A guide for 'fit for purpose' soil sampling

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Contents

1. Purpose

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

2. Introduction

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

Soil testing and plant analysis are invaluable tools to diagnose constraints to crop and pasture production. Fertiliser recommendations for agriculture require supporting soil and plant chemical analysis and interpretation, underpinned by samples that represent the relevant soil environment.

Soils are inherently variable. Natural soil variations result from soil parent material, topography, climate, hydrology, weathering and biological processes. Variability occurs horizontally and vertically, from the micro- to the macro-scale. Soil nutrient variations can be caused by animal management, tillage, drainage, crop removal and fertiliser and ameliorant inputs. Vertical variation can be associated with natural or induced soil horizon differences (erosion/deposition), nutrient mobility, waterlogging, mechanical disruption and nutrient placement. Variation can also occur temporally; between years, between seasons or more rapidly from applied fertiliser or animal manure.

Agricultural systems and technology continue to change and diversify. Minimum tillage, deep soil amendment, row cropping, raised beds, precision nutrient and ameliorant placement, and variable rate applications, all impact on soil conditions and nutrient availability within the root zone. Nutrient additions now also commonly involve organic, liquid and granular forms.

Technology now allows for real-time access to imagery, capture of geo-coordinates, and upload of field and meta-data. Sampling equipment continues to advance with the availability of power-driven sampling tools, reducing labour requirements so more samples can be taken and enabling deeper soil profile sampling.

Additionally, there is an increasing opportunity and need to link sampling protocols and fertiliser recommendations with the risk of nutrient loss and environmental pollution.

Collecting a representative soil sample is essential to meaningful soil analysis. Many of the differences in soil test results and ultimately in divergent fertiliser recommendations, can be traced back to sampling errors or varied sampling approaches, so it is essential to reduce errors by getting the sampling process right.

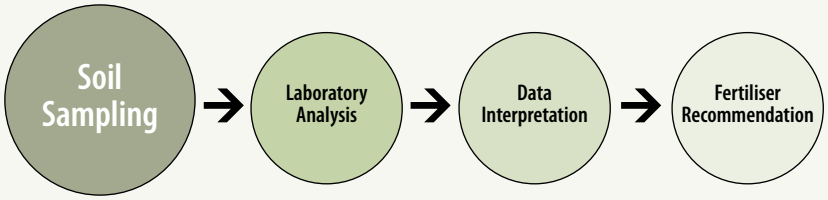

Figure 1. Accurate soil sampling is an important first step in a wholistic, four-part fertiliser recommendation process.

The importance of accurately collecting a representative sample (Figure 1) is highlighted by the fact that the dispatched sample to the laboratory represents around 0.00001% of the field soil being assessed (Figure 2).

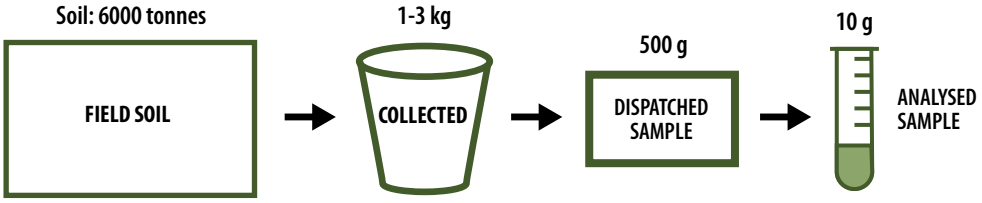

Figure 2. Field, collected, dispatched and analysised soil amounts.

Accuracy and reliability in soil test results.

In selecting a laboratory service provider, the following factors need to be considered and confirmed:

i. Participation in independent laboratory proficiency testing programs, whereby common homogeneous samples are sent for analysis to laboratories. The Australasian Soil and Plant Analysis Council (ASPAC) conducts the Proficiency Testing Programs for Australian laboratories. ASPAC publishes certification of test competence for all participating laboratories in the program triennially, so comparisons against the means and medians are available. Laboratories are certified for particular test analytes if their results meet the qualifying criteria, with their annual certification status updated on the ASPAC website.

ii. The use of recognised analytical methods which generate results that can be interpreted for Australian conditions, published interpretation data and/or historical records,

iii. Presence of a Quality Control system, by way of internally-driven procedures or by verification to the AS/ISO 17025 standard through an authority such as the National Association of Testing Authorities (NATA).

The comparative role of soil and plant analysis. Soil analysis measures nutrients and physio-chemical parameters in the soil. These measures indirectly predict how plant growth and product quality will respond to additional nutrient supply throughout a growing season. Plant analysis directly measures nutrient concentrations in living plant tissue, with interpretation specific to the plant growth stage. 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 by the plants. If there is some discrepancy between soil nutrient status and plant nutrient content, it may be necessary to investigate factors that can affect nutrient availability and uptake e.g. root diseases, herbicide damage, and water relations.

