-130	110-150	140-190	150-210
Moderate	131-180	151-230	191-280	211-330
High	>180	>230	>280	>330

Available Phosphorus

Available P tests aim to measure only the small proportion of the total P pool which is available for plant uptake. Soil tests for total nutrients (such as total phosphorus) should not be used in predicting fertiliser requirements, as total analyses measure forms of nutrients that are not available for plant uptake. There are many available P tests, but the most commonly used test in Victoria is the Olsen P test. The Olsen P test is well calibrated against pasture yields but is poorly correlated to field or horticultural crop yields and is used more as general guide in the latter industries.

Table 11 Olsen P (mg/kg) in 0-10cm surface soils (0-15 cm for horticultural crops)

	Dryland Pasture and Crops	Irrigated/High rainfall Pastures and Crops	Horticultural Crops
Low	<8	<12	<15
Marginal	8-12	12-18	15-25
Moderate	13-18	19-29	30-60
High	>18	>25	>60

Normally an Olsen phosphorus level in the moderate range is desirable. Improving the Olsen phosphorus level from 1-2 mg/kg (typical virgin ground) to a moderate level, requires very high inputs of phosphorus (could be over 200 kg/ha of phosphorus) in the developmental stages. The rate at which soil phosphorus levels increase is mainly dependent on P fertiliser rates and soil type.

The rate of phosphorus recommended in any situation is influenced by

- the current and target Olsen phosphorus level,
- soil fixation characteristics (such as carbonate, iron or aluminium levels),
- expected yields or stocking rates.

A Test is available to help assess the phosphorus fixation capacity, however knowledge of soil types allows for reasonably good estimates to be made. Ferrosols, (i.e. Krasnozems, red well-structured clay loams), for example, have a very high phosphorus fixation capacity and higher P inputs are required on these soils. Calcareous soils also require more phosphorus. For many crops, especially perennial horticultural crops, annual leaf/petiole testing is a better guide to the phosphorus requirements than soil test results.

Available Sulphur (in mg/kg)

Calcium dihydrogen phosphate plus charcoal-extractable sulphur (CPC sulphur) is a reliable indicator of plant-available sulphur status for pastures. This test has assumed increased significance owing to the widespread use of high-analysis phosphatic fertilisers which contain low levels of sulphur. The sulphur ranges below successfully predicted pasture responses to sulphur in 72 out of 98 field trials, but the test is a poor guide to predicting sulphur responses for field or horticultural crops. The poor correlation of the soil test for horticultural crops may be due to the ability of deep rooted crops (eg wheat), to tap sulphur sources further down the soil profile. Tests should be performed to assess subsoil reserves of sulphur. Plant tissue analysis or grain analysis provides a more reliable assessment of sulphur status than soil testing for crops other than pastures.

Table 12 Available sulphur (mg/kg) ratings for pasture

<4	low
4-8	marginal
9-12	moderate
>12	high

Where soil sulphur levels are high, a low sulphur fertiliser could be used for at least 1 year. Gypsum can be used at 300-400 kg/ha as a cheap source of sulphur if sulphur is not being applied in other ways in the fertiliser program. Some soils, particularly in North West Victoria naturally contain appreciable quantities of gypsum in the soil profile.

Nitrate and ammonium

In recent years, nitrate and ammonium have been analysed in the soil profile as a guide in predicting nitrogen fertiliser response for crops. Most predictive models for cropping involve taking a 60 cm sample, just prior to sowing and the total amount of available nitrogen is then calculated.

These models also estimate the amount of nitrogen that is likely to be released from the breakdown of organic matter over the growing season. Target crop yields are set based on estimates of the amount of available water for the crop and hence a prediction on whether the soil will adequately supply the nitrogen requirements of the crop is made. This model is a useful guide, but it only be should be used in combination with other guides such as test strips, paddock history, tiller density counts, sap nitrate testing, NIR, plant analysis etc and not relied on solely. Inter lab variation for nitrate can be very poor (some interlaboratory studies have shown a 10 fold variation in results) and a small change in a test results may result in a large change in predicted nitrogen requirement. Taking a representative sample from 0-60 cm is also difficult and most samples only consist of 6-10 cores, which may not be adequate.

