Plant sampling for agriculture – A guide

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Prepared by:

Chris Dowling
Back Paddock Company.

Doris Blaesing
RM Consulting Group Pty Ltd
(RMCG).

Australasian Soil and Plant Analysis Council (ASPAC) financial support for the development of this document is gratefully acknowledged.

ASPAC

Citation
Dowling CW and Blaesing DT (2022) Plant Sampling for Agriculture – A Guide, Fertilizer Australia, Canberra, Australia.

October 2022.

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Overview of the plant sampling process

Why sample plants for nutrient analysis?

Testing both plants and soil for nutrient levels protects

- **crop/pasture health,**
- **crop/pasture quality and**
- **yield**

before deficiencies or imbalances become a problem.

Plant sampling is an important part of a crop nutrition program. Plant analysis shows if the crop is taking up nutrients from the soil or through the tissue from a foliar application. Nutrient deficiencies in plants should be discovered before symptoms appear. A range of deficiencies can show similar symptoms, so symptoms alone cannot be used to accurately diagnose deficiencies. Notably, once symptoms appear, the crop or pasture has already suffered a serious setback. Plant testing results should be used together with soil testing results. If crops are irrigated, a water test may provide valuable additional information, especially if salinity is an issue.

Apart from soil nutrient levels and inputs of fertilisers and soil amendments, other factors that can affect nutrient uptake include plant variety, air and soil temperature, soil structure, soil biology, soil moisture level, tillage practices, pests, weeds and diseases.

Find out more in Sections 1 and 2 of this guide.

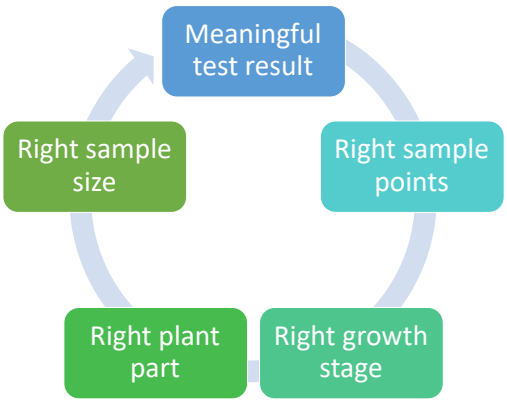
Plan the sampling

- Check farm, paddock location(s), and any available information, such as previous tests or spatial data.
- Consider ASPAC accreditation credentials of the laboratory.
- Decide which type of analysis is required and which laboratory to choose. Check the laboratory's website for specific sampling and documented sample handling requirements. Call the laboratory **beforehand**, if needed, to clarify any points you are not sure about.
- Things to take include gloves, sample bags and/or containers (e.g. for fruit), sample labels and/or bar codes (as required by the lab), permanent marker pen, overnight mail bags or courier bags, secateurs, safety knife, scissors, disinfectant, wet wipes, water to wash hands, esky or another receptacle to keep samples cool and dark.
- Check access and farm hygiene (biosecurity) requirements and potential health and safety hazards. Let colleagues or family know where you plan to go if travelling alone.

Find out more in Sections 3 and 4 of this guide.

Sampling

Make sure to sample the correct plant part at the correct growth stage (refer to Appendix 1) and correct sampling points in the crop and get the correct sample size.



The timing of sampling and the plant part sampled are critical because the optimum nutrient ranges for each crop vary with plant age and diverge in younger and older parts of a plant at the same overall crop growth stage. Nutrient levels vary within different plant parts and can increase or decrease at different growth stages. Sampling during conditions that cause plant stress (hot, cold, windy, dry or wet) or right after pesticide or fertiliser application can affect results. Make a sampling record or diary note, if any factors that may

influence plant analysis results could not be avoided to help with interpretation.

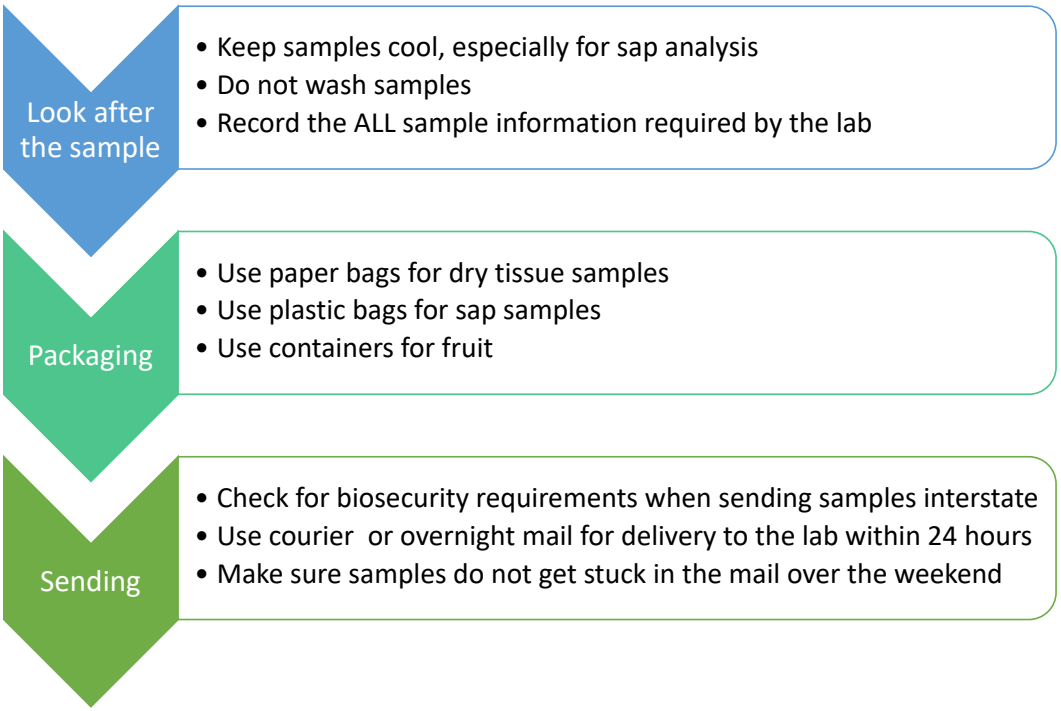
When monitoring crops sample from uniform, representative areas and representative plants for the overall crop. NDVI (Normalized Difference Vegetation Index) images can help to identify sampling zones. When sampling to diagnose a problem, sample from affected areas of the crop and take a comparative sample from areas of the crop or a comparative crop that is not affected.

Sample sizes need to be large enough for a laboratory to process for testing and have to be representative of the crop or crop area. Leaf samples for large-leaved crops should contain 20 to 30 leaves. Samples from small-leaved crops should have 40 to 50 leaves, about two full compacted handfuls. Petiole (or leaf stem) samples should contain approximately 100 to 150 petioles. For a dry tissue analysis, labs typically dry and grind all or a large proportion of the supplied sample, but most labs then only analyse a representative proportion (a few grams) of the dry, finely ground and mixed plant material. For a sap analysis, all of the sample is used for extraction, unless it is overly large; in that case, a representative subsample is used. Several millilitres of the extracted and filtered sap is then diluted and used for analysis. The instrumentation used for dry tissue and sap analysis in a lab is identical.

Find out more in Section 5 of this guide.

For detailed information on specific crops, refer to appendix 1 for dry matter analysis and appendix 2 for sap analysis.

Handling, labelling, packing sending to the laboratory.



Find out more in Section 6 of this guide.

New technologies

New technologies that may aid sampling, such as NIR (Near Infrared spectrometry)/ MIR (Mid Infrared spectrometry) and NDVI/ Red Edge, continue to emerge. Make sure you understand how these can be best used and the limitations. Ask an expert if unsure.

Find out more in Section 8 Appendix 6 of this guide.

Remember

1. Making decisions about fertiliser applications without soil and plant analysis is flawed and can cost the grower a lot in lost crop yield or quality, unnecessary expenditure, and adverse environmental consequences.
2. The analytical result is only as good as the sample.
3. Data interpretation is as important as good results, but typically, fewer interpretation data and guidelines exist for sap analysis in the public domain.

1. Purpose and introduction

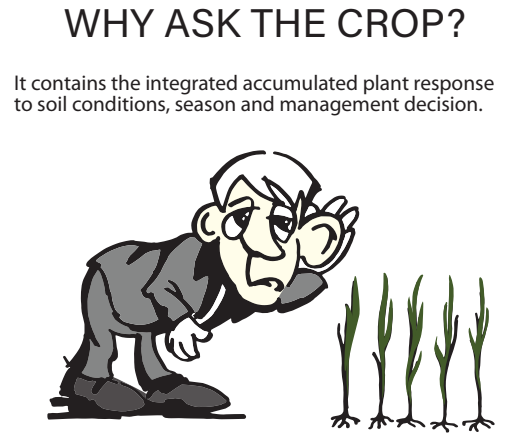
1.1 Purpose of this guide

The purpose of this document is to describe farm-based 'fit for purpose' plant sampling techniques. These guidelines ensure that sampling is well planned, well-equipped, and well-suited for its designated purpose.

1.2 Introduction

A key goal of the Fertcare® program is to improve soil and crop health, plant nutrition and environmental stewardship by encouraging greater adoption of soil, plant, and water testing.

Site-specific soil fertility and seasonal plant nutrition management rely on understanding the growing environment and expected crop nutrient removal rates, supported by soil and plant analysis data. Sound interpretation of analytical data requires collecting samples that represent the crop species and its growing environment.



Soils, and thus plant growth, are inherently variable.

Soil variability occurs horizontally and vertically and from micro- to macro-scales. The variation results from natural soil conditions and processes (soil parent material, topography, climate, hydrology, weathering, and biological processes), management practices and tactics (grazing, soil disturbance, crop choice, fertiliser and amendment use) and seasonal conditions.

Vertical variations in plant root distribution and soil conditions can result in soil nutrient availability and plant uptake differences. Vertical distribution is an essential consideration in determining the appropriate timing for plant sampling.

The timing of plant sampling should consider the distribution of the root system relative to the location of the seasonal supply of the nutrients of interest in the soil profile (Figure 1-1). Soil testing provides a rootzone overview of vertical nutrient distribution, which helps refine a plant sampling strategy.

Horizontal variation occurs due to historical soil disturbance, deposition, topography/ microclimate, or changes in soil formation on a broader scale.

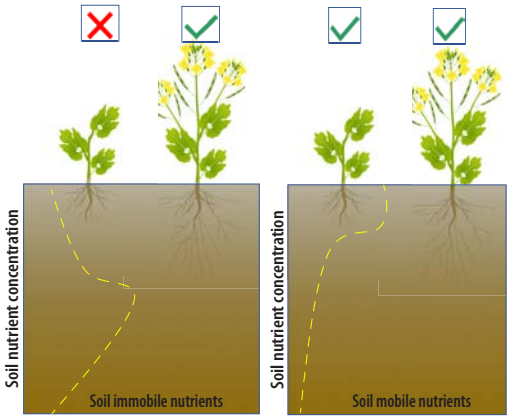


Figure 1-1. For mobile nutrients or where deep bands of immobile nutrients have been applied, sampling should be timed to reflect root access to most available nutrients.

Plant roots cover a more significant volume of soil, while soil samples are taken in discrete depth ranges that do not necessarily reflect root distribution. This is why plant testing adds complimentary information to soil testing and may better represent likely plant performance than soil sampling, especially in complex sampling situations such as:

- Deep banding of high rates of immobile nutrients outside the mechanical soil disturbance layer
- Fertigation where the soil-root-water bulb is the primary source of nutrients and water (refer to Figure 1-2)
- Water infiltration and distribution are uneven throughout the soil profile (refer to Figure 1-3)
- Where soil physical and/or biological constraints impact root structure/ nutrient uptake and/or plant growth rate.

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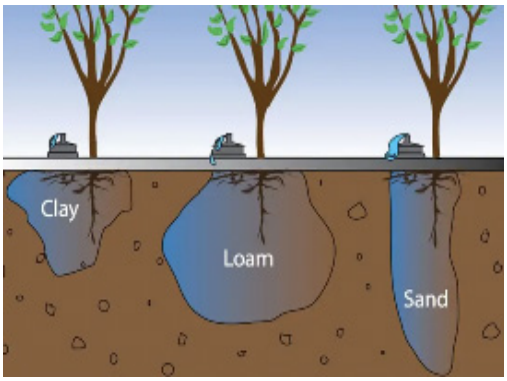

Figure 1-2. Influence of soil type on water distribution in the root zone

Figure 1-3. Soil water profile illustrating variability in distribution and infiltration (Photo courtesy: Marcus Hardie, University of Tasmania)

Agricultural systems and technology continue to change and diversify. Minimum or no-tillage, strip tillage, deep placement of soil amendments, row cropping, raised beds, precision nutrient and ameliorant placement, cover crops, and variable rate applications, all impact soil conditions, root distribution and nutrient availability within the root zone. Nutrient additions commonly include various organic or inorganic products/amendments in liquid or solid form, applied using a range of volumes, application methods, placements, and timings, which all impact nutrient availability.

Technology that allows real-time access to imagery, capturing geo-coordinates, uploading field and meta-data can help locate sampling locations based on quantifiable differences in soil conditions and plant growth. These technologies also allow for more meaningful use of soil and plant analytical data for site-specific nutrient management.

At a minimum, some plant sampling may be required to validate the differences detected using spatial and proximal sensing tools. Growth stage, plant part sampled and its location (especially for trees), row orientation, time of day, recent weather conditions and management operations, and the type of analyses to be performed are all important considerations for planning sampling. Interpretation of results needs consideration of varietal differences and yield goals.

Where soil physical and biological constraints impact root structure/nutrient uptake and/or plant growth rate, the nutrient concentration in the plant alone may not be sufficient to provide clear cause and effect relationships in different locations, particularly where whole tops are sampled. Nutrient dilution or concentration resulting from aboveground biomass differences between areas need to be considered (i.e. high biomass growth may result in nutrient dilution whereby low biomass may give increased nutrient concentration).

Additionally, there is an increasing opportunity and need to link sampling protocols, interpretation of data and fertiliser recommendations to manage the risk of nutrient losses from the root zone and environmental pollution.

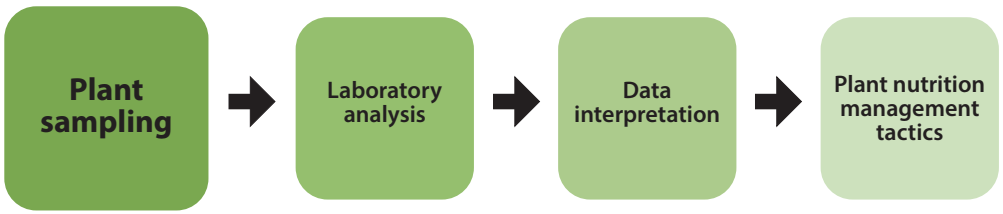

Figure 1-4. Correct plant sampling is an important first step in a holistic four-part interpretation and recommendation process.