3. Why collect soil samples?

Soils are analysised for a variety of reasons including describing their inherent chemical, physical and biological properties, matching specific plant species and cultivars with soil characteristics, assessing organic and inorganic contaiminants and accumulation, determining nutrient availability, monitoring changes due to inputs and management and assessing environmental risk.

The reasons for soil sampling can be grouped into four categories:

- Predictive (which nutrients do I need and how much?),
- Monitoring (have my soil nutrient concentrations changed over time?),
- Diagnostic (is a soil chemical parameter causing spatial differences in my crop or pasture growth?), and
- Compliance (do my soils meet required environmental standards?).

> ***Clearly defining the reasons why sampling is undertaken is essential when developing a sampling plan.*** "What is the question your client wants answered? If you don't know, don't sample until you do". Clearly defining why you are sampling will guide your 'fit for purpose' soil sampling.

In some cases, there may be multiple purposes in mind when collecting soil samples from a farm; a combination of predictive, monitoring, diagnostic and compliance sampling may need to be implemented.

Predictive sampling aims to assess nutrient availability and chemical constraints in the root environment for a current or proposed crop or pasture type. Usually undertaken at a block or paddock scale, with little if any previous information. Soil-test results are bench-marked against interpretation guidelines (i.e. Better Fertiliser Decisions for Cropping and Pastures) and used to predict soil constraints to plant growth and likely responses to fertiliser and soil ameliorant additions. Predictive sampling requires an understanding of the current farm-system and management practices, so that the soil fertility and chemical conditions of specific paddocks or blocks can be described, and inputs determined.

Monitoring aims to assess trends in soil nutrient levels over time. Changes in soil test information between seasons and cropping cycles, in association with soil fertility targets, are used to develop and refine site-specific fertiliser and ameliorant additions. A monitoring program requires:

- ongoing consistency of sampling methods, minimising factors that may account for variations in soil fertility and chemical conditions
- the establishment and reuse of specific sampling locations that represent the key crop system and soil types
- sample collection in the same way, at the same depth, at the same time off year, with analysis derived from the same laboratory
- consideration of atypical variations in seasonal and climatic conditions. For example, it may be necessary to avoid sampling after extended dry spells.

Diagnostic sampling is reactive and aims to provide site-specific soil chemical data to help explain an earlier observed crop or pasture production outcome. Areas of 'poor and better' crop or pasture growth within management zones or paddock should be sampled at multiple depths to help define differences in soil nutrient supply and/or the incidence of soil limitations such as soil acidity, alkalinity, salinity, sodicity, and in low-lying coastal areas – acid sulphate soils.

Compliance sampling aims to provide soil analytical data to aid environmental and/or human health risk assessment. This may include benchmarking soil analytical results against national or international thresholds for heavy metal contamination (i.e. cadmium, lead, arsenic). Soil salinity / sodicity / nutrient levels may be assessed to contribute to design of programs for land application of wastewater. Increasingly, existing phosphorus and nitrogen soil fertility status is used as a justification to limit fertiliser inputs to land in environmentally sensitive catchments.

Soil fertility and chemical condition mapping allows translation of soil test results into a visual representation of fertility and chemical conditions across the farm and highlights between-paddock or block variability (Figure 3). Mapping soil test results allows for a quick visualisation of variability within the farm and highlights areas where nutrient inputs should be curtailed or increased. Mapping of soil test results across the farm is also useful in defining nutrient transfers such as regular forage harvesting, animal feeding areas and application of manure/effluent, or identifying the risk of metabolic problems in livestock.

Different colour schemes, depending on the context, may be used to correspond to soil nutrient status and targets (i.e. very high, high, adequate, marginal and deficient). Paddocks or blocks are then colour coded based on soil test results. Soil pH and salinity maps similarly determined are useful for targeted soil amendment decisions such as lime and gypsum.

Soil chemical, physical and biological conditions can vary substantially within larger paddocks, with different production potentials or management requirements present (Figure 4). Tools that integrate soil chemical, physical and biological conditions through plant responses can enable targeted inputs that aim to optimize production potential at a sub-paddock scale and is termed 'Precision agriculture'.