What is the most limiting factor to crop growth?

It is important to consider many influences in order to determine appropriate fertiliser inputs. This includes factors such as drainage, disease and weed control as well as other soil nutrient levels.

The concept of most limiting factor should be considered before applying nutrients. For example, a soil may have a very low level of Olsen phosphorus (3 mg/kg), but applying a lot of phosphorus may be of little benefit if the soil is extremely saline. Similarly, responses to potassium fertiliser may be poor until soil phosphorus reserves are satisfactory.

Deciding on nutrient inputs

There are a number of guidelines to help predict likely nutrient requirements for a given crop and they are listed below.

- Amount of nutrients removed in the harvest. Based on target yields or level of production it is possible to estimate the amount of nutrients removed from the paddock. E.g. a 5 t/ha crop of wheat would remove about 15 kg/ha of potassium.
- Soil test results. In general, the higher the soil test result the less nutrient recommended. Where soil nutrient levels are very high, it is good practise to utilise some of the existing soil reserves. For example, even though a dairy paddock may lose 100 kg/ha of potassium per year from milk and hay exports and leaching, it is pointless to apply potassium if the soil potassium level is very high.
- Other Losses of nutrients. Leaching, soil and water erosion, and fixation can also result in loss of nutrients. Nitrogen can also be lost by volatilisation (loss as a gas). The mode of application of nutrients can sometimes influence these losses. For example, splitting high rates of nitrogen fertiliser on a sandy soil and using appropriate irrigation practises can result in less leaching than a single large nitrogen application. Banding phosphorus closer to the seed is likely to result in less phosphorus fixation than broadcasting phosphorus
- Local soil knowledge. There are always exceptions to the rule and a lot of the exceptions relate to certain soil types. The soils in the Goulburn Valley for instance generally do not respond to potassium fertiliser. The red well structured friable soils called Ferrosols found around Ballarat, Thorpdale, Red Hill, Toolangi and Silvan have a high phosphorus fixing capacity and a very high pH buffering capacity, hence more phosphorus and lime would be required on these soils compared to other soils with the same test results.
- Trial results. Agriculture Victoria and fertiliser companies have run fertiliser trials which provide useful feedback on nutrient responses for certain crops on certain soil types. For example, most potato trials usually show a good response to phosphatic fertiliser even though very little phosphorus is removed in the crop.
- Visual symptoms of crop. Symptoms of nutrient deficiency will influence fertiliser advice.
- Grower experience. Years of grower experience should not be discounted.

Interpretation of Soil Physical Data

Soil Description

Soil samples have their colour described based on a Munsel colour chart. The use of a standard colour chart is used so objective colour descriptions can be made. Soil colour should be used primarily only for the identification and separation of different district soils and not as a measure of soil fertility, organic matter content, iron oxide content or drainage characteristics. For example it is generally considered that the red soils are more fertile. However, some red soils are very poorly structured, as well as being highly saline, particularly at depth.

Subsoil colour is usually more useful to a soil advisor than surface soil colours. The degree and colour of mottles in the soil provides valuable information on drainage (or lack thereof). Mottle colour assessments must be performed on unground samples.

Texturally, soils are grouped according to their clay content, for example, as sand - clay loam - light clay - medium clay - heavy clay. These texture classes and their sub-categories (e.g. sandy clay loam, loamy sand) frequently have an influence on the interpretation of chemical test results as well as in the identification and separation of different district soils. For example, clay loams and clay tend to "fix" phosphorus thus making it less available to plants. Hence a sandy loam would require less phosphorus fertiliser than a clay loam to achieve the same target soil-P level. On the other hand, coarse sand and sandy loams, particularly if low in organic matter content, can be readily leached of nutrients and hence may need more frequent fertilising. Soils with a very high content of organic matter are described as organic or humic soils. Where organic matter is extremely high the soils are described as peats.