The importance of correctly collecting a representative sample (or samples) of plant material to send to the laboratory becomes evident when considering that the sample (20 g of dry matter [DM]) may represent the total crop biomass from a couple of hundreds of kilograms to hundreds of tonnes per hectare. In the extreme, the sample sent to the laboratory may represent just 0.00006% of the total crop biomass. For a single test, the laboratory may analyse only 120 – 500 mg of the 20 g dry sample (refer to Figure 1-5). On some occasions, collecting duplicate representative samples from a single paddock is recommended as a quality control procedure to lead to confidence in laboratory data.

10 t/ha DM **500g sample (20g DM)** **500mg analysed**

Figure 1-5. Relative amounts of dry matter in the field, in the lab sample and the quantity analysed by the lab.

2. Why collect plant samples?

The mineral nutrition of crops/pastures has a major impact on productivity and quality of produce, including a vital role in feeding livestock and people. Plant analysis is necessary to guide the development and fine-tuning of soil fertility, fertiliser management and plant nutrition programs.

Figure 2-1 shows a generalised relationship between plant nutrient concentration and relative yield. In this conceptual model, the following zones are described:

- Deficient: plant tissue nutrient concentration is low, with crop and pasture yield constrained. Deficiency symptoms are likely to be visible. Plants are often responsive to nutrient inputs with economic responses. Nutrient use efficiency is typically high in this zone.
- Optimal range: As nutrient concentration increases, crop and pasture yield response slows and eventually reaches maximum relative yield. This is the nutrient concentration zone where the marginal benefit of additional yield equals the marginal cost of additional nutrient input. Nutrient use efficiency is typically optimised in this zone.
- Luxury: No additional yield benefit is obtained from increasing tissue nutrient concentration, therefore profit may decline with additional nutrient input. This zone is characterised by low nutrient use efficiency with any nutrient application leading to accumulation in the soil and an increase in the risk of nutrient loss.
- Incipient toxicity: As nutrient concentration increases, yield begins to slowly decline. This zone is characterised by poor nutrient use efficiency and unprofitable nutrient application.
- Toxic: As nutrient concentration increases, yield declines rapidly and toxicity symptoms may be visible. This zone is characterised by very poor nutrient use efficiency. When plants with high nutrient concentrations of some elements are consumed by animals or humans, there may be adverse implications for animal or human health.

The shape of this generalised relationship can change for different nutrients and there can be interactions between nutrients. Soil conditions can also have a major effect on the relationship between plant nutrient concentration and relative yield.

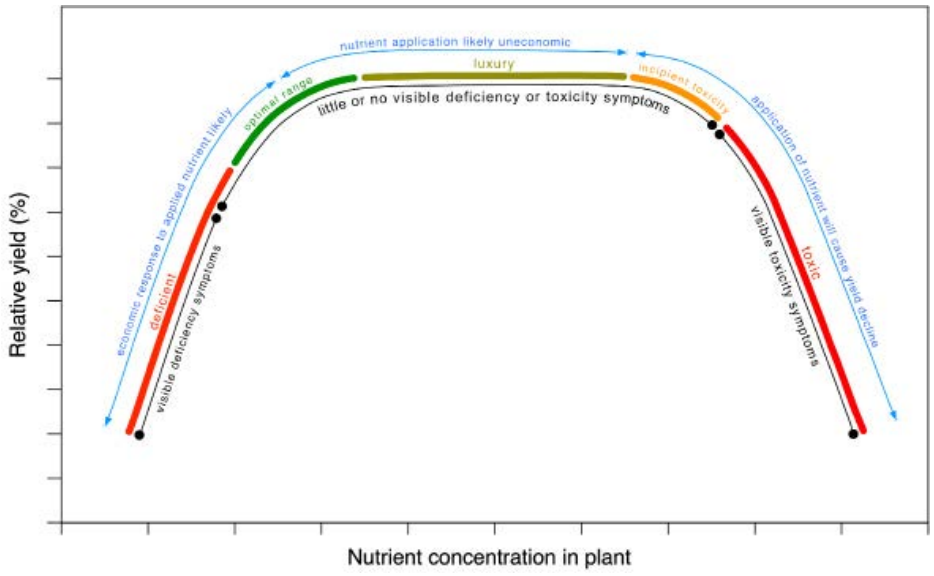

Figure 2-1. General relationship between plant nutrient concentration and relative yield

Waiting for visible deficiency symptoms to indicate a nutrient shortfall will generally mean that yield and/or quality may have already been compromised. The situation may deteriorate by the time the cause is diagnosed and acted upon. An extended setback in plant growth by most nutrient deficiencies cannot be entirely regained by subsequent treatment. Even before deficiency symptoms become visible, significant yield potential may already have been sacrificed. Plant analysis is currently the **only** practical management tool to help diagnose the risk of a crop entering a setback during the growing season. Still, such knowledge may have little practical use for the current crop. It depends on the speed of getting samples to the laboratory and the speed of getting results back from the laboratory. Rapid plant testing is the only practical management tool that helps identify nutritional deficiencies and remedial action that could be taken for the current crop.

The main purpose of a plant testing is to gain information about the nutritional status of a crop. Plant testing allows you to:

- Monitor a crop's nutrient composition and diagnose nutrition problems likely to affect production, i.e.
  - Identify deficiencies or imbalances early, before nutrient levels are low enough to cause symptoms ("hidden hunger") and reduce potential yield or quality
  - Diagnose the cause of visual deficiency or toxicity symptoms correctly to at least reduce the damage caused by the deficiency, and to select the correct management intervention
  - Exclude nutritional disorders as a cause of unthrifty growth or symptoms.
- Assess nutrient availability of the soil, substrate, or nutrient solution (i.e., nutrients may be in the root zone or hydroponic solution but not be available to the plant due to nutrient fixing, ion competition, root disease or adverse growing conditions. Unfavourable growing conditions include high or low temperature, dry or wet conditions, pH extremes, salinity/sodicity, humidity or other management inputs).
- Provide an objective basis for adjusting a nutrient management program and fertiliser recommendations.
- Monitor the outcome of fertiliser applications and crop use of soil amendments.
- Predict whether nutrient deficiencies are likely to occur in the current or even succeeding crops.
- Estimate the removal of critical nutrients by a crop to replace them if necessary.
- Provide a quicker assessment of the response to nutrient addition, application method, timing and / or rate compared to soil analysis.

Plants take up most of their mineral nutrients from the soil via roots and associated symbiotic organisms such as mycorrhizae. That is why a plant analysis should be viewed together with a recent soil analysis and recent and planned nutrient inputs.

It is essential to clearly define the reason/s for plant sampling to develop an appropriate sampling plan. What is (are) the question(s) to be answered? Clearly defining the objective of sampling will guide the development of a 'fit for purpose' plant sampling approach.

The reasons for plant testing are five-fold – predictive, monitoring, diagnostic, compliance and farm or paddock nutrient and crop performance mapping (Table 2-1).

Table 2-1. Five main reasons for plant sampling

Type	Questions	Conditions
Predictive	Are plant nutrient concentrations adequate to meet production and quality targets? Do constraints to nutrient availability and root uptake exist? What are likely responses to fertiliser and/or other ameliorant additions?	Predictive sampling requires understanding of the current production system, specific environment, crop/pasture variety needs, growth stages, and management practices to determine any input requirements and other management approaches.
Monitoring	Is nutrient uptake / accumulation adequate to date? If not, which nutrients need to be added and how much of each nutrient should be applied during the remainder of crop growth?	Monitoring aims to assess trends in plant nutrient concentration over time. Changes in concentrations between seasons and cropping cycles can be used to develop and refine site-specific fertiliser and ameliorant additions over time in association with soil fertility targets. A monitoring program requires a plan to ensure: • ongoing consistency of sampling methods minimising factors that may account for variations in soil fertility and chemical conditions or crop performance that is not representative for most of the crop • the establishment and reuse of specific sampling locations that represent the key crop system and soil types (unless they appear to be not representative for some reason) • sample collection, in the same way, the same growth stage, at the same time of year, with analysis derived from the same laboratory (or at least the same preparation and analytical method). Consideration of atypical variations in seasonal, management and climatic conditions. For example, it may be necessary to avoid sampling after extended dry or wet spells or during extreme temperatures. In some crop types, e.g. tree crops, soil and plant samples are taken at the same growth stage each year to provide an integrated plant nutrient status and soil nutrient supply picture.

Table 2-1. Five main reasons for plant sampling

Type	Questions	Conditions
Diagnostic	What is the reason for a crop/pasture not performing as expected? Does plant (root) health, available soil nutrient concentration or a soil constraint cause general or spatial differences in crop/pasture growth?	Diagnostic sampling is reactive and aims to provide site-specific soil fertility and/or plant nutrient status data to help explain observed crop or pasture production outcomes. Areas of 'poor and better' crop or pasture growth within management zones or paddock should be soil and plant tested (potentially at multiple soil depths) to help define differences in soil nutrient supply and availability for plant uptake and/or the incidence of soil limitations such as compaction, waterlogging, soil acidity, alkalinity, salinity, sodicity, and in low-lying coastal areas acid sulphate soils. Potential subsoil constraints should be investigated for deep rooting crops/pastures (i.e., soil testing of subsoil samples). Plant health, especially root health and soil profile distribution, should be checked to understand potential impacts from pests and diseases. Where areas with different aboveground biomass are to be compared, measurement of the biomass from the individual areas sampled is essential for interpretation.
Compliance	Do plant heavy metal, e.g. cadmium or lead, concentrations meet Environmental Standards? Do plant nutrient concentrations meet guidelines for environmental management plans, e.g. Reef Plan NP for bananas?	Compliance sampling aims to provide plant analytical data to aid environmental and/or human or livestock health risk assessment. This may include benchmarking soil and or plant analytical results against national or international thresholds for heavy metal contamination (e.g., cadmium, lead, arsenic), human/animal pathogens or residues from plant protection products.
Farm or paddock nutrient and crop performance mapping	Soil chemical, physical and biological conditions and thus crop performance can vary substantially within larger paddocks. If a large paddock is managed differently, this means some areas could benefit from different inputs, if they are large enough and different enough. Remote biomass sensing tools that integrate soil chemical, physical and biological conditions through plant responses can direct targeted inputs to optimise production potential at a sub-paddock scale (precision agriculture).	The use of drones and satellites allows for remote crop/pasture performance imaging. The reason(s) for differences should be investigated. Plant analyses of different zones can identify whether nutrient availability or uptake may differ. Underlying reasons can be soil conditions or plant health. Once this is understood, decisions about the strategic use of fertilisers and or products to enhance crop resilience can be made.

2.1 Comparing the roles of soil and plant analysis

Soil analyses measure nutrients and physio-chemical parameters of the soil. Results provide information about potential nutrient availability for a crop and how plant growth and product quality may respond to additional nutrient supply via fertilisers or soil amendments throughout a growing season, given no other constraints, e.g., water.

Plant testing measures nutrient concentrations in living plant tissue, with interpretation specific to the plant growth stage and plant vigour. It provides information on actual nutrient availability and uptake from the root zone until the sampling date. Sap analysis is most influenced by the growing conditions immediately before sampling, especially when using sap analysis. To build the best picture of overall soil fertility, both soil and plant samples are often used together. They complement each other because a soil test estimates what should be available to plants and the plant test measures if it is taken up.

Occasionally there are discrepancies between soil nutrient status and plant nutrient content, hence it may be necessary to investigate factors that can affect nutrient availability and uptake, such as pH, salinity/sodicity, temperatures, root diseases, herbicide damage, compaction, nutrient stratification, subsoil constraints, nutrient fixation (e.g., of phosphorus), slow nutrient release from soil pools (e.g., potassium, sulfur or nitrogen) and water relations (dry or wet conditions). Root length, density and distribution are the key factors influencing nutrient uptake. Anything that restricts healthy root growth will limit nutrient uptake, even if soil resources and fertiliser applications appear adequate and balanced.

3 Laboratory analysis

3.1 Which sample and analysis method to choose

The type of sample taken and the preferred analysis depend on the information needed to make nutrient planning or management decisions. Table 3-1 provides an overview of which analysis supports different nutrient management decisions.

Petioles and leaves are the most used plant parts for plant analysis strategies. However, fruit analysis has become popular because the analytical data provides information on nutrient partitioning in the plant and potential quality issues with the harvested crop (e.g. calcium deficiency in fruit reduces shelf life). Fruit analysis on a dry weight basis, with additional moisture content, can typically be conducted by laboratories under very similar procedures to the leaf testing and the same range of analytes. Laboratories generally will provide detailed sampling, sample handling, labelling and transport instructions on their website.

Table 3-1. Using plant analysis to make good nutrient management decisions.

Decisions	The information gained from the analysis	Analysis	Plant part	Timing	Comments
Nutrient budget, nutrient management plan	Total nutrient uptake	**Dry tissue analysis**	Entire above ground plant parts	At maturity	The difference between nutrient uptake and removal provides information on the amount of nutrients recycled if crop residues are returned to the soil.
	Total nutrient removal	**Dry tissue analysis**	Plant parts taken at harvest, e.g. tubers, fruit	At maturity	
Monitor and adjust nutrient management plans Determine fertiliser applications to correct deficiencies and imbalances ASAP	Current nutrient uptake around the time of sampling Nutrient uptake trends How well plants can take up nutrients under current growing conditions	**Sap analysis**	Depending on plant and growth stage: • entire plant • stems • petioles • young fruit • tubers, rhizomes, bulbs	Early growth stages to enable corrective action Any growth stage for diagnostic sampling	The usual turnaround time for results from the lab is 24-48 hours Desired ranges for sap tests are mostly available from the laboratories conducting the testing.

Table 3-1. Using plant analysis to make good nutrient management decisions.

Decisions	The information gained from the analysis	Analysis	Plant part	Timing	Comments
Assess how well nutrient management plans have worked	Nutrient accumulation in plant tissue up to the time of sampling How well plants can take up and utilise nutrients	**Dry tissue analysis**	• entire plant • stems • petioles • young fruit	At the start or end of the significant growth phases	When planning fertiliser applications to correct any deficiencies and imbalances, the lag time between sampling, getting results and applying fertiliser needs to be considered, especially for short-season crops. Desirable level ranges may not be available for all crop growth stages or plant parts
Determine fertiliser applications to correct deficiencies and imbalances in the current or following crop (fodder or pasture)	Availability of nutrients to grazing animals	**Dry tissue analysis** **Sap analysis**	Sample of typical leaf, stem and species composition grazed by animals	At optimum grazing DM quantity for pasture	Some agronomists use sap analysis, however, dry tissue analysis is the usual standard. Feed testing is recommended to assess the overall nutritional value of fodder and pasture.