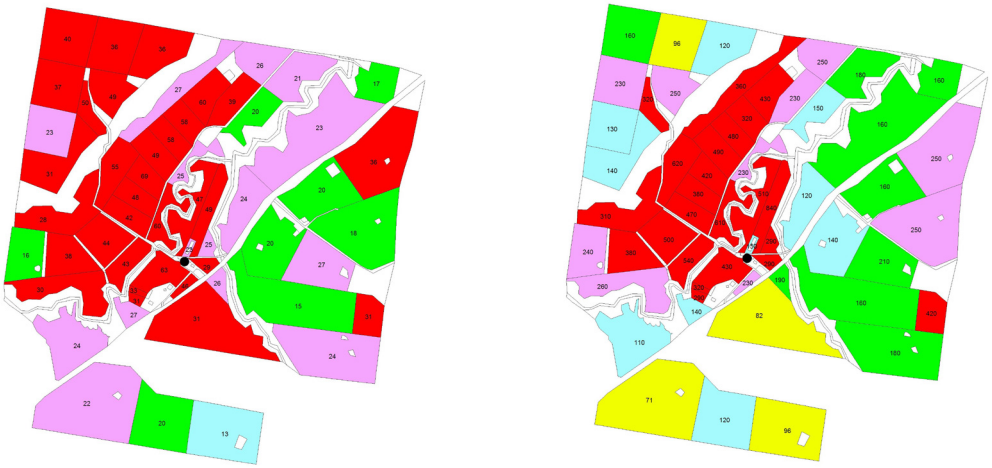

Figure 3. A nutrient map on an Australian dairy farm for Olsen P (left) and Colwell K (right). Red indicates very high, blue is high, green is adequate, orange is marginal and yellow is deficient nutrient P or K availability. The dot represents the location of the dairy shed. Source: Gourley et al (2007).

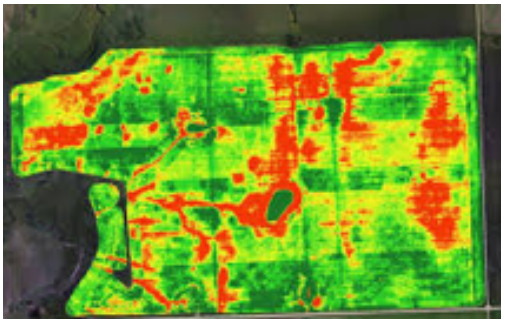

Figure 4. A satellite near infra-red (NIR) image of a farm, with colour changes highlighting increasing crop density (red is low, dark green is high).

4. When to sample

Sampling must be conducted at a time that allows for analysis of the sample and its interpretation in advance of the time for recommended treatment. In most situations, this will be at least 4 weeks before fertiliser is to be applied. Where acidity, salinity (salt) or sodicity (poor soil structure) is expected to be a problem, soil analysis is recommended several (3 - 4) months prior to planting to provide time for lime or gypsum to be applied and take effect.

Wherever possible, sampling must be separated in time from the application of fertiliser or soil amendments. If this is not possible, it may be necessary to adjust sampling protocols to ensure that variability introduced by fertiliser application is accounted for, and a representative sample is collected (see Section 6.3).

5. Selecting areas to sample within the farm

Before commencing sampling, it is important that a farm specific 'sampling map' be developed. Sampling locations within an individual farm must consider the purpose of sample collection, current crops and growth stages, previous cropping history, yield and quality objectives, tillage practices, soil types, drainage, topography and potential environmental risks from nutrient loss.

5.1 Farm level sampling strategies

There are a range of strategies that can be used when soil sampling a farm (Table 1). The most comprehensive and ideal sampling strategy is to sample every paddock or even sub-paddock areas, every year to support an evidence-based approach to fertiliser decision making. Other options include cycling around the farm over a 3 - 4 year period until the whole farm is completed, selecting 'typical or representative' paddocks, or bulking samples that have similar characteristics.

The strategy used should address the sampling purpose and consider the cost of soil testing against the potential production benefits, savings in fertiliser, and costs to implement alternative approaches to fertiliser management.

Table 1. Differing farm level sampling strategies. More asterisks are better. Modified from Brown (1999).

Sampling strategy	Description	Comments	Preference
Complete monitoring/ farm cycling	Sample every paddock every year.	Provides comprehensive information. Costly and labour intensive to implement; may deliver the best returns.	****
Cycling	Selection of sampling areas representing a different third or quarter of total paddocks each year. Rotate annually until every paddock is sampled, then repeat	Allows for the complete coverage of all paddocks over 3 - 4 years. Not suitable if management and inputs are changing in paddocks yearly.	***
Representative	Selection of typical paddocks representing the range of conditions across the farm (e.g. soil type, topography, drainage, fertiliser inputs, crop history, yield performance). Sample every 1 - 3 years.	Most common sampling strategy. Good selection of paddocks is critical as results will be assumed to apply to other similar management areas. Need to review management and inputs annually.	**
Uniform spread	Bulked samples from areas that have similar conditions (e.g. soil type, topography, drainage, fertiliser inputs, crop history, yield performance), regardless of paddock boundaries. Used to composite paddock samples.	Enables bulked samples to be collected across the farm and provide broad-scale soil test results. Can mask spatial variability between areas and promote uniform rather than variable fertiliser management.	*

5.2 Aerial photographs and developing a farm map

An aerial photograph is a useful first step in creating a farm map that informs the sampling plan (Figure 5). In addition to detailed property and paddock boundaries and dimensions, infrastructure such as buildings, roads and laneways, gates and watering points should be identified. The farm map should also categorise bushland, hydrological characteristics such as waterways and gullies, flood plains, soaks and wetlands, and topographic characteristics (i.e. step-rises, sandy ridges, etc.). These physical features can greatly influence soil characteristics and management practices that in turn impact on soil test results. Knowledge of these features will also aid the sampler to identify how to get around the farm, specific paddocks or blocks, potential sampling hazards, and to pace sampling effort in a paddock to ensure a representative sample is collected.