Gravel content can modify the texture description as the latter is carried out after gravel has been removed by sieving. The amount of gravel in a sample can be a useful indication of soil type. For example, high gravel content may indicate an ironstone layer in the subsurface which is commonly associated with molybdenum responsive soils in Southern Victoria.

The descriptive terms used for free carbonate content are; negligible, trace, slight, moderate and much. High contents of free carbonates can be detrimental to the growth of some plant species (e.g. lupins, citrus, azalea and daphne).

Aggregate Stability

Soil aggregate slaking and clay dispersion in water is assessed to measure the stability of field aggregates or laboratory hand-remoulded soil. The tests are simple but provide a lot of information on potential soil structural problems

Slaking

Slaking is the breaking down of the aggregate or crumb structure of a soil, when wet, into smaller aggregates. When the soil dries, the smaller aggregates or individual grains of soil

may block some of the soil pores, resulting in reduced porosity and drainage. Soil structure is often poor.

Frequently cultivated are prone to slaking. Sub-soils typically have a slaking problem because there is not organic matter to hold them together. Slaking soils can be improved by increasing the organic matter, minimising cultivation and slow wetting of the soil if irrigating. The degree of slaking soil is described by the terms; water stable, partial slaking and considerable slaking. Sands and sandy loams are described as having minimal aggregation as they are basically structureless.

Clay dispersion

Dispersion is the separation of clay particles from the aggregates when the soil is wet. This results in a cloudy or muddy appearance around the soil aggregate. Soils with an ESP over 6% and/or soils with negligible salinity levels tend to disperse, particularly if the soil is worked.

The soil structure of dispersive soils is usually improved by the addition of calcium salts, usually as gypsum, but sometimes lime. The addition of organic matter also helps prevent clay dispersion. Roots growing prolifically through the soil are more effective at binding soil aggregates together rather than applied organic matter from composts etc. This is one reason why soil from established pastures generally have stable aggregates.

Both dry aggregates and moist remoulded ground samples are assessed for clay dispersion at 2 hours and at 20 hours. The degree of dispersion of soils is described by the terms; nil dispersion, slight dispersion, moderate dispersion, strong dispersion and complete dispersion at each reading. Sands and sandy loams are described as having minimal aggregation as they don't have enough clay for clay dispersion to be a problem.

Dispersion of remoulded aggregates without dispersion of the dry aggregates indicates that the soil does not currently have a problem with structure but could develop poor structure if over-cultivated, particularly if in a wet state. In this case gypsum could be applied as a precaution against poor soil structure developing on continually cropped soils. Dispersion of both dry aggregates and remoulded aggregates indicates that a current soil structure problem exists and use of gypsum would be beneficial in improving structure. The severity of clay dispersion can be rated according to the following table.

Saline sodic soils may not exhibit a clay dispersion problem due to the elevated soluble salt concentration. However if the soluble salt levels drops, clay dispersion and poor soil structure may result.

Table 13 Aggregate dispersion rating

	Dry aggregate		Remoulded aggregate	
	Reading at 2 hrs	**20 hrs**	**Reading at 2 hrs**	**20 hrs**
Nil	0	0	0	0
Slight	1	1	1	1
Moderate	2	2	2	2
Strong	3	3	3	3
Complete	4	4	4	4

As an example, a soil having a dispersion reading of nil (2hrs), slight (20 hrs) on the dry aggregate and moderate (2 hrs) and strong (20 hrs) on the remoulded aggregate would have a dispersion index of 6. In general the higher the dispersion index the more likely gypsum will be recommended.

Exchangeable Cations (calcium, magnesium, potassium and sodium)

These tests are primarily used for prediction of soil structural problems and hence have been included in this section of the manual. From the analytical data, the need or otherwise for gypsum can be estimated since calcium and potassium are believed to aid soil structure and sodium and magnesium destroy it. In many soils, levels of exchangeable sodium and magnesium increase down the soil profile and exchangeable calcium levels decrease.

The most important relationship between cations is that of the exchangeable sodium percentage (ESP). The ESP ideally should be under 6 %. Soils with an ESP over 6 % are termed sodic and may have soil structural problems, such as clay dispersion. Soils with an ESP of over 15% are very likely to have soil structural problems. Many soils are naturally sodic. Irrigating soils with sodic water may also make a soil sodic over time.