3.2 Which analytical suite to choose

Most dry tissue plant samples are analysed for total nutrient content using two or three extraction methods and analytical finishes. Modern analytical finishes (e.g. Inductively Coupled Plasma Optical Emission Spectroscopy) allow multi-elemental determinations to be made. Therefore restricting the number of nutrients to be measured in a sample is not likely to reduce costs. Even where there are no established interpretative guidelines, it can be helpful to test plant tissues to establish baselines for monitoring or to compare areas with different productivity (e.g. good vs bad plant performance).

Table 3-2 provides an overview of typical analytical groups.

Table 3-2. Nutrients analysed in dry tissue plant analysis. "Less commonly analysed" nutrients are generally added to the "commonly analysed" for a more complete assessment.

(extraction groups: green = nitric acid + hydrogen peroxide, blue = water extract, black = direct combustion analysers or wet chemistry). Nutrients in italics are commonly available in sap tests.

Frequency of use	Check	Nutrients
Commonly analysed	Plant performance	N, *P, K, S, Ca, Mg, Na, Zn, Mn, Fe, Cu, B, Mo*
Less commonly analysed	Plant performance	*NO_3-N, Cl, NH_4-N,* Ni, Si, C
Less commonly analysed	Animal performance/ health	Ni, Co, Se
Less commonly analysed	Food/feed safety	Cd, Mo, Co, Se, Pb, Cr, As, Ni

3.3 Accuracy and reliability of laboratory results

Chemical analysis is subject to measurement uncertainty, and in selecting a laboratory service provider, the following factors need to be considered and confirmed, particularly the ASPAC Certification status of the laboratory:

- Is the laboratory involved in independent laboratory proficiency testing programs, whereby participating laboratories analyse standard homogeneous plant samples? The Australasian Soil and Plant Analysis Council (ASPAC) oversees Proficiency Testing Programs for dried plant tissue for Australian laboratories. Certification status is updated annually on the ASPAC website (https://www.aspac-australasia.com/).
- The Fertcare Accredited Adviser (FAA) minimum proficiency standard for plant tissues is a total of 10 plant analytes from the list below, with the first three being compulsory.

1. Nitrogen	8. Chloride
2. Phosphorus	9. Copper
3. Potassium	10. Zinc
4. Sulphur	11. Manganese
5. Sodium	12. Iron
6. Magnesium	13. Boron
7. Calcium	14. Molybdenum

- Currently, there are no Australasian proficiency programs for other plant analysis methods such as sap analysis. Some laboratories with ASPAC certification for dry tissue testing also provide plant sap analysis. Where dry tissue laboratory processes and QA principles are applied to sap, there is a reasonable probability that the results will be precise (the ability to get the same analytical result from a sample when the analysis is repeated). Still, accuracy (close to the "true value" or mean/ median of results from NATA accredited and/or ASPAC certified laboratories) is unknown. Therefore, it is important that repeated sap analyses are from the same laboratory, and interpretation ranges are from a consistent source.
- The use of recognised analytical methods which generate results that can be interpreted for Australian conditions. Where published, interpretation data relevant to current Australian production systems and varieties and/or a body of historical records should be used.
- Presence of a Quality Control system through internally driven procedures or verification of the AS/ISO 17025 standard through an authority such as the National Association of Testing Authorities (NATA).

4 Planning plant sampling

As described in this Guide, plant sampling and analysis should be part of a farm's soil fertility and plant nutrition strategy. Results are more likely to be of higher reliability and complement other quantitative measurements. The highest consideration in collecting samples is to "do no harm" to farm assets, soils, crops, livestock, or yourself. A good sample collection plan and situational awareness go a long way to keeping everyone and everything safe, and to sampling correctly.

4.1 Sample site access, hygiene and farm biosecurity

Contact the landholder to get current information on site access, safety considerations, hygiene, farm biosecurity and government human health alert status.

General biosecurity information can be found at the Plant Health Australia website https://www.planthealthaustralia.com.au/.

Human health alert bulletins and travel restrictions can be found on the website of state and territory health departments.

- Carry a kit to disinfect your shoes. If disposable gloves are not worn, disinfect your hands also.
- Do not enter paddocks with a dirty vehicle as wet or dried soil could come off.
- Carry shoe covers and disposable overalls if you need to enter a diseased crop.

Viral and bacterial diseases and seeds from weeds, can be carried on shoes and clothing. Ask the landholder to provide you with a farm vehicle if you are concerned about biosecurity risks when using your own. Every farm should have a sign-in system as part of their farm safety and biosecurity system; make sure you sign in or if that is not possible, keep a record of your movements on the farm and share it with the landholder.

Some examples of pests and diseases of concern include (but are not limited to):

- Sugar cane smut
- Phylloxera
- Red Imported Fire Ants
- Potato Cyst Nematode
- Golden Cyst Nematode
- Green Snail
- Onion Smut
- Halophytophthora (previously Phytophthora cinnamomi),
- Fusarium oxysporum
- Bacterial wilt.

More information can be found at State and Commonwealth Government biosecurity websites, such as including the following:

- Commonwealth: http://www.agriculture.gov.au/biosecurity/legislation
- New South Wales: https://www.dpi.nsw.gov.au/biosecurity
- Queensland: https://www.business.qld.gov.au/industries/farms-fishing-forestry/agriculture/land-management/moving-plant-soil
- South Australia: http://www.pir.sa.gov.au/biosecurity/plant_health#toc0
- Tasmania: https://dpipwe.tas.gov.au/biosecurity-tasmania
- Victoria: https://agriculture.vic.gov.au/ https://agriculture.vic.gov.au/biosecurity/moving-plants-and-plant-products/overview-moving-plants-and-plant-products
- Western Australia: https://www.agric.wa.gov.au/biosecurity-quarantine/quarantine/importing-western-australia/importing-plantand-plant-product

4.2 Work health and safety (WHS)

A variety of methods can be used to collect plant samples. Each method has inherent safety hazards that must be mitigated through good management and work practice.

At the core of work, safety is a safe work plan followed accordingly. The plan may include but not be limited to consideration of:

1. Appropriate training and induction

2. Operational and site hazard identification, preparation and being prepared to respond to the unexpected before sampling commences, including:

    a. communication with the landholder about sampling plans and potential hazards.

    b. familiarity with local conditions, site access and trafficability in expected conditions.

    c. fitness of vehicle and operator to undertake the required travel.

    d. experience in servicing and operating the required equipment safely, equipment failure.

    e. pesticide application awareness and knowledge of re-entry periods.

    f. agricultural equipment and or livestock location.

    g. powerlines - overhead and underground, other relevant farm infrastructure.

    h. biological hazards including feral and aggressive farm animals; organisms that cause allergic or other severe reactions, including plants, bees, snakes, and ticks.

3. Planning for, having available, and using appropriate personal protective equipment and suitable communications equipment based on:

    a. the type of sampling equipment

    b. location/terrain at the sampling site

    c. weather, and

    d. other expected hazards (refer to point 2).

4. Sampling location and work plan shared with others, especially if working alone or remotely.

4.3 Plant sampling kit

A plant sampling kit should contain an appropriate selection of the following items:

- gloves (unpowdered).
- laminated copy of sampling timing and plant part for commonly sampled plant species.
- sample bags (paper for dry tissue and plastic for sap samples) and or containers (e.g., for fruit).
- sample labels and or bar codes.
- permanent marker pen, pencil.
- overnight mail bags or courier bags.
- secateurs, safety knife, scissors.
- disinfectant for tools.
- wet wipes, water to wash hands.
- esky, car fridge or other receptacles to keep samples cool and dark.

4.4 Sampling conditions

A range of soil and climatic variables can affect plant nutrient concentration, e.g.,

They include but may not be limited to:

- weather conditions that may influence plant nutrient content, including
  - light intensity – plants require a period after sunrise each day or after abnormally overcast conditions to fully recover photosynthetic rate. Collecting samples while the plant's photosynthetic rate is slowed may give results not representative of "normal" growth and generate plant nutrient concentrations outside the ranges in interpretation guidelines.
  - air temperature – extremes of air temperature (causing frosting or wilting) also change photosynthetic rate. Plant sampling should be left until normal growth is resumed after an extreme temperature event (e.g., frost, heat) or recent management activities (e.g. irrigation).
  - don't sample in the first two weeks after fertiliser has been applied to the soil.
  - foliar application of fertiliser– residues on leaves may affect the analysis. Nutrients are absorbed at different rates from the plant tissue surfaces. It is essential to ensure sampling is timed to measure the plant's nutrient content, not residues on the surface. The time from foliar application to resampling is dependent on the nutrient of interest and a range of factors that control absorption rate. Table 4-1 provides general information about the absorption rate of a range of foliar-applied nutrients to guide resampling after a foliar application.

Table 4-1. General guide to the absorption rate of foliar-applied nutrients[1].

Nutrient	Time of 50% absorption
Nitrogen (as urea)	0.5 – 2 hours
Phosphorus	5 – 10 days
Potassium	10 – 24 hours
Calcium	1 – 2 days
Magnesium	2 – 5 days
Sulphur	8 days
Zinc	1 - 2 days
Manganese	1 – 2 days
Iron	10 – 20 days
Boron	1 – 2 days
Molybdenum	10 – 20 days

  - applications of pesticide application – some pesticides, e.g., fungicides and other chemicals can contain significant quantities of nutrients whilst others (herbicides and plant growth regulators (PGR) have some activity in plants that may change root or shoot growth patterns

[1](accessed 24/10/2021, https://www.yumpu.com/en/document/read/11305601/foliar-nutrition-midwest-laboratories-inc, https://helenaagri.com/fieldlink/understanding-foliar-nutrition/)

- irrigation/rainfall – high soil water conditions can temporarily affect the availability of nutrients by restricting root elongation and/or overall function due to oxygen deprivation, and/or cause changes in the plant availability of nutrients (e. g. Fe and Mn), sometimes increasing availability/uptake and in others decreasing it.

It is generally recommended to sample once there is evidence of new growth (new shoots/ leaves or white roots) rather than sampling while plants are dormant due to adverse or abnormal growing conditions.

Nutrient concentrations in Table 4-2 show the effect of time of day and soil P level on plant tissue concentration of nitrogen (N), phosphorus (P), potassium (K), zinc (Zn) manganese (Mn) and boron (B). It confirms the effect P can have on Zn uptake and that dry tissue nutrient levels can vary depending on the time-of-day samples are collected. Therefore, for monitoring purposes, it is best to always sample the same crop at around the same time of day and not when conditions are too hot, too dry, too cold, or too wet. These recommendations also apply to sampling for sap analysis.

Table 4-2. Effect of time of day and soil P concentration on plant dry tissue concentrations of P and other nutrients in wheat (Kaiser, 2013)

Soil test P status / sampling time	N %	P %	K %	Zn (mg/kg)	Mn (mg/kg)	B (mg/kg)
Very low soil test P. Sampled early morning	5.69	0.32	2.26	39.4	64.1	30.0
Very low soil test P. Sampled mid afternoon	5.6	0.45	2.31	38.5	53.9	39.8
Very high soil test P. Sampled early morning	6.36	0.48	1.94	37.0	53.5	29.0
Very high soil test P. Sampled mid afternoon	5.69	0.56	2.14	35.7	53.8	33.0

4.5 Consideration of laboratory location and transit time

Most samples supplied to laboratories for analysis can degrade in transit if not prepared for despatch correctly, even if transit time and conditions are favourable. It is important to be aware of:

- the average transit time and seasonal variations
- seasonal difference in storage conditions while in transit from the point of despatch to the laboratory
- anomalies from postal or freight transit contractor, e.g., days to avoid despatch
- communication from laboratory or service supplier about changes to receival days and opening hours, e.g., emails or website updates about public holidays.

If unsure about transit times, conditions and lab-specific requirements, a call to the laboratory before sampling can provide the required information.

5 Sampling strategies and procedures

5.1 Overview

A plant sample must represent the crop/paddock, distinct sampling areas within a crop, or different treatments. The person/s sampling must collect an adequate number of plants or plant parts at defined growth stages and age to represent the total plant population in the paddock, sampling area or plot (refer Appendix 1 & 2 and CSIROs Plant Analysis: An Interpretive Guide for increased detail in crop sampling guidelines).

The quality of a sample submitted to a laboratory will directly affect the analysis's quality, results, and interpretation. It is important to plan each sampling and prepare all materials needed beforehand.

Irrespective of whether you are sampling for dry matter/tissue or sap analysis, samples should NOT be collected:

- late in the week, causing them to be in the mail or with a courier over the weekend.
- near roads, livestock pads or camps, trees, waterlogged areas or other abnormal parts of a crop.
- with dirty or sweaty hands, when having sunscreen or other contaminants on hands (e.g., from food). Gloves are strongly encouraged.
- into dirty sampling containers or bags or using dirty, sweaty hands (e.g., after soil sampling).
- when a crop is affected by heat, cold, drought, wind or waterlogging.
- directly after irrigation or rain when the rootzone aeration may be compromised; ideally, the soil should be at field capacity to maximise root uptake and growth rate.
- from plants or plant parts that are dry or dead, mechanically damaged, sunburned or affected by insects and diseases (unless they are diagnostic samples).
- from plants that are covered in dust/dirt
- from plants that have been recently sprayed with pesticides or fertilisers.
- from different varieties for one sample, even if from the same paddock, as nutrient concentrations can be varietal dependent.

If forced to sample under challenging conditions or you want to monitor the effect of certain conditions, make sure you record the conditions and purpose of sampling to assist interpretation of results.

Try to collect a sample that is clean and free of dirt, obvious spray residues or any other type of contamination (sunscreen, sweat, etc.). However, do not attempt to wash the sample in the field. Leave this to the laboratory staff, who can clean leaves more efficiently if needed. Notify the laboratory before dispatch and ask about arranging decontamination using accepted methods.

Paper bags are used for dry matter/tissue samples and plastic bags for sap samples. Place samples in an esky or car fridge but not directly on a freezer pack.

Other points to consider are:

- Generally, a minimum of 30-50 individual leaves, petioles or shoots (or other plant parts as specified for the crop and growth stage) should be collected for a representative sample for both types of analysis. For sap analysis, if individual plant parts are small, 50+ may have to be collected to extract sufficient sap in the laboratory. If items to sample are large, e.g., fruit or tuber samples, it may be worth discussing minimum sample numbers with the laboratory e.g., whether perhaps 10-12 will be sufficient. Some literature sources report sample numbers of far less than 30, however, a higher number of individual leaves or petioles helps ensure a representative sample has been collected. Refer to Appendices 1 and 2 for further details on plant parts and the number of items to collect).
- After sampling for a sap analysis, remove leaf blades from petioles, or excess foliage from, e.g., onion, corn or carrot samples before posting. This minimises moisture loss and helps maintain the sample integrity is maintained during transit.