With the ubiquity of mobile devices and Geographical Information Systems (GIS), aerial photography, satellite imagery and other coverages such as farm and paddock boundaries are often accessible both online and offline to assist with this task.

5.3 Accounting for soil types, landscapes, hydrology and topography

It is useful to know the locations and characteristics of specific soil types within a farm in order to make sound soil and fertiliser management decisions (Isbell, 1996). Soil properties such as soil structure, depth, texture, salinity, acidity, waterlogging or compaction can limit crop and pasture growth even when the soil has adequate nutrients. Changes in soil characteristics can also involve vertical stratification such as topsoil depth, structural impedance to root growth and drainage.

The wide variety of soil types present across our agricultural regions reflect differences in soil forming processes dictated by factors such as geology, landform, stream activity, vegetation, climate and the degree of weathering. Australian Soil Resource Information System (ASRIS) provides online access to the best publicly available information on soil and land resources in a consistent format across Australia.

Soil maps are useful in identifying and describing soil types (Figure 6). Regional soil maps can be used in combination with the farmer's existing knowledge of the farm soil types to produce a soil map at a paddock scale. At a broader scale, the use of on-line information such as the CSIRO SoilMapp App can provide useful soil descriptions.

Figure 5. Identify farm, paddocks, block boundaries

Figure 6. Farm boundary and identified differences in soil types across the farm.

5.4 Identifying paddock / block management practices

Paddocks or blocks that have differing management regimes (i.e. tillage, previous cropping histories, irrigation systems, fertiliser, ameliorants and by-product inputs), need to be identified and categorised. Similarly, areas with observed or measured yield performance differences should also be identified and categorised. Electromagnetic surveys may also assist with the identification of soil sampling zones.

In cropping systems, these differing regimes could include fertiliser application methods (banding, previous placement, broadcasting, fertigation, etc) and tillage methods (i.e. spading, raised beds, minimum tillage). In grazed pasture systems, these regimes may also include day and night paddocks, regular fodder harvesting, high feeding areas, effluent application areas and extensively managed run-off blocks. Within paddock differences can also be significant, caused by stock camps, access to water and shelter, gateways, and supplementary feeding locations.

5.5 Selecting representative paddocks / blocks for sampling

The number of areas selected to be sampled should recognise the diversity of groups identified and the purpose behind the sampling process. Setting up a simple matrix based on a paddock or block identification (identifier) matched against defined management practices (i.e. production potential, soil type, previous inputs, etc.) can assist in grouping paddocks and identifying representative areas to sample. For paddocks or blocks with the same soil types, and that have a similar management regime, an individual or group of paddocks with an average productivity can be selected to represent the rest of the paddocks or blocks in that group (Figure 7).

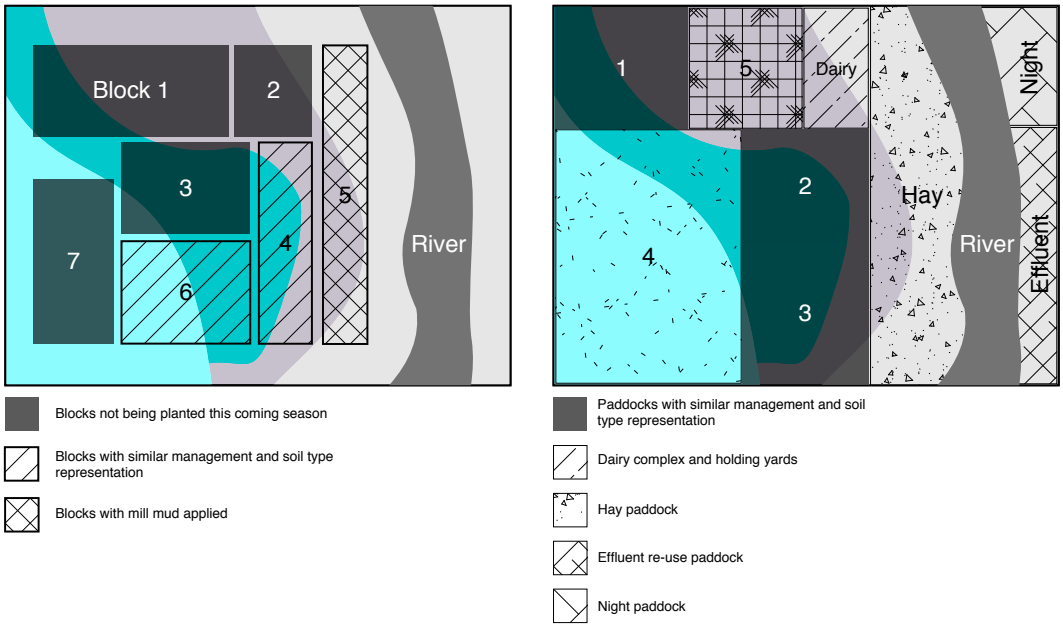

Figure 7. Example of categorising (for soil sampling) sugar cane blocks (left) or pasture paddocks (right) with similar management regimes, overlying differing soil types. Labels indicate paddock or block names.