For soils with a cation content (less than 4 meq/100 grams – based on the four major cations) the ESP can be misleading. For these soils an actual level of exchangeable sodium of 0.6 meq/100 g can be used as an alternative guide as to whether soil structural problems are likely. Soils with a very low clay content such as sands and sandy loams are less likely to have soil structural problems even if the ESP is high as there is much less clay to disperse.

High levels of exchangeable magnesium in relation to calcium can also result in poor soil structure but the relationship is not as robust as the ESP relationship. Ideally, for good structure, a soil will contain less than 6% sodium and the Calcium:Magnesium ratio will be greater than 2.5.

The exchangeable cation test has other potential uses such as the diagnosis of deficiencies of cations. For example, low exchangeable magnesium (less than 0.5 meq/100 grams) may be a useful indication of magnesium deficient soils for horticultural crops. Conversely, high exchangeable magnesium percentages may induce potassium deficiency and conversely high potassium percentages may result in magnesium deficiency.

Improving soil structure with calcium

If clay dispersion is a problem, the cause is likely to be due to high levels of exchangeable sodium, although in the Red Brown Earths of northern Victoria, low electrical conductivity levels are the main cause of clay dispersion. An application of calcium salts may be warranted.

Application of calcium (in the form of gypsum or lime) displaces some of the sodium and magnesium in the soil and also increases the electrolyte concentration. Lime is often recommended on acid soils and gypsum on neutral to alkaline soils and in some cases both lime and gypsum are recommended. Gypsum is 100 times more soluble than lime and hence is often recommended where a quicker response is required. The addition of calcium changes the soil chemistry which may improve soil structure. Note there are many other factors other than clay dispersion that influence soil structure such as organic matter content, soil texture, compaction etc.

Gypsum use is based on the following factors:

- Clay dispersion index in the surface and sub-surface soils
- Sodicity levels and calcium:magnesium ratios
- Soil salinity levels
- Value of the crop, with gypsum being recommended more frequently for high value crops
- Frequency of cultivation, with gypsum being recommended more on continually cropped land
- Need for sulphur
- Whether calcium is being supplied from other sources, eg lime
- Gypsum quality

Typical gypsum rates range from 2.5 - 7.5 t/ha. Where test results indicated higher rates are require, the total application may need to be applied over several years, to avoid inducing a salinity problem.

Organic Matter

Low levels of organic matter are typically found in sands and sandy loams, particularly if the soil is continually cropped. Pastures under irrigation or high rainfall often have organic matter levels over 5%. Measureable increases in organic levels require very high applications of organic matter: >100 t/ha.

Table 14 Generalised organic matter ratings

Organic matter level %	Rating
< 1	very low
1-1.9	low
2-4.9	moderate
5-10	high
> 10	Very high

Continuously cropped vegetable or cereal paddocks often have soil carbon levels below 1%. Although minimal tillage and stubble retention programs may help maintain organic matter levels, large inputs of organic matter (over 100 t/ha) are required before any measureable increase in organic matter is obtained in a soil test result (consider that the mass of soil in one ha, to a depth of 10cm is around 1300 tonnes). Not all forms of organic matter are suitable as inputs.

The ratio of carbon to nitrogen lies between 10 and 15 for most soils. Peaty soils have high C/N ratios; often as high as 50 due to high plant component. Soils with C/N ratios of greater than 20 tend to be poorly nitrified.

1.2 INTERPRETATION OF LIME AND GYPSUM ANALYSIS

Lime

The Victorian fertiliser regulations, categorises lime quality on the basis of its effective neutralising value. The ENV is expressed on an "as received basis" , i.e. it includes moisture.

- Grade 1 ENV over 80%
- Grade 2 ENV 65-80 %
- Grade 3 ENV 50-65%

Material with an ENV of less than 50% does not comply with the regulation standards for lime and can not be sold as such. Under the fertiliser regulations lime must comply with the limits set for levels of cadmium, lead and mercury of 10 mg/kg, 100 mg/kg and 5 mg/kg respectively.