- When sampling young fruit (e.g., cucumbers, tomatoes, capsicums), collect around 200 g of fruitlets. If not sure, ask the laboratory for specific instructions.
- Subsampling destroys sample integrity, and results will be affected. For example, when sampling whole shoots of tillering plants, subsampling to reduce sample quantity is not recommended as the main shoots and tillers of tillering plants are likely to differ significantly in nutrient content. Subsampling may therefore change the ratio of mainstems and tillers of different ages, and therefore nutrient content in the sample can be compromised.
- Where multiple options for sampling are available at a particular growth stage (see also Table 5-1), sampling plant parts that are newly matured (e.g., specific reference leaves) is generally more effective to give information on the uptake of immobile nutrients (e.g., Ca, Zn, and Mn). Entire tops, which can be a mix of plant parts and phenological development stages (e.g., tillers), are generally preferred for conditionally mobile nutrients (e.g., B) and nutrients that are xylem mobile (e.g., N, P, K). When interpreting results from this kind of targeted sampling, the standard interpretation guides based on a particular sampling technique will not apply. They still may be used as a rough guide.

Table 5-1. Individual differences in nutrient mobility within the plant determines the plant parts with the lowest and highest concentrations.

Nutrient mobility	Nutrient examples	Sample
Immobile	Ca, Zn, Mn	newly matured plant parts
Conditionally mobile	B	entire tops
Xylem mobile	N, P, K	entire tops

5.2 Plant biomass dilution

A fundamental principle of plant analysis is that the chemical composition of a plant reflects the nutrient uptake and hence growth at any time. Any factors that change the growth rate or nutrient uptake in different paddock locations may create significant variations in plant nutrient concentration.

Nutrient supply via soil reserves and fertilisers may be adequate, but plant uptake may be reduced from root system restrictions due to for example, water logging or disease.

The above are a particularly important considerations when sampling whole tops in different areas with significantly different above-ground biomass from the same management zone.

Where different biomass volumes occur, interpretation of the nutrient status in whole tops can be very difficult to establish unless the interpretation system used caters for the "nutrient index" approach, i.e., accommodates the interrelationship between plant biomass and nutrient concentration. An example of a "nutrient index" approach can be found in Figure 5-1.

Biomass differences frequently occur with dual samples taken for diagnostic comparison. In this situation, sampling from plant parts of the same age (e.g., youngest expanded leaf) and less affected by the biomass differences is preferable. Sap analysis may be another option in some species. Carry a kit to disinfect your shoes. If disposable gloves are not worn, disinfect your hands also

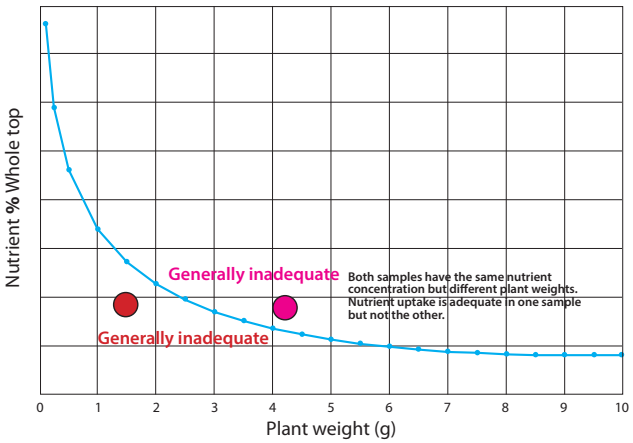

Figure 5-1. Nutrient index interpretation process takes account of both nutrient concentration and plant weight.

5.3 Sampling pattern for a selected area with no previous fertiliser banding

Different sampling patterns (Figure 5-2) have varying attributes (Table 5-2) that need to be considered depending on the purpose of sampling. When sampling plants, the same strategy/collection points should be used as for soil sampling. Having soil analysis data from the same sample sampling area strengthens the interpretation of plant analysis data. Refer also to section 5.6.2.

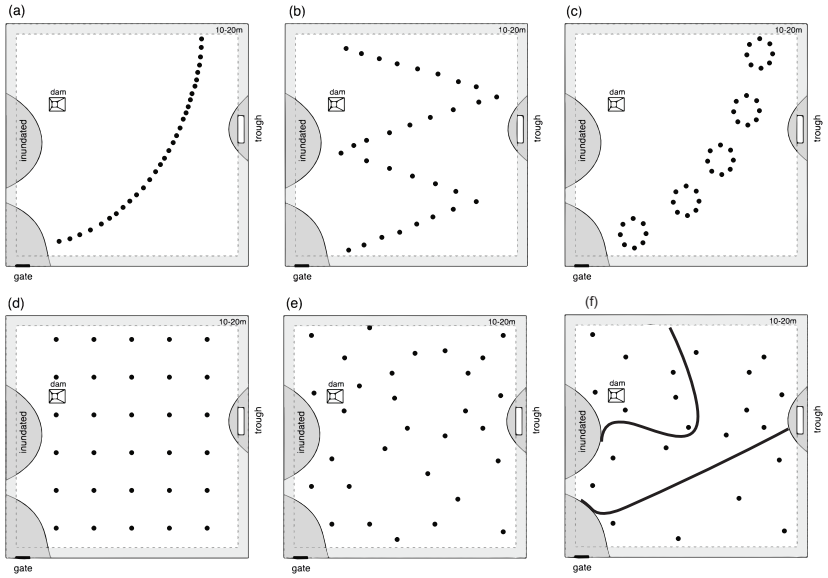

Figure 5-2. Examples of sampling patterns: a) transect, (b) zigzag, (c) cluster, (d) uniform grid, (e) random, (f) zonal.

Table 5-2. Attributes and comparison of soil and plant sampling pattern strengths and weaknesses (* weak, *** strong).**

Pattern	Repeatability for monitoring	Labour efficiency	Likelihood or representative sample	Reducing the risk of bias
Transect	*****	*****	***	***
Zigzag	*****	****	****	****
Cluster	*****	****	**	**
Uniform grid	**	**	*****	*****
Random	*	**	*****	****
Zonal	****	****	*****	*****

The samples from each subsection sampled can be combined into one sample, if subsections are uniform, or for example belong to a group or unit identified via NDVI.

If the crop is not uniform, each paddock subsection/zone must be sampled and analysed separately.

5.4 Sampling pattern for selected areas with previous fertiliser banding or drip fertigation

Where there has been zonal or precision placement of fertiliser for field crops, trees, vines, etc., plant sampling should be based on application patterns. The reason being that plant composition test results may vary according to how plants intersect the fertilised zone (e.g., deep placement). Where all plants can equally access areas of nutrient enrichment, sampling patterns referred to above will adequately represent the average plant status. The spatial variability in plant composition is smaller than that in soil composition.

5.5 Documenting and recording plant sampling location and pattern

With the ubiquity of mobile devices, recording the location of paddocks, sample routes and even individual plants and soil cores, along with data such as sampling personnel, date time stamps and sampling equipment used, is now routine. When implementing a sampling plan, it is important to record the specific sampling locations representing a sampling site within each representative paddock, block or management zone, so that one can return to the same spot, transect or pattern (Figure 5-2). Reducing spatial sampling variability helps identify trends in the fertility status and plant performance site over time.

Recording of geo-coordinates and associated metadata provides numerous benefits:

- Allows the sampling pattern to be repeated later (and pattern to follow the soil sampling pattern, if recorded)
- Provides confidence to clients, peers and auditors that samples have been collected appropriately
- Ensures connection between sampled location and important meta-data (i.e., sampling procedure, sampling depth, date and time, practitioner, equipment used, etc.)
- May help to explain unusual soil or plant test results with additional information from producers
- Metadata allows for later analyses to assist with detection of systematic sampling issues and identify more efficient sampling approaches.

Figure 5-3 shows soil and dry tissue test results for phosphorus (P) taken from the same sampling points. There is a reasonable correlation between the trends in soil and plant analyses. If the correlation was poor, consider investigating growing conditions and crop management factors.

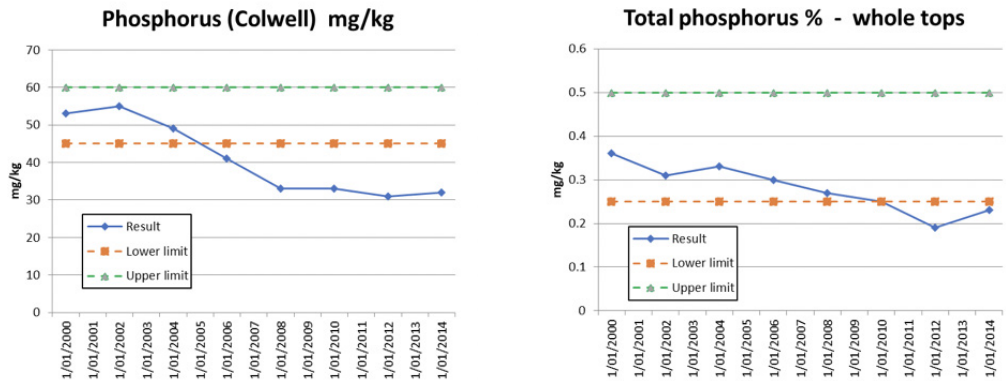

Figure 5-3. Example of soil and plant tissue test results for phosphorus (P); the orange and green lines indicated the desirable range which lies between the two lines.

5.6 Selecting areas to sample

Farm-level sampling strategy should be developed before sampling. Sampling locations within an individual farm must consider the purpose of sample collection, the crops and growth stages, previous cropping history, yield and quality objectives, soil types, overview fertiliser and amendment applications and plant growth variability.

5.6.1 Developing a farm map

The nearly ubiquitous availability of GIS computer-based mapping packages that record, store and display natural and man-made features, farm boundaries, operations, management inputs, production, and analytical records make plant sampling and data interpretation easier and more accurate. GIS packages that are accessible on- and offline are an excellent tool for planning and recording a sampling strategy, which can then be actioned. GIS tools make it easier to return to the same areas for subsequent crop checking and sampling and determine management zones within a crop that may need to be treated separately from each other, if required based on nutrient analyses and or vegetation indices. Figure 5-4 shows examples of farm maps produced in preparation for soil and plant sampling. A Normalised Differential Vegetation Index (NDVI) overlay can be used to identify distinct sampling areas within paddocks.

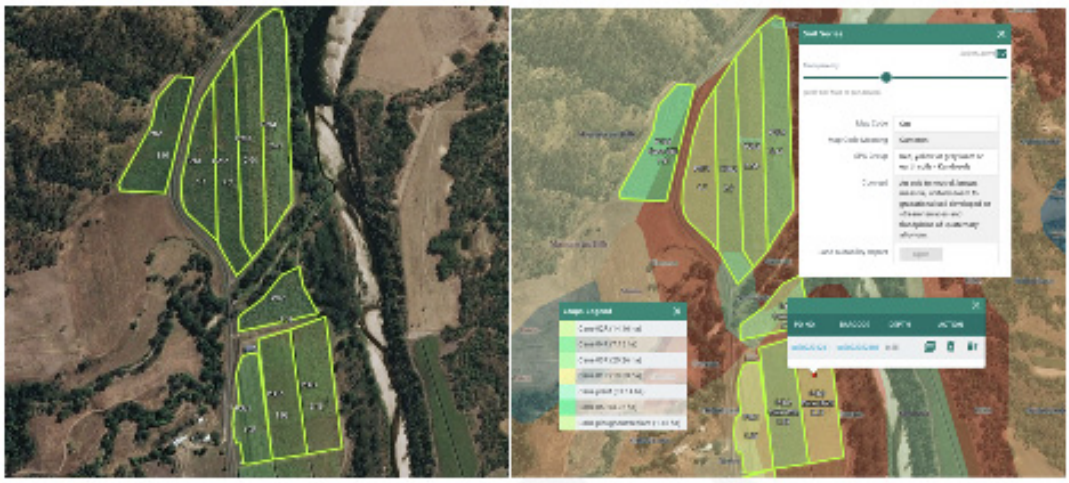

Figure 5-4. Production area boundary map (left) and boundary map, soil series names and soil monitoring point (orange dot, right) – see also Figure 5-5

5.6.2 Considering results of previous soil analysis results

Where the data exists, plant samples for monitoring should be taken around the site of soil tests so that the results are more directly related to the soil condition. Plant nutrient concentrations may sometimes appear to have little direct relationship to soil amendments and fertilisers used, or crop performance due to other factors influencing plant and especially root function and thus nutrient uptake. It is helpful to measure the change in nutrient uptake (nutrient concentration in sap or accumulation in dry matter) in contrasting areas of soil tested as the basis for further investigation of reasons for differences in plant performance or as a response to soil management.

5.6.3 Selecting representative paddocks / blocks for sampling

The number of selected areas should recognise and reflect the scale of difference in productivity, the purpose of sampling, testing and how the analysis data will be used. Setting up a simple matrix based on a paddock or block identification (identifier) matched against defined parameters or management practices (i.e. plant species, previous crop, inputs, NDVI values, etc.) can assist in grouping paddocks and identifying representative areas to sample (Figure 5-5).

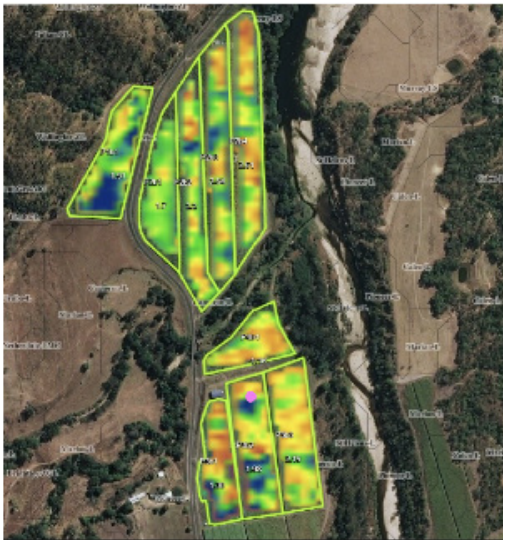

Figure 5-5. A satellite near infra-red (NIR) image of a farm, with colour changes highlighting differences in crop density (red is low, dark blue is high), soil monitoring point indicated by pink dot.

5.7 Defining plant parts and growth stages

When planning plant sampling, plant part and stage of growth are two of the most important decisions. A "fit for purpose plant sampling program" ensures that **the timing and plant part are identified from published standards well before sampling** to ensure close alignment with calibrated critical ranges. When sampling non-standard plant parts or growth stages, accurate interpretation of the plants' nutritional status becomes more difficult because critical ranges may not exist. Even without critical ranges, plant testing can help identify nutrient imbalances. Comparisons between poor and well-performing crops or paddock areas can be helpful for troubleshooting and improving the crop.

As leaves age, nutrient concentrations change (Figure 5 6). However, leaf mineral concentrations are frequently relatively stable for a period for most nutrients; this generally defines the sampling period used to generate critical ranges. It may not always be the agronomically best timing. For instance, in perennial fruit crops, the time of relative stability is after harvest. This means the results have no use for the current season. They help to review the effectiveness of the preceding nutrition program and point towards changes to a planned post-harvest program or issues to address in the coming season.