6. Procedure for collecting soil samples from selected paddocks/blocks

Irrespective of the crop, topography, management or region, the objective is to collect representative soil samples that are "fit for purpose" for the question being asked. In most cases this involves the collection of a representative composite soil sample consisting of a specific number of soil cores or sub samples, from a specified location, using a specific sampling pattern, at a specific depth, at a specific time.

Composite samples help to reduce costs and problems associated with spatial variation but should represent a homogenous population. Each core should contribute equally to the analysed subsample, with the objective of achieving an unbiased estimate of the mean value.

Soil test calibration experiments, which form the basis of defining plant response to fertiliser additions, rely on soil samples collected from defined locations, depths and other factors. It is therefore essential that soil sample collection reflects these established sampling criteria and is "representative" of the crop or pasture root environment.

6.1 Sampling approaches

With site-specific management being implemented on many farms, there is a growing need to characterize the variability in nutrient needs across the farm, often at a paddock or sub paddock level. Minimising variability within the sampling area by choosing the same soil type, cropping history and management can reduce the number of cores required for a representative composite sample. Where paddock variability is high, more cores are needed to adequately represent the paddock or blocks within a paddock (more details are provided in section 6.3).

The sampling approach should have an organized and systematic pattern to characterize the variability within the paddock.

Stratified sampling is the preferred systematic approach based on soil type, management history, etc. This may result in more than one composite sample collected per paddock or block (Figure 8).

Ultimately collected samples aim to be representative of the area the farmer aims to treat uniformly with fertilisers or soil amendments. In some cases, this may mean that only the dominant soil type or management zone within a paddock or block is sampled.

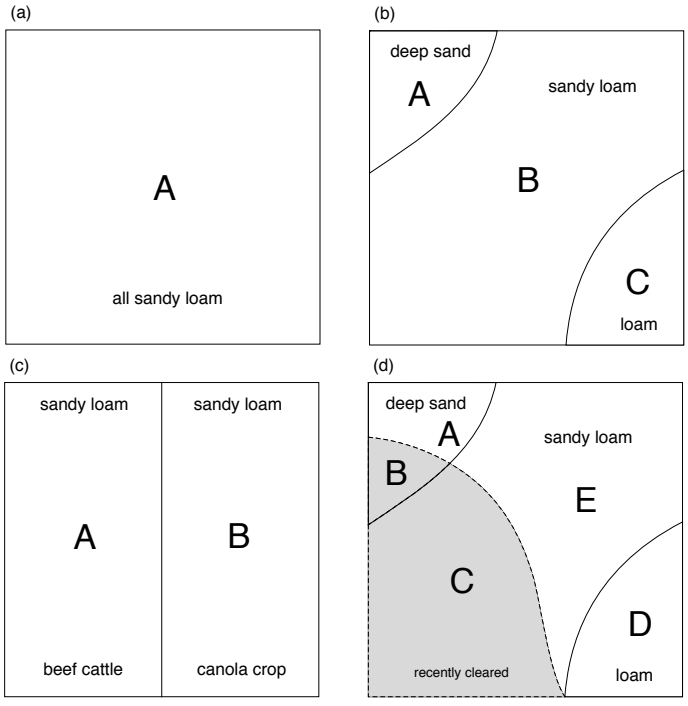

Figure 8. Refining potential sampling areas within a paddock/block based on different soil types and management history. Capital letters indicate that the stratified sampling approach would result in (a) 1 composite sample, (b) 3 composite samples, (c) 2 composite samples, (d) 5 composite samples within the paddock/block.

6.2 Areas to avoid

Areas to avoid should be considered in relation to the purpose or objective of sampling since it may be necessary to sample unusual areas in order to diagnose nutritional issues. Hence the following listed areas to avoid relate mainly to sampling for predictive or monitoring purposes, rather than diagnostic reasons.

Some areas to avoid are not always visible during the optimal sampling time, whereas others such as areas near gates and troughs may be clearly visible (Figure 9). For example, during summer, urine patches cannot be seen, and dung may have been incorporated into the soil by dung beetles.