Costing limes

Because lime quality varies markedly, the cost of limes should not just be based on the cost per tonne spread. The costing should be based on be done on the basis of dollars per tonne spread and the ENV value. For example:

- Lime A costs $ 45 per tonne spread and has an ENV of 56 with a cost of $ 0.80 per ENV unit.
- Lime B costs $ 60 per tonne spread and has an ENV of 82 with a cost of $ 0.73 per ENV unit.
- Lime B is therefore the cheaper lime.

In Victoria, lime samples that have an ENV value of less than 50% can not be called limes, but they can still be called "liming materials". Depending on price per ENV unit, these lower quality products may still be an option if you wish to increase soil pH, but you will obviously need to apply much higher rates.

Calculation of ENV (effective neutralising value)

ENV is calculated from the NV (neutralising value) with an adjustment factor based on sieve fractions. Coarse lime is assumed to be less effective than fine lime (imagine lime the size of peas compared to talcum powder) and hence an effectiveness factor is applied to various lime sizes. Lime coarser than 850 um is considered to be only 10% effective. Lime between 300-850 um is considered to be only 60^ effective whilst lime finer than 300 um is considered to be 100% effective. An example of an analysis (wet weight basis) of an agricultural lime follows:

Total calcium	24 %
Calcium expressed as calcium oxide	34%

Calcium expressed as calcium carbonate	60%
Total magnesium	7.2%
Magnesium expressed as magnesium oxide	12%
Magnesium expressed as magnesium carbonate	25%
Moisture loss at 110°C	5
Neutralising value	91 %
Material coarser than 850 um	12% with an assumed effectiveness 10%
Material between 300-850 um	35% with an assumed effectiveness 60%
Material fine than 300 um	54% with an assumed effectiveness 100%

ENV = NV X a particle size factor.
Particle size factor = % lime > 850 um x 0.1) + (% lime between 300-850 um X 0.6) + % lime < 300 um X 1).

From the above analysis the particle size factor equals (0.12 X 0.1) + (0.35 X 0.6) + 0.54 X 1) = 0.76.
ENV = NV X 0.76 = 91 X 0.76 = 69 %

Note that Calcined or partially calcined limes are assumed to be 90% effective for material retained on a 850 um sieve and 100% effective for material passing though an 850 um sieve, hence a different ENV is applied to such limes. For example, if the above lime was a calcined lime it would have an ENV of 91%.

Note: a theoretical Neutralising Value can be calculated by: CaCO3 % +[2.5 x MgO] % = Neutralising Value

Types of lime

Agricultural ground limestones

Agricultural lime is the termed used to describe a range of naturally occurring limestones, with varying levels of calcium and magnesium carbonate. Agricultural lime is the most common type of lime used in agriculture or horticulture. Agricultural limes with a magnesium carbonate level of 28% and a calcium carbonate level over 35% can be called dolomites. Dolomite can be used where magnesium is required as well as an increase in soil pH.

Ground Burnt Agricultural lime (G.B.A)

G.B.A lime or quick lime is produced from burning agricultural lime, resulting in predominantly a calcium oxide product. G.B.A lime is used where a quick pH change is required and is commonly applied in the vegetable industry where there may be less than 2 weeks from harvest to planting the next crop. G.B.A lime is mainly used in horticultural situations.

By-product limes

Some lime is produced as a by-product from industry such as cement kiln dusts. Cement kiln dusts are very fine and provide a significant amount of potassium which can be beneficial to pastures in particular.

Gypsum

The Victorian fertiliser regulations specify that to call a product a gypsum, it must have a minimum of 50% calcium sulphate, in either the hydrated or anhydrous form. Gypsum is categorised as follows:

- Grade 1 gypsum must contain a minimum of 15% sulphur and a minimum of 19 % calcium.
- Grade 2 gypsum must contain a minimum of 12.5 % sulphur and a minimum of 15.5 % calcium
- Grade 3 gypsum must contain a minimum of 10 % sulphur and a minimum of 12.5% calcium
- Phospho-gypsum must contain a minimum of 17% sulphur and a minimum of 21 % calcium.