Checking a crop as early as possible in the season allows adjusting the nutrition program before the crop is affected by deficiencies or imbalances. **The later in the life of a crop a nutrient analysis is done, the more difficult it is to rectify any issues.**

Planning should include obtaining interpretation guides from a reputable source (e.g., laboratory, agronomist or researcher who developed interpretation guidelines) before sampling. Such guides may also provide specific sampling information for certain situations. Appendix 1 includes references that cover plant sampling guidelines.

Several phenological growth stage systems have been in use in Australia, which has caused confusion. In recent years **there has been a move to wider adoption of the decimal system based on BBCH growth stages**[2] . Zadok growth stages for cereals is based on

the BBCH system. Groups of plant species may have different descriptions for growth stages or missing growths stages, but the basic underlying structure from germination to senescence remains (Table 5-3).

In many crops, some BBCH stages occur concurrently. For instance, a plant may be actively growing, have flowers and fruit (e.g., tomatoes) in this case the growth stage to record is the latest the crop has entered. In the example for tomatoes, growth stage 7 would be selected if fruit is forming, even though the plants are still growing and are initiating new flowers.

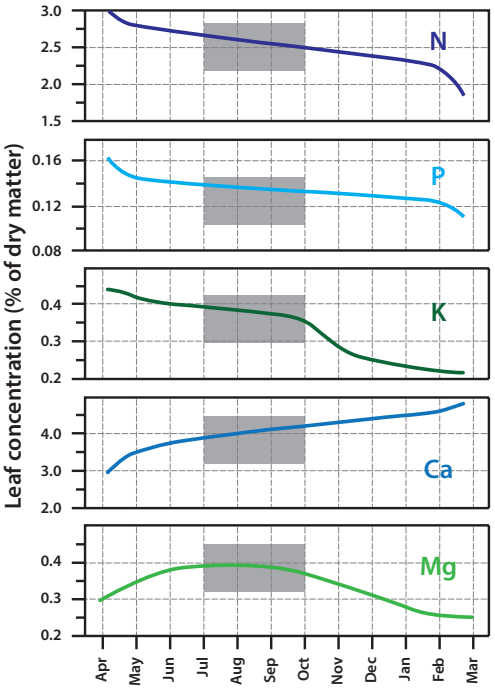

Figure 5-6. Example of changes in seasonal nutrient content and chosen sampling period.

Table 5-3. Principal BBCH growth stages

Decimal code	Nutrient examples
0	Germination, sprouting, bud development
1	Leaf development
2	Formation of side shoots, tillering
3	Stem elongation or rosette growth, shoot development
4	Development of harvestable vegetative plant parts, bolting
5	Inflorescence emergence, heading
6	Flowering
7	Development of fruit
8	Ripening or maturity of fruit and seed
9	Senescence, beginning of dormancy

[2]The BBCH-scale is used to identify the phenological development stages of plants. The abbreviation BBCH derives from the names of the originally participating German stakeholders: "Biologische Bundesanstalt, Bundessortenamt und Chemische Industrie".

The description of plant parts used in calibration is generally specifically defined in sampling guides. Common terms for plant parts to sample include:

- Youngest mature leaf (YML)
- Youngest expanded blade (YEB)
- Leaf below youngest expanded blade (YEB +1)
- Youngest expanded blade minus petiole (YEB-Pet)
- Youngest fully expanded leaf (YFEL)
- Recently mature leaf
- Whole tops (WT)
- Whole shoot (WS)
- Wrapper leaf (WL)
- Trifoliate leaf (TL)
- Stem (S)
- Youngest open leaf (YOL)
- Youngest open blade (YOB)
- Petiole (PET).
- Grain
- Fruit

5.8 Appropriate number of plants to sample to achieve a representative sample

Lateral and vertical variability of soil characteristics in combination with sampling patterns can significantly influence plant test results, so collecting from an adequate number of plants to account for this variability is critical to achieving a representative sample. The number of plants or plant parts required in a composite sample to be 95% confident that the mean value has a prespecified margin of error is shown in Figure 5-7 (Gilbert, 1987). Paddocks with high variability require more plants sampled for the same error than paddocks with low variability. Collecting the same number of plants in paddocks with low variability will result in lower errors than in paddocks with high variability. A compromise is to specify an acceptable error, i.e., ±15% with 95% confidence (Brown, 1999), and assume an average variability (coefficient of variation (CV) = 50%). On this basis the number of plants required would be ~40.

Creating a number of independent sampling areas within paddocks based on prior knowledge such as soil test results may reduce the variability between plants and therefore reduce the required number of plants that make up a composite sample. However, this increases the total number of samples and associated costs and assumes that farmers will vary fertiliser practices according to the area-based sampling within a paddock to benefit from the added sampling cost.

In some cases, a compromise between the number of plants sampled and the sample volume that can be sent to the laboratory may be necessary. In some situations, this may be achieved by changing the plant part sampled, e.g., a leaf or leaf segment rather than the whole plant, locating drying and grinding services, or using the above statistical principle to make a valued judgement about the consequences of reducing the number of plants per sample.

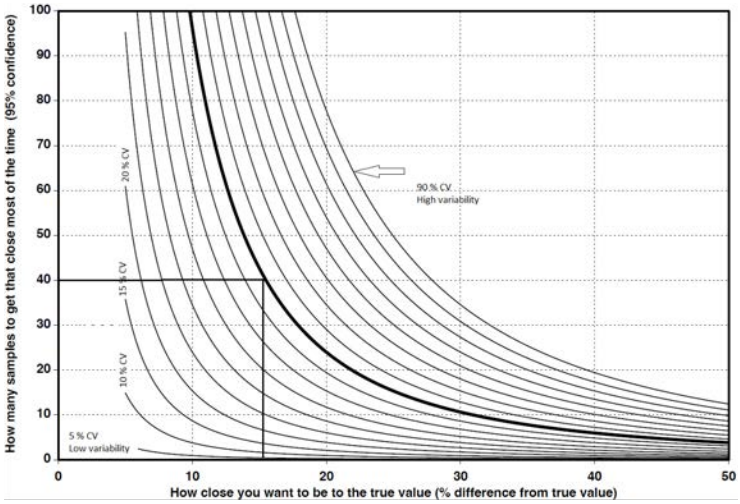

Figure 5-7. Number of samples required to be 95% confident that the collected sample has a specified % difference from the true value for situations of different variability. Figure developed using statistical procedures described by Gilbert (1987).

6 Post sampling handling and dispatch

6.1 General considerations

- Do not wash the sample; the laboratory will clean it properly if required and requested.
- Do not leave samples in open bags or the car for longer than necessary.
- Be careful that the correct sample is placed in the correct bag, i.e., it corresponds to the information on the label or electronic recording system used.
- Submit the sample to the laboratory for analysis. Specify the analysis required and any other relevant information using the information form (label) provided by the lab, a generic label or electronic options e.g. online or App-based capture of information.
- Keep the samples cool until dispatch. Get the samples to the laboratory or area for processing within 24 hours of taking the samples.
- If using overnight mail, check when it must be at the post office. If using a courier service, check whether overnight delivery is possible. Typically, couriers are faster, more reliable and trackable.
- If the lab does not provide bags, use paper (dried sample analysis) or plastic Ziplock (sap analysis) lunch bags that are large enough to be comfortably closed.
- Do NOT use bags for soft fruit samples, use plastic containers.
- Keep a copy of the labels and additional information sent and recorded, best electronically using a suitable program or app. Verbal records for your own use may be kept as voice records (Dictaphone, smartphone).

6.2 Recording sample information labelling

Record information that helps the interpretation of results - as soon as possible - after sampling. If a laboratory provides comments on results and requires additional information, this information should be sent to the laboratory along with the following records that should have been taken at sampling.

- date and time of sampling
- sampling site location or paddock identification (always use the same identification for the same site)
- crop species and variety
- plant part and development stage, e.g., youngest fully developed leaf
- planting date
- soil moisture status at the time of sampling, soil texture / last irrigation or rain
- any observed symptoms above and below ground (e.g., root damage or discolouration)
- previous crop(s)
- fertiliser and pesticide history
- crop growth stages at the time of sampling
- any other information you consider may impact the interpretation of the analysis

7 Sampling checklists

Actions			Guide section
Planning			4 and 5
Develop a 'fit for purpose' plant sampling plan that identifies the reasons for sampling, each step to take including information, materials and equipment needed and who needs to be informed.			4 and 5
Select a sampling pattern that provides a representative sample, is repeatable and efficient.			4
Schedule sampling at the same time each year and align with future fertiliser decisions.			4 and 5
Avoid sampling during periods of plant stress.			4
Select laboratory test product with the range of nutrients most likely to support the reason for sampling.			3
Sample Collection			5
Check and select "fit for purpose" sampling equipment.			5
Follow work health and safety guidelines and ensure cleanliness throughout the sampling and handling procedure. Gloves are strongly encouraged.			4.1
Dried tissue/Dry matter analysis - Follow work health and safety guidelines and ensure cleanliness throughout the sampling and handling procedure. Gloves are strongly encouraged.	Sap analysis - Follow work health and safety guidelines and ensure cleanliness throughout the sampling and handling procedure. Gloves are strongly encouraged.	Livestock mineral nutrition from pasture-based feed - Follow work health and safety guidelines and ensure cleanliness throughout the sampling and handling procedure.	
Dried tissue/Dry matter analysis - Collect samples from at least 30 – 40 plants to form a bulked sample of at least ~500 g fresh plant material.	Sap analysis - Collect samples from at least 30 – 40 plants to form a bulked sample of at least ~500 g fresh plant material, if individual plant parts are small, a greater number of samples will be required.	Livestock mineral nutrition from pasture-based feed - Collect a grab sample representative of the grazing animals' typical diet (species mix and height) from at least 30 – 40 locations to form a bulked sample of at least ~500 g fresh plant material.	
Dried tissue/Dry matter analysis - Sample the correct plant part and timing, including in tree crops, consideration of orientation to the sun.	Sap analysis - Sample the correct plant part and timing, including in tree crops, consideration of orientation to the sun.	Livestock mineral nutrition from pasture-based feed – not applicable.	
Avoid damaged or diseased plants and atypical areas for a representative sample such as stock camps, fence lines, tree lines.			5
Record geo-coordinates of sample patterns, crop/variety, plant development stage, date, field conditions, fertiliser and pesticide history.			5

Actions			Guide section
Dried tissue/Dry matter analysis - Record geo-coordinates of sample patterns, crop/variety, plant development stage, date, field conditions, fertiliser and pesticide history.	Sap analysis - Record geo-coordinates of sample patterns, crop/variety, plant development stage, date, field conditions and fertiliser history.	Livestock mineral nutrition from pasture-based feed – Record geo-coordinates of sample patterns, plant development stage, date and field conditions.	
Handling and dispatch			6
Protect collected plant sample from heat, sun and contamination.			6
Dried tissue/Dry matter analysis - Package sample in a suitable size high wet strength paper bag with unique sample identification code, sample location identifier and contact person.	Sap analysis - Package sample in a suitable size sealable plastic bag with unique sample identification code, sample location identifier and contact person.	Livestock mineral nutrition from pasture-based feed – Package sample in a suitable size high wet strength paper bag with unique sample identification code, sample location identifier and contact person.	
Send to the laboratory shortly after collection. Before dispatch, samples may be briefly stored in a refrigerator at 3 - 5°C before dispatch. Sap analysis samples must not be frozen.			6
Correctly fill out all details on the sample submission forms.			6
Follow relevant biosecurity requirements concerning the movement of samples within and across state borders, and within and between farms.			5 and 6

Appendices

Appendix 1 – timing, plant part and sample number for dry matter analysis

The information below is based on some Australian standard interpretation guidelines for collecting samples for dry tissue (matter) analysis (adapted) from: Plant Analysis – an interpretation guide, Reuter and Robinson (1996). For further information refer to plant analysis information provided by laboratories or research papers. Ensure desirable ranges apply to Australian conditions, production systems and varieties used.

Check with the person doing the interpretation for the most appropriate sampling guidelines and whether the adaptions suggested above are suitable.

The '# NEEDED' column shows the number of plants that will need to be sampled to ensure representative sampling of plant parts. If plants are small, a larger number of plants or plant parts may be required to supply the laboratory with 200–500 g of wet material to meet the laboratory requirement of 20 g of dried sample. Fresh leaves contain at least 85% water by weight.

The 'timing' column provides information on the growth stage or time of year to collect samples. GS stands for growth stage.

Annual Broadacre crops

Crop	Timing	Plant part	# Needed
Barley	Seedling to early tillering (GS 14–21).	Whole tops cut off 1cm above ground.	40
	Early tillering to 1st node (GS 23–31).	Whole tops cut off 1cm above ground.	25
	Emergence of head from boot (GS 50–51).	Whole tops cut off 1 cm above ground.	25
	Early tillering to 1st node (GS21–31).	Youngest expanded blade (YEB) plus next 2 lower blades.	40
Canola	6 leaf to rosette.	Whole tops.	25
	Prior to flowering.	Youngest mature leaf.	40
Chick-peas	Pre-flowering.	Whole tops.	25–40
Cotton	All growth stages.	Youngest mature leaf blade without petiole.	40–50
	All growth stages.	Petiole of youngest mature leaf blade – for NPK only.	40–50
Cowpea	Pre-flowering.	Youngest mature blade (trifoliate leaf).	40–50
Faba beans	Vegetative pre-flowering.	Whole tops.	20
	Early flowering.	Recently mature leaf.	75–100
Lentils	Pre-flowering.	Whole tops.	25–40
Lupins	Pre-flowering.	Recently mature leaf.	50–75
Linseed	Immediately pre-flowering.	Upper fully expanded leaves FEL stripped from stem.	100s
	63 days after sowing DAS.	Whole shoot cut 2 cm above ground level.	30

Crop	Timing	Plant part	# Needed
Maize	24 to 45 days after planting.	Whole tops – seedlings 15cm to 40cm tall cut off 1cm above ground.	40
	Prior to tasselling.	Fully developed leaf below whorl. Cut leaf at base where it joins the sheaf.	25
	Silking to tasselling.	Ear leaf. Cut leaf at base where it joins the sheaf.	25
Mungbean	Pre-flowering.	Youngest mature blade (trifoliate leaf).	40–50
Navybean	Pre-flowering to early flowering.	Most recently mature trifoliate leaf.	30–40
Oats	Seedling to early tillering (GS 14–21).	Whole tops cut off 1cm above ground.	40
	Early tillering to 1st node (GS 23–31).	Whole tops cut off 1cm above ground.	25
	Emergence of head from boot (GS 50–51).	Whole tops cut off 1 cm above ground.	25
	Early tillering to 1st node (GS21–31).	Youngest expanded blade (YEB) plus next 2 lower blades.	40
Peanut	Pre-flowering to early flowering.	Most recently mature trifoliate leaf.	40–50
Peas (field)	Pre-flowering.	Youngest mature compound leaf (leaves from 3rd to 5th nodes from top).	60–80
Rice	Mid tillering until panicle initiation.	Y leaf i.e. most recently expanded leaf.	50
	Mid tillering until panicle initiation.	Whole shoot WS – whole tops cut off 1 cm above ground.	25
Sorghum	Seedlings < 30cm tall.	Whole plant – seedlings to 30 cm tall cut off 1cm above ground.	40
	Just prior to flowering or at early flowering.	3rd leaf below the whorl.	30
Soybean	Early flowering to early pod set.	Most recently mature trifoliate leaf.	30–40
Sugarcane	During active growing season (November to May).	Leaf strips from third leaf from top of stalk from stalks of average height (first leaf is one that is more than half unrolled). Third leaf corresponds to top visible dewlap. Fold third leaf in half and cut and retain the folded middle 100–150mm section. Retain this middle 200–300mm section and discard the rest. Strip out and discard the midrib from this 200–300 mm section of leaf strip.	30–40
Wheat	Seedling to early tillering (GS 14–21).	Whole tops cut off 1cm above ground.	40
	Early tillering to 1st node (GS 23–31).	Whole tops cut off 1cm above ground.	25
	Emergence of head from boot GS 50–51).	Whole tops cut off 1 cm above ground.	25
	Early tillering to 1st node (GS21–31).	Youngest expanded blade (YEB) plus next 2 lower blades.	40

Pasture

Where sampling is to provide an understanding of nutrient concentration ingested by animals, sampling should include plant material from a representative proportion of the diet being consumed.