If the objective is to obtain a representative sample for the purpose of determining fertiliser requirements, excluding high producing areas (such as urine and dung patches, cut and fill areas) would likely result in samples that are not representative of the entire paddock area.

Areas of a paddock to consider where there is a high likelihood of introducing variability in nutrients or other soil parameters include:

Visible areas

- Within 10 to 20 m of current and old fence lines
- Near gates
- Stock camps
- Feed trails and feed-out areas
- Stock tracks
- Dam sites
- Areas of differing drainage patterns and cut and fill areas.
- Near troughs
- Gilgai's or melon holes

Non-visible areas

- Areas where fertiliser or lime has previously been dumped
- Timber burns
- Headlands
- Corners of paddocks that have been cultivated or planted from the perimeter inwards
- Poorly drained areas
- Areas of poor growth or excessively good growth, e.g. dung and urine patches in crops or pastures during summer sampling.
- Areas of differing fertiliser usage including in the fertiliser band under the rows, tree canopies, or from non-uniform fertiliser spreading

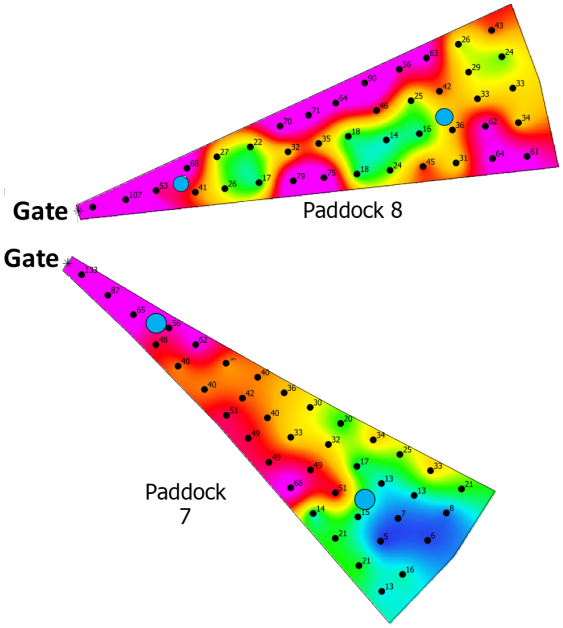

Figure 9. Spatial variability of Olsen P within a pasture paddock grazed by dairy cows. Colours: Purple extremely high, Red very high, Orange high, Yellow above optimum, Green optimum, Blue, very low. The blue dots represent the location of water troughs. Source: Cotching et al. 2019.

6.3 The correct number of soil cores to achieve a representative sample

Lateral and vertical variability of soil characteristics in combination with sampling patterns can significantly influence soil test results, so collecting an adequate number of cores to account for this variability is critical to achieving a representative sample. The number of cores required in a composite sample to be 95% confident that the mean value has a prespecified margin of error is shown in Figure 10 (Gilbert, 1987).

Paddocks with high variability require more cores for the same error than paddocks with low variability. Collecting the same number of cores 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 cores required would be ~40.