Under the Regulations gypsum must also comply with the limits set for levels of cadmium, lead and mercury of 10 mg/kg, 100 mg/kg and 5 mg/kg respectively.

An example of an analysis of a pit gypsum follows:

Material less than 2mm	75 %
Total calcium	22.6 %
Total sulphur	12.7 %
CaSO4. 2H20 calculated from S	68 %
Total sodium	< 0.1 %
Moisture loss at 40 degrees	8

Sodium salt is included as part of routine analysis. The percentage of gypsum is calculated from sulphur rather than calcium as calcium may be in forms other than gypsum, e.g. as calcium carbonate (limestone).

Types of gypsum

The vast majority of gypsum sold in Victoria is pit gypsum. Pit gypsum was originally deposited in an ancient marine environment. Some gypsum produced from crushed plasterboard is also sold. The supply or sale of phospho-gypsum (a by-product of the fertiliser industry) is negligible.

Costing gypsum

Similar to costing limes, gypsum should be costed taking into account gypsum purity and dollar per tonne spread

Gypsum A	$ 20 per tonne spread and has a gypsum purity of 65 %
Gypsum B	$ 30 per tonne spread and has a gypsum purity of 85%

Gypsum A costs 20/65= $ 0.38 per unit of pure gypsum
Gypsum B costs 30/85= $ 0.35 per unit of pure gypsum

Gypsum B is therefore marginally cheaper.

Mathematical Conversion

1. pH

pH (in calcium chloride) is on average about 0.7 pH units lower than pH (in water).

For saline soils, the difference the pH in water reading in particular is lower and hence the difference between the two pH methods may be only 0.2 of a pH unit.

2. Electrical Conductivity

Electrical conductivity (EC) is expressed in deci Siemens per meter (dS/m).

0.1 dS/m = 100 uS/cm
= 100 umbho/cm

To convert from EC to total soluble salts (TSS) in ppm or %, use the following equations:

TSS (ppm) = EC (dS/m) x 2970
or TSS (%) = EC (dS/m) x 0.297

Water analysis is not discussed in this manual but the conversion factor from EC to TSS (mg/kg) in water is approximately 640 and this factor is sometimes mistakenly applied to soil samples.

3. Exchangeable cations

i. Exchangeable Calcium (Ca)

1 milliequivalent/100 gram soil
= 1meq/100g = 200mg/kg

ii. Exchangeable Magnesium (Mg)

1meq/100g = 120mg/kg

iii Exchangeable Sodium (Na)

1 meq/100g = 230mg/kg

iv Exchangeable Potassium (K)

1 meq/100g = 390 mg/kg

v % Calcium

$$\% \text{ Ca} = \frac{\text{exchangeable Ca (meq/100g)}}{\text{sum of 4 cations(meq/100g)}} \times 100$$

vi% Magnesium

$$\% \text{ Mg} = \frac{\text{exchangeable Mg (meq / 100g)}}{\text{sum of 4 cations (meq / 100g)}} \times 100$$

vii % Sodium (ESP)

$$\% \text{ Na} = \frac{\text{exchangeable Na (meq / 100g)}}{\text{sum of 4 cations (meq / 100g)}} \times 100$$

viii % Potassium

$$\% \text{ K} = \frac{\text{exchangeable K (meq / 100g)}}{\text{sum of 4 cations (meq / 100g)}} \times 100$$

For cations analysed by the Gilmans method, aluminium can also be expressed as a percentage of cations

4. Organic Carbon

Organic carbon X 1.72 = organic matter

5. Conversion from Olsen phosphorus to Colwell

The Colwell phosphorus method extracts more phosphorus than the Olsen method, particularly on soils high in organic matter and the following rough rules of thumb are provided.

Sands/sandy loam	Colwell is 1.25 - 2.5 times the Olsen value
Loams/clay loams	Colwell is 2 - 3.5 times the Olsen value
Clay	Colwell is 3 - 5 times the Olsen value