Crop	Timing	Plant part	# Needed
Annual medics and clover	Active growth prior to flowering.	Youngest open leaves and petioles. All above ground parts.	50
Lucerne	Prior to flowering.	Growing tips (upper 10–15 cm of stems). All above ground parts.	30
Temperate grasses	During active growth.	Youngest mature leaf blades. Whole tops cut 3–5 cm above soil level.	40

Annual horticultural crops

Crop	Timing	Plant part	# Needed
Broccoli	Early heading.	Most recently mature (MRM) leaf at early heading.	20
Bean (Green or French)	Before flowering. At early (first) flowering. Full flowering.	Most recently mature (MRM) trifoliate leaf plus petiole at each growth stage.	50 50 50
Beetroot	When roots 4–6 cm diameter.	MRM Most recently mature leaf.	40
Brussels sprouts	At early sprouts.	MRM Most recently mature upper leaf at heading (early sprouts).	20
Cabbage	5 weeks after transplanting. 8 weeks after transplanting. Heads half grown. At harvest.	MRM Most recently mature leaf. MRM Most recently mature leaf. Wrapper leaf. Wrapper leaf.	30 30 15 15
Capsicum	Prior to flowering. First flowers open. Early fruit set. Early harvest.	MRM plus petiole (Most recently mature leaf plus petiole) at each growth stage.	50 50 50 50
Carrot	Roots 1–3cm diameter. Harvest.	Sample most recently mature leaf minus extended main petiole (at each growth stage).	50 50

Annual horticultural crops

Crop	Timing	Plant part	# Needed
Cauliflower	Buttoning. Heading.	MRM Most recently mature leaf at each growth stage.	15
Celery	6 weeks after transplanting. At maturity. Mid growth period.	Outer petiole. Outer petiole. MRM leaf plus petiole (Most recently mature leaf including petiole) (different data set).	50 50 20
Chinese Cabbage	8 leaf stage. At maturity.	Oldest undamaged leaf at each growth stage.	30
Cucumber	Before flowering. Early flowering.	MRM plus petiole (Most recently mature leaf plus petiole) at each growth stage.	25 25
Lettuce	8 leaf stage Heads half grown At maturit	MRM (Most recently mature leaf) Wrapper leaf Wrapper leaf	40 20 20
Potato	Tuber initiation Tuber bulking	PYML (Petiole of the youngest mature leaf) (5th leaf from the growing point) at tuber initiation (tubers double the normal stolon diameter) and also during tuber bulking.	40
Potato	Plants at 20-25 cm high At first flowers Tubers half grown	MRM (Most recently mature) leaf plus petiole at each growth stage	40
Tomato	5 leaf stage First flower Early fruit set First ripe fruit During harvest period	MRM plus petiole (Most recently mature leaf plus petiole) at each growth stage	40

Temperate perennial trees and vines

Crop	Timing	Plant part	# Needed
Almond	Mid to late January.	Normal sized leaves, shoulder-high from non-fruiting spurs on spur bearing cultivars or mid-shoot on the current season's extension growth on non-spurring varieties. Take at least 4–5 leaves from the periphery of each of 20–30 similar trees of a single cultivar and rootstock.	150
Apple	Late January to mid-February.	Entire leaf (including petiole) from mid-shoot position on current season's growth. Take at least 4 leaves from the periphery of each of 20–30 similar trees of a single cultivar and rootstock.	120
Apricot	January and February.	Mid shoot leaves from current seasons flush. Take at least 4 leaves form the periphery of each of 20–30 similar trees of a single cultivar and rootstock.	120
Cherry	January and February.	Mid shoot leaves from current seasons flush. Take at least 4 leaves from the periphery of each of 20–30 similar trees of a single cultivar and rootstock.	120
Citrus – Qld	February–March	Healthy, mature leaves from middle of non-fruiting terminals of previous spring flush 5–7 months old. Take leaves at shoulder height at various positions around the trees. Avoid sampling spring flush terminal that have reflushed.	200
Citrus – Riverland, Sunraysia	Leaves are six months old.	Most recent fully expanded leaf on a non-fruiting terminal otherwise as for Qld.	200
Grapes – Petiole	October–November.	Petioles from leaves opposite bunch at base of shoot at full bloom (80% cap fall). One petiole per vine from a planting.	150
Grape – Leaf Blade	Veraison.	Leaf blades from leaves opposite bunch at base of shoot. One leaf per vine from a single variety x rootstock planting.	100
Olive	September–December.	Latest mature leaves just prior to flowering. 5–10 leaves each from 20–30 trees from a single planting and variety.	150
Peach & Nectarine – Low Chill	Sample 2 weeks after harvest before summer pruning or fertilizer application.	Sample mature leaves from midpoint of exposed shoots from current season's terminal growth. Take at least 4 leaves from the periphery of each of 20–30 similar trees of a single cultivar and rootstock.	150
Peach & Nectarine – High Chill	Mid-January–Mid February.	Sample mature leaves from midpoint of exposed shoots from current season's terminal growth. Take at least 4 leaves from the periphery of each of 20–30 similar trees of a single cultivar and rootstock.	150

Temperate perennial trees and vines

Crop	Timing	Plant part	# Needed
Pear	Late January–Mid February.	Sample mature leaves from midpoint of exposed shoots from current season's terminal growth. Take at least 4 leaves from the periphery of each of 20–30 similar trees of a single cultivar and rootstock.	150
Plum	Jan–Feb (d'Agen),	Entire leaf (including petiole) from mid-shoot position on current season's growth. Take at least 4 leaves from the periphery of each of 20–30 similar trees of a single cultivar and rootstock.	150
Raspberry	Late Summer–Autumn.	Sample 5th–12th leaves from the terminal 150 mm of the new canes (primocanes, that is non-fruiting) 2–3 weeks after final pick.	

Subtropical and tropical perennial trees and vines

Crop	Timing	Plant part	# Needed
Avocado	April–May.	Recently matured fully expanded leaves (4–5 months old) from non-fruiting terminals. 6–8 leaves from 10 trees of a single cultivar and across the planting.	80
Banana – Sth Qld & Nth NSW	Late January to mid-February.	Entire leaf (including petiole) from mid-shoot position on current season's growth. Take at least 4 leaves from the periphery of each of 20–30 similar trees of a single cultivar and rootstock.	120
Banana – Nth Qld	Before bunching.	Two strips 20cm wide from each side of midrib to margin from the centre section of the third fully expanded leaf.	24
Citrus – Qld	February–March.	Healthy, mature leaves from middle of non-fruiting terminals of previous spring flush 5–7 months old. Take leaves at shoulder height at various positions around the trees. Avoid sampling spring flush terminal that have reflushed.	200
Custard Apple	Late Feb or early March.	Sample youngest mature leaf from non-fruiting terminals in after the second major growth flush.	40
Lychee	1–2 weeks after flower panicle initiation (May- August).	Select first healthy leaf bunch under the panicle from each of 8 branches distributed uniformly around the tree. Sample from 20 trees from a single planting and variety.	160
Macadamia	September to November just before spring flush.	Mature leaves (6–7-month-old) from2nd whorl of current season's growth, from non-flushing terminals. 5–10 leaves each from 10–20 trees from a single planting and variety.	100

Subtropical and tropical perennial trees and vines

Crop	Timing	Plant part	# Needed
Mango – Tropics	May–July.	Latest mature leaves when tree is growing slowly prior to flowering. 5–10 leaves each from 10–20 trees from a single planting and variety.	50
Mango – Subtropics	August–September.	Latest mature leaves just prior to flowering. 5–10 leaves each from 10–20 trees from a single planting and variety.	50
Passionfruit	July–August (cool slow growth months).	Youngest fully expanded mature leaf behind a recent flush of growth. 6 leaves from east or north side of vines from 20 vines per block.	120
Pawpaw	Spring.	Sample petioles from the youngest fully expanded leaves subtending the most recently opened leaves. Use entire petiole and collect 20 over a 1 ha block.	20

Appendix 2 – Growth stage, plant part and sample number for sap analysis

Check with the laboratories you are using prior to sampling to ensure the general information provided here applies. The laboratory should be able to offer information on crop and variety specific sampling needs and interpretation aids for crops grown under Australian conditions. Check with the laboratory how the desirable ranges have been developed. A standard sap test range is: Nitrate (NO_3), Chloride (Cl), Ammonium (NH_4), Phosphorus (P), Potassium (K), Calcium (Ca), Magnesium (Mg), Sulphur (S), Zinc (Zn), Boron (B), Sodium (Na), Copper (Cu), Manganese (Mn), Iron (Fe) and Molybdenum (Mo). Sap brix and additional elements can be tested on request by some laboratories.

User notes:

1. Find the crop name from the first column
2. Note the recommended timing (Growth Stage, which links to growth stages for which desirable levels are available)
3. Note the required plant part – it is critically important to follow these guidelines so analytical results can be compared against "Desirable Ranges" which are based exclusively on these plant parts and Growth Stages
4. Note the quantity required – if we receive insufficient sample material, analysis will not proceed; collect more rather than less!
5. Record the corresponding Growth Stage number (listed in the table) in the marked column on the Sample Information Sheet, which can be accessed from the lab's website or by calling the lab
6. Note that if a growth stage is not included on the sample information sheet, results cannot be reported against the "Desirable Ranges" for that crop.

Crop name	Suggested timing of sampling	Plant part needed	quantity required	Growth stages (BBCH) required for interpretation of results	
Prunus spp. vegetative	Begin sampling at or just before GS 7.2 (shuck fall). A second sample should be taken at stone hardening (7.5). Nutrition should be monitored throughout nut development by taking 2–3 samples at equal intervals apart. A final sample should be taken at harvest or prior to post harvest applications.	Collect 10 cm of new shoot tips from current season's growth at mid crown height (or shoulder height for large trees). Sample from the same trees for subsequent sampling.	30 to 40 shoot tips.	up to 5.0 7.0–7.2 7.3 7.4 7.5–7.9 8.0–8.6 8.7–8.9 9.0–9.1	Vegetative Early fruit enlargement/ Shuck Fall Mid fruit enlargement Mid fruit enlargement Stone Hardening Fruit Maturation Ripe Fruit for Harvest Post-harvest
Prunus spp. fruit	Sample at growth stages 7.2–7.9 (fruit 20% to full size) through to preharvest. It is recommended to sample fruit at the same time as shoots.	Whole fruit are selected from around the whole tree (at least 20 representative trees). Stems may be left to prevent 'bleeding' e.g. for cherries.	At least 40 young fruit and 20-30 mature fruit.	7.0 –7.2 7.3 –7.4 7.5 –7.6 7.7–7.9. 8.0 – 8.8 8.9	Early fruit development Early-mid fruit Early stone hardening Late stone hardening; 70%–90% final fruit size Fruit maturation, pre-harvest Harvest

Crop name	Suggested timing of sampling	Plant part needed	quantity required	Growth stages (BBCH) required for interpretation of results	
Pome fruit spp. – vegetative growth	Begin sampling at fruit set (or earlier to check remobilisation of reserves), then take three samples during fruit development at equal weeks apart. Sample again at harvest and take a final sample post-harvest to monitor any post-harvest application.	Collect at least 10 cm of new shoot tips from current season's growth at mid crown height (or shoulder height for large trees). Sample from the same trees for subsequent sampling.	At least 20 shoot tips.	3.1–3.9 5.3 6.9 7.1 7.2 7.3 7.4 7.5 8.1 8.7	Shoot development Open cluster End of flowering Fruit development (10mm) Fruit development (20mm) Second fruit fall (30mm) T-stage Fruit development (1/2 final size) Beginning of ripening Harvest maturity
Pome fruit spp. – fruit	Begin sampling at early as GS 7.1 (10 mm fruitlets) through to harvest (to determine storage capacity).	Send whole fruit (not halved) in secure plastic bags. Be aware of bruising and loss of juice when packing.	Representative number of fruit per sample e.g. 10+ apples, more for smaller / younger fruitlets.	7.1 7.2 7.4 7.5 8.1 8.5 8.7 9.1	Fruit size up to 10 mm Fruit size up to 20 mm Fruit size 40 mm, T stage Fruit half final size Beginning of ripening Advanced ripening Fruit ripe for harvest Post-harvest
Avocado	Begin sampling before or by fruit set. A second sample should be taken by 2nd fruit drop (7.1). Nutrition should be monitored during fruit growth by taking three samples at equal weeks apart. A final sample should be taken at harvest to determine post-harvest applications.	Collect either 15 cm of fresh shoot tips, or full leaves with the entire leaf petiole intact.	20 shoot tips, each 15cm long; or 40+ leaves.	5 6 6.9 7.1 7.5 8 8.5 9	Pre Flower Fruit set 1st Fruit drop 2nd Fruit drop Fruit sizing Fruit fill Harvest Dormant
Banana	Sample at stage 4.9 (sucker development), then at 6.5 and again at 7.0.	Collect 15 cm of midrib from where the leaf blade begins on the 3rd leaf from the top of the main plant, counting the youngest still furled leaf as the first.	10 leaf midribs.	4.9 6.5 7	Development of the suckers Fruit sizing Fruit fill