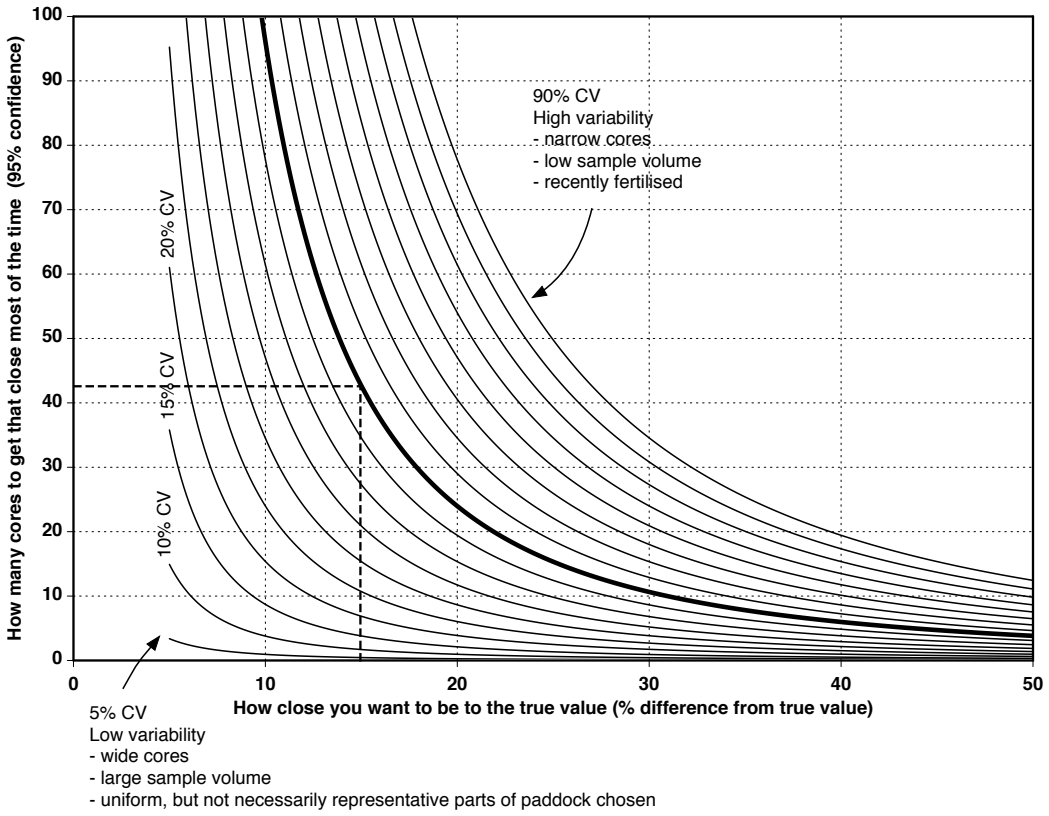

Figure 10. Number of cores required to be 95% confident that the collected sample has a specified % difference from the true value for situations of different variability. Figure developed using statistical procedures described by Gilbert (1987).

Creating a number of independent sampling areas within paddocks may reduce the variability between cores and therefore reduce the required number of cores 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.

It should also be recognised that variability is likely to decrease with increasing core diameter (Figure 11). This means fewer cores for large diameter samplers, and more cores for small diameter samplers. Irrespective of core diameter, this would result in a sample with a mass of around 1000 - 1500 grams, and pragmatic adjustment of the number of cores according to core diameter to achieve the same assumed variability.

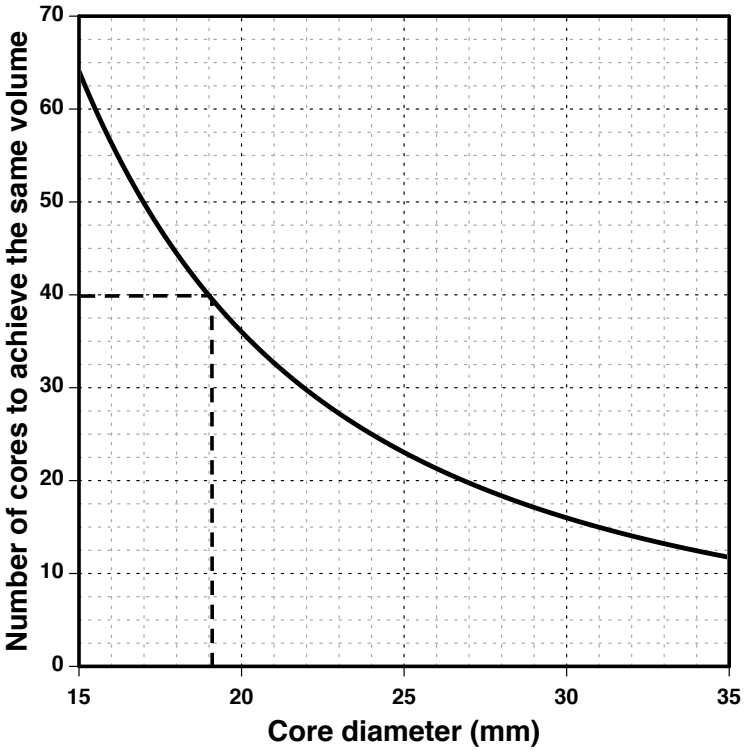

Figure 11. Number of soil cores required to achieve the same sampled area, volume and assumed variability as a standard 40 cores from a 19 mm diameter sample tube. Figure developed from first principles based on Brown (1999).

From a practical perspective, the number of cores should be around 30 - 40 for 19 mm diameter cores and 20 - 30 for 25 mm diameter cores (±15% error), whereas for lower variability samples, the number of cores may be reduced. Selecting an area of low variability in order to reduce the number of cores and sampling effort is not an appropriate approach when the overall objective is to collect a representative sample. Neither is the collection of one large sample from a single location an appropriate approach.

Table 2 provides general guidelines for the number of cores per composite sample from a paddock with "typical" variability based on a range of soil chemical attributes to be 95 % confident in achieving a result ±15 % of the mean (Figure 10). Whilst some soil analytes are less variable than others, in most cases samples are collected to determine multiple analytes. The analyte with the highest variability should therefore determine the number of cores to be collected.

The number of cores required for subsoil samples can be reduced as subsoils often show less variability (Figure 10) than surface soils. Reducing the number of subsoil cores is also a compromise for the additional effort required for deep samples.

Table 2. How many cores are enough for surface soils? (adapted from Brown 1999 and Figure 11).

Number of cores		Comments
19 mm tube	25 mm tube	
30 - 40	20 - 30	Suitable for all tests except where fertiliser or a soil amendment recently applied, fertiliser banded or high stocking rate.
60 - 80	40 - 60	Suitable for all tests where fertiliser or amendments have recently been applied.
>80	>60	Generally, no significant gain in precision unless the site has high variability.