Crop name	Suggested timing of sampling	Plant part needed	quantity required	Growth stages (BBCH) required for interpretation of results	
Grains and other Monocotyledons	Sample 7–10 days prior to intended fertiliser applications, e.g. at tillering (21–29), stem elongation (30–34), and/or booting stages (37–49).	Select whole plants from a 1–2 ha representative area of the crop. Retain the entire top of the plant before tillering, or 10cm of the basal plant part; remove all roots prior to postage to avoid soil contaminating.	50–100 plants, with roots removed.	12 to 15 21–29 30–34 37–49	5 or more leaves Tillering 21–29 Stem elongation 30–34 Booting 37–49
Herbs	Sample as required. Sampling early in a crop's life gives a better chance of correcting deficiencies and maintaining good nutrient levels and balances	Collect one stem or side shoot per plant; select a stem or side shoot with young, but fully expanded leaves. Discard the leaves and retain the stems or shoots for analysis. OR, depending on growth habit, select the YFEL and retain petiole for analysis.	30 –100 stems, side shoots, or petioles, (if individual pieces are 5 cm or longer, 30 pieces are sufficient).	Mostly unknown	Use BBCH principle growth stages as a guide
Amaranthaceae, subfamily Betoideae e.g. beetroot, silverbeet	Commence sampling by stage 3.3, and sample fortnightly until stage 4.5. Alternatively, sample 1 week prior to intended fertiliser applications.	Take the first fully expanded leaf, usually the fourth or fifth leaf out from the growing point of the plant. Discard the leaf blades and retain the petiole (leaf stalk) for analysis.	Minimum of 30 petioles.	1.4 3.3 3.9 4.2 4.5 4.9	Seedling 30% crop cover/plant size 90% crop cover/plant size Bulb 20% of final size Bulb 50% of final size Harvest
Rubus spp. plant	Begin sampling once in full leaf, and monitor fortnightly or as required until harvest begins.	Take sample from main stems, taking the first fully expanded trifoliate leaves from a representative area of the planting. Collect as much of the petiole as possible, and strip leaf blade carefully.	Minimum of 50 trifoliate leaves, retaining the leaf stalk.	5 5.5 6.1 7.1 7.5 8 8.5 9	Flower buds visible Mid inflorescence emergence Early flowering Early fruit development 50% fruit formed Early harvest Mid harvest Post-harvest

Crop name	Suggested timing of sampling	Plant part needed	quantity required	Growth stages (BBCH) required for interpretation of results	
Blueberry plant	Begin sampling at early fruit set; take three samples during fruit development. Diagnostic sample may be taken at any time. Use the shoot and fruit development stages as a guide.	Collect 10 cm of new shoot growth (tip) at mid bush height. Sample the same plants or at least from the same area for subsequent sampling.	25–30 shoot tips.	3.1 6.5 6.9 7.2 7.5 7.7 8.1 8.5 9.1	Early shoot development Mid flowering All petals fallen, end of flowering Fruit size up to 20% of final size Fruit about half final size Fruit about 70% of final size Beginning of ripening, pink fruit 50% fruit harvested Post-harvest, foliage still fully green
Legume spp.	Sample as required. Note our available data range are limited.	Select the youngest fully expanded leaf and strip leaf blades, retaining the petioles. For seedlings, send entire plants. Remove the leaf blade, retaining the midrib petiole for analysis. Remove roots from seedlings.	40–50 plants; If sampling large plants the volume may be reduced to 20–30 plants.	3.3 3.6 5–5.9 6–6.5-6.9 7 -7.9 9	3 Visibly extended internodes 6 Visibly extended internodes Flower Budding First flower buds visible outside leaves over mid to late flowering Pod development Harvest
Brassica spp.	Begin sampling by stage 2.2 (vegetative) and continue until 30% or 50% of the expected head/ sprout size is reached (stage 4.3 or 4.5) at fortnightly intervals. If not fortnightly, sample a minimum of 3 times between stages 2.2 & 4.3.	Collect 1 leaf per plant from a representative area of the crop. Select the youngest fully expanded leaf (YFEL), usually the tallest leaf in young plants. Strip the leaf matter away leaving the petiole and midrib for analysis.	20-30 petioles from 20-30 plants	1.6-1.9 2 – 2.3 2.4 3.5 3.8 4.1 4.3 4.5 4.7 4.9	Leaf development (6-9 leaves) Late vegetative Head initiation (e.g. broccoli, cauliflower, cabbage) Main stem elongation Budding (e.g. B. sprouts) Buttoning, early head, early sprout 30% final frame/head/ sprout size 50% final frame/head/ sprout size 70% final frame/head/ sprout size Harvest/head/sprout tightly closed
Pastures, turf, grasses general	As required.	Collect fresh grass above ground parts only as would be grazed.	Select 20-30 random sites across the sampling area	Record relevant maturity indicator	Unknown

Crop name	Suggested timing of sampling	Plant part needed	quantity required	Growth stages (BBCH) required for interpretation of results	
Fruiting solanaceous crops (tomato, capsicum, eggplant)	Begin sampling at stage 2.1 (vegetative) and monitor every 10–14 days until stage 7.7 or as required.	Collect 1 leaf per plant, select the youngest fully expanded leaf (YFEL), usually the forth leaf from the top, from actively growing plants. If leaves are very small, collect young side shoots or a greater number of leaves. Record the latest growth stage i.e. if a plant is still flowering but has developed first fruit, the growth stage is early fruit development.	50 petioles (if plants are very small, more than 50 petioles or young side shoots may be collected).	2.1 5.1 6.1 6.7 7.3 7.7 8.5 8.9	Vegetative growth Inflorescence emergence Early flowering Late Flowering Early fruit development Late fruit development Early harvest Late harvest
Flowers (excluding bulb flowers)	Begin sampling at early vegetative stage, and go to stage 5.2 (mid bud development).	Select 5-10 cm long new growing tips or side shoots from representative plants (1 per plant). Remove the leaflets and retain the shoot tip for analysis.	Collect 30–50 shoot tips.	1 1.1 1.3 5.0 5.2	Establishment Early vegetative growth Late vegetative growth Bud development starts Mid bud development
Root vegetable tops (carrot, parsnip etc)	Begin sampling at stage 1.5 (vegetative growth), continue fortnightly until stage 4.6.	Send entire tops of young plants up to stage 1.8. Later, the root and leaflets should be removed, retaining the centre petioles and stalks for testing	30 plants for stage 1, later 20 plants.. A representative number of roots are required, at least 10-12 past GS 4.2	1.5 1.8 4.2 4.4 4.5 4.6 4.7 4.8	5th true leaf unfolded 8th true leaf unfolded 20% expected root diameter 40% expected root diameter 50% expected root diameter 60% expected root diameter 70% expected root diameter 80% expected root diameter
Root vegetable roots (carrot, parsnip etc)	As required when root development has commenced.	Whole roots with no top. Please ensure roots are cleaned to remove any soil contamination. Collect 15–20 roots, making sure all dirt has been wiped clean.	15-30 young roots, minimum of 8 mature roots per sample.	4.2 4.5 4.6 4.8	20% expected root diameter 50% expected root diameter 60% expected root diameter 80% expected root diameter

Crop name	Suggested timing of sampling	Plant part needed	quantity required	Growth stages (BBCH) required for interpretation of results	
Citrus tree	Begin sampling at pre bloom, take a second sample at flowering. Take four samples at equal distance apart during the fruit growth stage. Take a final sample at harvest.	Collect 10 cm of new shoot tips from current season's growth at mid crown height (or shoulder height for large trees). Sample from the same trees for subsequent sampling.	20–25 shoot tips.	5 6 7.1 7.4 7.9 8.9	Inflorescence emerge Flowering Fruit development Fruit development Fruit development Fruit ripening
Citrus fruit	Fruitlets should be collected from stage 7.4 through to harvest. Valuable data is obtained when sampling fruit at the same time as shoots.	Fruitlets from a consistent position per tree from representative trees.	20 fruitlets. The quantity should remain constant when repeat sampling.	7.4 7.9	Fruit Set Fruit Set
Cotton	Sample at 14 day intervals, from as early as the unfolding of the seventh or eighth leaf (1.7 or 1.8) through to 1 week prior to the final fertiliser application or cutout.	From randomly selected plants, collect the youngest fully expanded leaf (YFL), which generally is on the fourth or fifth node below the terminal. Discard the leaf blade and retain the petioles for analysis.	50–80 petioles, depending on the growth stage (more when younger).	2.1–2.8 2.9 3.1–3.9 5.1 6.1 6.5 7.2 8.1	Veg growth (formation of side shoots) Veg growth (9 or more side shoots) Crop cover (plants meet between rows) Bud development (pin-head square) Early flowering (early bloom) Full flowering (mid bloom) 20% of bolls final size Start of boll opening (NAWF)
Head lettuce	Begin sampling at stage 1.8, follow with a second sample at stage 4.1, and a final sample at 4.5 (mid heart development) Sample more frequently, if imbalances have to be corrected.	Remove the YFEL (usually the leaf wrapping the head). Remove the leaf blade, retaining the petiole and midrib for analysis.	At least 20 leaves, more if plants are young/small.	1.5 1.8 4.1 4.3 4.5 4.7	Leaf Development Leaf Development Early Heart Early-mid Heart Mid Heart Pre Harvest
Cucurbita spp (e.g. cucumber, pumpkin, zucchini, melon)	Begin sampling at stage 1.5 and continue fortnightly or until stage 7.1.	Select the youngest fully expanded leaf (YFEL), usually the 4th or 5th leaf back from the growing tip of the plant).	20–40 petioles (depending on size). Remove leaf blade and retain the petiole for analysis.	1.5 1.9 6.1 7.1	Vegetative Vegetative Flowering Fruit Growth

Crop name	Suggested timing of sampling	Plant part needed	quantity required	Growth stages (BBCH) required for interpretation of results	
Flower – generic	Begin sampling at stage 1.3 late vegetative) and go to stage 6.5 (mid flowering).	Collect the YFEL or a 10cm long new growing tip (1 leaf or shoot tip per plant). Remove the leave blades or leaflets and retain the petiole or shoot tip for analysis.	50–100 leaves or 30–50 shoot tips depending on flower type.	1 1.1 1.3 5.5 6.5 8.5	Establishment Early vegetative Late vegetative Mid bud development Mid flowering Full Flower
Bulb flowers	As required.	Whole plants from above the ground for young or small plants.	Sample 15-20 plants.	1 1.1 1.3 5.5 6.5 8.3 8.4 8.5	Establishment Early vegetative Late vegetative Mid bud development Mid flowering Daughter bulb sized up and white Daughter Bulb Sized up and 50% Coloured Bulbs Mature
Allium spp	Begin sampling at stage 1.3 (3 – 4 leaf) and continue at fortnightly intervals or as required through to stage 4.6.	Retain whole young plants (remove roots). For older plants remove the tips of leaves and the bulb, retaining 10 - 20 cm of plant collar above the bulb. 'Bulking' refers to expansion of the base of leeks.	20–50 plants (more plants while small).	1.3 1.4 4.1 4.3 4.5 - 4.6 4.7- 4.9	Early Vegetative Early Vegetative Early bulbing (bulking) Early-Mid bulbing (bulking) Mid bulbing (bulking) Mid-Late bulbing (bulking)
Grape Berries – Generic	As required – A berry analysis will provide good information on nutrient translocation to the fruit	Berries on the stalk. Be aware that fruit may crush during transport and leak juice, affecting the analysis	Approx. 6 bunches or 10 –12 berries per vine from a representative number of vines.	8.1 8.3 8.5 8.9	Veraison Berries coloured Softening of berries Berries ripe for harvest
Grape Plant - Generic	Begin sampling as early as stage 1.5 (vegetative growth) and go to stage 8.9 (harvest). Sample 3–5 times.	Select the YFEL from healthy shoots at mid canopy. Once bunches have formed you may decide to collect leaves from opposite the basal bunch (bunch at the bottom of the cane) as well, or exclusively, to judge nutrient supply to berries.	Collect 30–50 petioles, discard all leaf blade prior to posting.	1.5 5.5 6.8 7.5 7.9 8.1 8.9	Vegetative Inflorescence swelling 80% Cap Fall Pea Sized Berries Bunch Closure Veraison Harvest Maturity

Crop name	Suggested timing of sampling	Plant part needed	quantity required	Growth stages (BBCH) required for interpretation of results	
Nuts	As required.	Collect 10 cm of new shoot tips from current season's growth at mid crown height (or shoulder height for large trees).	20 shoot tips, each 10–5cm long.	1 2 3 4	Vegetative Flowering Nut set & early development Nut expansion, pre-harvest
Kiwi fruit plant Passionfruit plant	Begin sampling by stage 5, and continue until stage 7.9 as required. Monitoring early in the season is important for setting up a good crop.	Select the youngest, fully expanded leaf (YFEL) including the entire petiole. Discard the leaf blade and retain the petiole for analysis.	80 petioles (if plants are very small, more than 80 petioles may have to be collected).	1 & 5 6.1–6.8 7.1–7.4 7.5–7.9	Vegetative & pre-flower Flowering Early fruit development Late fruit development
Baby leaf crops	Begin sampling from GS 1.5 as required, taking 2 – 4 samples throughout the crop (more frequently if imbalances need correcting).	Collect entire plants or the YFEL from randomly selected plants, depending on size. Remove the leaf blade, retaining the petiole and midrib for analysis.	20–50 leaves, depending on variety/size.	1.5 1.8 4.1 4.5 4.7	5 True Leaves True Leaves Harvest 1 Harvest 2 Harvest 3
Olive	Begin sampling at stage 3 (shoot growth), and continue through to stage 8.1 (late fruit growth) or as required.	Collect 20–30 cm of the new shoot tips from current season's growth at mid crown height (or shoulder height for large trees) from around the whole tree. Sample from a representative area of the grove.	100–150 shoot tips (the less succulent the shoots, the more tips are needed for the required amount of sap). Approx. 40 olives for fruit analysis.	3 5.1 6.1 6.9 7.1 8.1 Fruit	Shoots reach 30% of final size Early flower cluster development 10% of flowers open Fruit set Fruit about 10% of final size Beginning of fruit colour Fruit analysis
Pineapple	Begin sampling at 3 months, then every 2–3 months until fertiliser applications are finished.	Take the YFEL – usually the fourth or fifth leaf out from the centre of the crown (also the leaf that appears the tallest inside the crown). Retain the bottom part of the leaf (10–15cm) for analysis.	20–30 leaves, depending on size.	1 to 2 6 to 7	Vegetative Generative (flowering, fruiting)

Crop name	Suggested timing of sampling	Plant part needed	quantity required	Growth stages (BBCH) required for interpretation of results	
Potato	Begin sampling at stage 1.7 (vegetative, pre-tuber) and go to stage 4.6 (mid tuber bulking). Fortnightly sampling through tuber bulking is recommended.	Collect 1 leaf per plant; select the youngest fully expanded leaf (YFEL), usually the fourth leaf from the top. Discard the leaflets and retain the petioles for analysis. Collect samples from a representative area in the crop. Return to the same area for subsequent samples.	20–30 petioles	.5 1.7 1.8 2.3 - 2.7 3.1 - 3.3 4.1 – 4.3 4.4 – 4.6 4.7 - 4.9	Emergence Pre-tuber Begin of tuber initiation Tuber set phases Tuber development phases Early tuber bulking phases Mid tuber bulking phases Late tuber bulking phases
Potato tuber	At harvest.	Whole tubers.	10–12 tubers, more if small	8.9	At harvest
Strawberry	Begin sampling at stage 1.9 (new leaves) and continue through to harvest as required.	Select the youngest fully expanded leaves (YFEL) from 40–50 plants from a representative portion of the crop. Retain as much petioles as possible, and discard the leaves, retainning the leaf stalk/ petiole for analysis.	40–50 petioles initially, less as older plants are sampled.	1.7 1.9 5.5 6.5 6.7 6.9 7.3 8.1 8.5 8.9	More than 7 leaves More than 9 leaves Trusses emerge 50% bloom Full bloom 90% Petal fall Seeds visible on young fruit First colour First fruit full colour Main harvest
Strawberry fruit	As required.	Whole fruit with or without stems.	At least 15–20 pieces of fruit.	8.1 – 8.9 as required	N/A

Appendix 3 – Comparison between dry matter and sap analyses for nutrient management decisions

In plants, nutrients are present in two forms. Some are present as dissolved organic salts, which are raw materials necessary for further growth (the sap for the purpose of testing). Others have been assimilated by the plants and have become part of organic components such as proteins, chlorophyll and enzymes, or structural units such as cell walls (the 'tissue' for the purpose of testing).

Conventional dry matter analysis (dry tissue/ash) measures all nutrient elements, elemental forms 'raw' plus assimilated, within a sample. Therefore, dry tissue analysis provides an historical nutrition summary from the start of growth to sampling. Results are reported as grams per 100 grams (%) or milligrams per kilogram (ppm) of oven dry plant matter.

Sap analyses measure only 'the raw material', i.e., current nutrient uptake that is driving plant growth around the time of sampling. Sap test results are reported in milligrams per litre (ppm) of fresh plant sap.

Plant material contains varying amounts of sugar, starch, and cellulose. These carbohydrates do not contain plant nutrients, but they affect the weight of the dry matter sample. Dry matter analysis results are reported as a percentage of the dry matter weight. The practical effect of this is that dry matter results will show lower nutrient levels as the carbohydrate proportion in the tissue goes up. Lignin and cellulose content increases with plant age. That is why desirable nutrient levels in dry matter drop considerably during the growing season (Figure 8-1). This must be considered when taking samples and interpreting dry matter analysis results, i.e., results for a certain crop growth stage must be compared to the desirable nutrient level at that growth stage.
If a deficiency limits growth it takes time for a dry matter analysis to indicate this because a certain "background" level of accumulated nutrients is always measured. Either the sampled leaf or petiole must increase in weight, or the limiting nutrient must be translocated to other parts of the plant to clearly show changes in nutrient uptake. Both processes are slow. Excess is shown somewhat faster than deficiency as no growth or translocation processes are necessary.

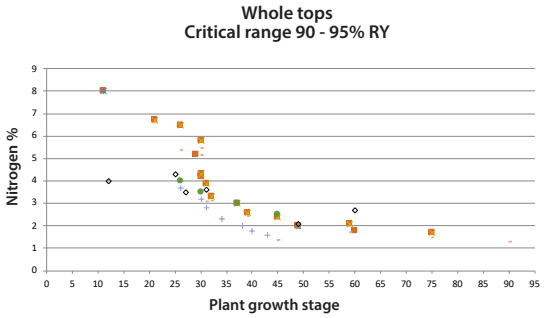

Figure 8-1. Change in dry matter nitrogen concentration (N %) of whole tops in a cereal crop across phenological stages (source C Dowling).

Sap analysis is not affected by the above-mentioned variations in carbohydrate content, but nutrient uptake levels may vary with plant utilisation, which, for some nutrients, changes with the physiological growth stage and time of day. As sap analysis only measures current nutrient uptake, environmental conditions, and plant stress (climatic and crop management factors) may have a greater impact on results than they have on dry matter analysis results. It is therefore important for agronomists and growers to consider multiple interactions between crop management (e.g., irrigation), climate, soil conditions (e.g., causing root growth restrictions) and nutrient uptake when interpreting sap analysis results. Results will alert agronomists and growers who are undertaking the monitoring if conditions have become unfavourable for a balanced nutrient supply to the crop.
Sap analysis measures only the current nutrient status of a crop. Both, deficiencies, and excesses are shown by the analysis within a short time of the change in uptake. Reaction to nutrient applications can be monitored effectively by sap analyses at defined growth stages. Because the testing is rapid (can be done on site using field testing equipment, or quickly in a laboratory) remedial action can be taken for the standing crop. The best example being

nitrate in petiole (xylem) sap. Australian researchers have calibrated sap nitrate at defined growth stages to yield for a range of crops and have published such work. In other publications sap nitrate testing has also been used to predict toxic levels of nitrate in ryegrass for grazing cattle and to predict not only the nitrogen status but when to initiate harvesting for flue cured tobacco. All these examples demonstrate that sap testing of petioles for nitrate is a better indicator of nitrogen status than total nitrogen in dried tissue. For an experienced user of the technology, the odds are high that a treatment has a predictable, positive effect on yield and quality. Nutrient uptake ratios give an insight into uptake conditions in the rootzone around the time of sampling. A sap brix test in addition to nutrients, gives information on the crop's carbohydrate production and thus energy level. Table 8-1 provides and overview of benefits and limitations of the analysis of plant sap analysis.

Table 8-1. Benefits and limitations of plant sap analysis.

Benefits	Limitations
Provides a consolidated summary of the total amount of nutrients being taken up by a plant	Does not reflect stores or re mobilisation of phloem non-or variably mobile nutrients e.g. Ca. Particularly important in perennials.
Reveals varietal differences in nutrient uptake	More prone to rapid and significant variation due to changes in primary growth factors such as leaf water content which can mask the true nutrient supply status.
Is a tool to adjust fertilisation strategies accurately and quickly	Best used as a regular monitoring tool so repeated sampling in a production cycle is required to understand trends.
Makes it possible to optimise nutritional status to improve natural disease resistance	
Reveals a nutrient deficiency in an early stage	
Gives the opportunity to fine-tune fertiliser application for optimal production	
Can be more directly related to the fertigation solution composition if samples of both are taken at the same time.	
Fast turnaround as samples do not need to be dried	

Appendix 4 – New and other technologies including in field analyses

Near Infrared Reflectance (NIR), Mid Infrared Reflectance (MIR)

NIR (Near Infrared Reflectance) and MIR (Mid Infrared Reflectance) technologies are non-destructive methods to detect plant chemical concentration using reflectance or absorption of a single or range of light wavelengths. These technologies can be applied from across a range of scales, benchtop (single sample), proximal (hand-held field scanner) to remote (satellite). NIR and MIR measurement outputs need to be calibrated against known nutrient levels in an identical matrix.

Where the intensity of reflectance or absorbance of wavelengths are strongly correlated to plant nutrient concentrations (calibrations), these low-cost non-destructive methods potentially could be used as surrogates for traditional chemical extraction methods if accurate and stable calibrations with current methods can be established. Vegetation interacts with solar radiation in a different way than other natural materials. The vegetation spectrum (Figure 8-2) typically absorbs in the red and blue wavelengths, reflects in the green wavelength, strongly reflects in the near infrared (NIR) wavelength, and displays strong absorption features in wavelengths where atmospheric water is present. Different plant materials, water content, pigment, carbon content, nitrogen content, and other properties cause further variation across the spectrum. Measuring these variations and studying their relationship to one another can provide meaningful information about plant health, water content, environmental stress, and other important characteristics. These relationships are often described as vegetation indices (VIs).

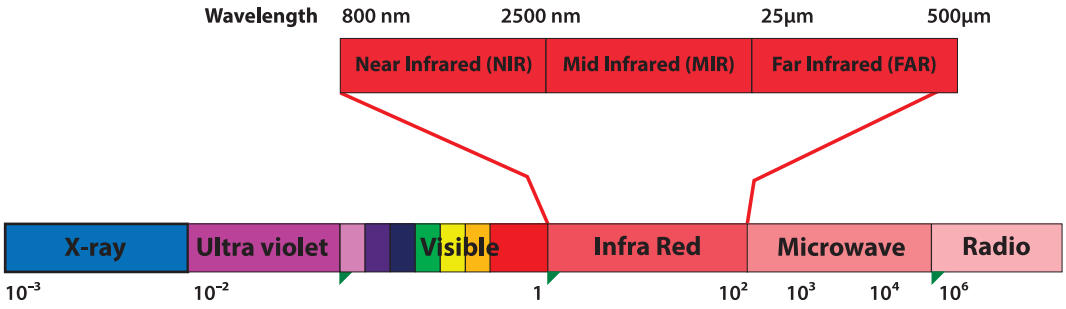

Figure 8-2. Electromagnetic spectrum

Figure 8-3 provides an overview over the vegetation spectrum and the type of information it provides.

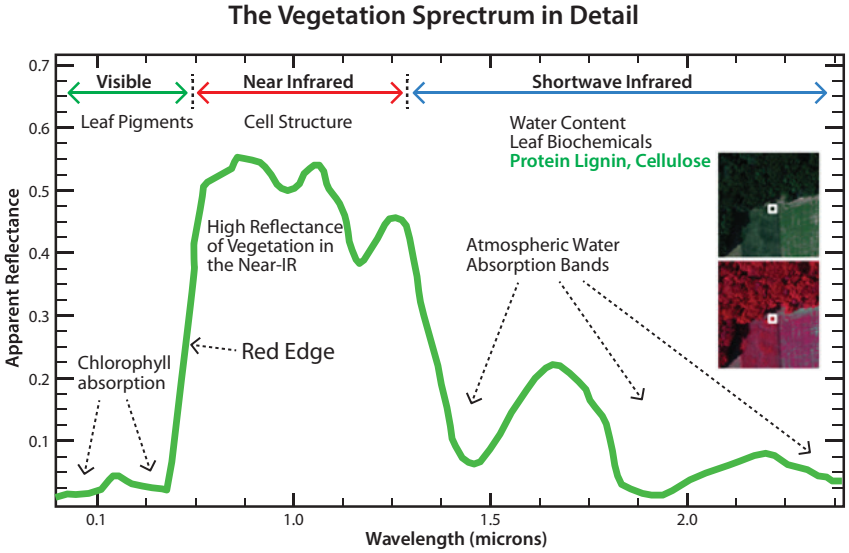

Figure 8-3. Vegetation spectrum details (accessed 05/05/2021, https://www.l3harrisgeospatial.com/Learn/Whitepapers/Whitepaper-Detail/ArtMID/17811/ArticleID/16162/Vegetation-Analysis-Using-Vegetation-Indices-in-ENVI)

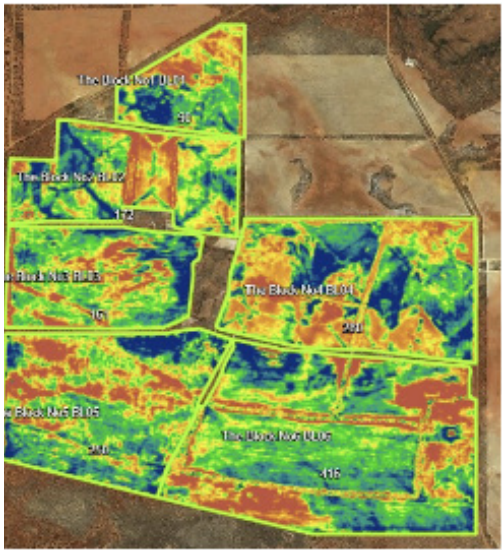

Figure 8-4. Paddock maps showing difference in vegetation / biomass via Normalized Difference Vegetation Index (NDVI)

Red Edge Normalized Difference Vegetation Index (NDVI705) is a modification of the broadband NDVI. It is intended for use with very high spectral resolution reflectance data, such as data from hyperspectral sensors. The NDVI705 differs from the NDVI by using bands along the red edge, instead of the main absorption and reflectance peaks. The NDVI705 capitalizes on the sensitivity of the vegetation red edge to small changes in canopy foliage content, gap fraction, and senescence. Applications include precision agriculture, forest monitoring, and vegetation stress detection based on:

NDVI705 = (750nm - 705nm) / (750nm + 705nm)

The values of this index range from -1 to 1. The common range for green vegetation is

In field analyses

In field analysis of nutrient content of plants is available for a limited range of nutrients, generally N and K via measurement of sap nutrient concentration and indirect measurement using electronic devices that measure absorbance or reflectance of light from a leaf or canopy.

In field analysis tools provide a quick overview of plant status but are likely to be less reliable and repeatable compared to laboratory methods because of uncontrolled variables such as often ad hoc sampling of a small number of plant parts, sap extraction and contamination, lack of filtration, dilution accuracy (if diluted), poor calibration, temperature, humidity, and ion interference in the case of specific ion meters, as well as calibration stability and chlorophyll density variation in leaves for instruments measuring chlorophyll density. The technology in handheld meters is primitive compared to the methods and state of the art technology used in laboratories.

When using field testing equipment it is important not to rely on the calibration done by the manufacturer. Just as laboratory equipment that costs hundreds of thousands of dollars needs to be calibrated before running samples, these quick tests need to be calibrated against standard solutions before running samples.

Figure 8-5 provides images of a limited number of examples for field-based instruments SPAD 502 - chlorophyll density (Minolta), Cardy Nitrate meter – sap nitrate (Horiba), Greenseeker – NDVI (Trimble) and Merck Reflectoquant ® (Merck)

Figure 8-5. Some examples of field-based instruments (left to right): SPAD 502 - chlorophyll density (Minolta), Cardy Nitrate meter – sap nitrate (Horiba), Greenseeker – NDVI (Trimble), Merck Reflectoquant ® spectrophotometer (Merck KGaA)

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    - Australian Precision Ag Laboratory (APAL) - https://www.apal.com.au/PlantSamplingInstructions.aspx
    - Back Paddock (BPC) - Environmental Analysis Laboratory (EAL)- https://www.scu.edu.au/media/scueduau/eal/submissions/Plant-and-leaf-sampling-guide74d8.pdf
    - Hortus Analytical, a division of Novum Lifesciences - https://www.novumlifesciences.com.au/sap-sampling-guide/
    - Nutrient Advantage Laboratory (NAAL) - https://www.nutrientadvantage.com.au/~/media/Files/NA/Sampling/Sampling%20Procedure%20-%20Plant%20Tissue.pdf
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