6.4 Sampling pattern for selected area with no previous fertiliser banding

Once you have chosen your sampling approach, areas to avoid, and the number of cores to be collected for a composite sample, a sampling pattern needs to be selected (Figure 12; Table 3). Different sampling patterns have varying attributes that need to be considered depending on the purpose of sampling. For example, complete monitoring (Table 1) where every paddock is to be sampled each year is likely best sampled using transect, zigzag or possibly cluster patterns because of efficiency and the potential for automation of the sampling process.

Table 3. Paddock/block sampling patterns and attributes. More asterisks are better.

Pattern	Repeatability for monitoring †	Labour efficiency	Ability to automate	Likelihood of representative sample	Reducing risk of bias
Transect	*****	*****	*****	***	***
Zigzag	*****	****	*****	****	****
Cluster	*****	****	***	**	**
Uniform Grid	**	**	**	*****	*****
Random	*	**	*	*****	****

† Use of geo-coordinates and GPS map enables highest repeatability.

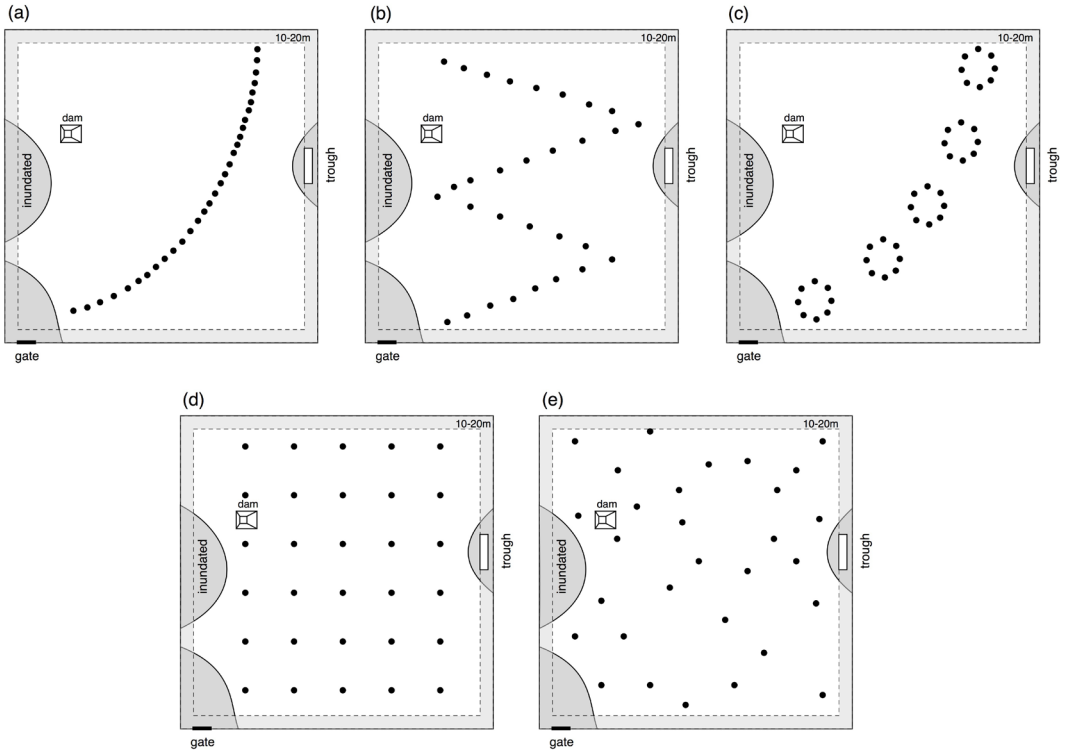

Figure 12. (a) transect, (b) zigzag, (c) cluster, (d) uniform grid, (e) random

6.5 Sampling pattern for selected area with previous fertiliser banding

Where there has been zonal or precision placement of fertiliser for field crops, trees, vines, etc., particular sampling patterns are recommended because soil test results may vary according to how collected soil cores intersect with the zone of placed fertiliser.

In some cases, the fertility of banded / fertigated and unfertilised locations may be very similar, whilst in others the fertility of banded / fertigated and unfertilized locations may be disparate. Fertigated drip and under-tree-sprinklers are likely to cause marked differences in nutrient concentrations, particularly when there is little soil disturbance.

Typically, a composite sample consists of one core intersecting a fertiliser placement area and a specified number of cores collected between the fertilised area, taking consideration of band spacing, diameter of the placed fertiliser band and nutrient mobility, and sample core diameter (Figure 13). This approach can be modified for soil sample collection for fertigated tree crops within the root zone.

A core collected from soil including an applied fertiliser band or drip fertigation may contain higher nutrient concentrations than one taken just a few centimetres away.

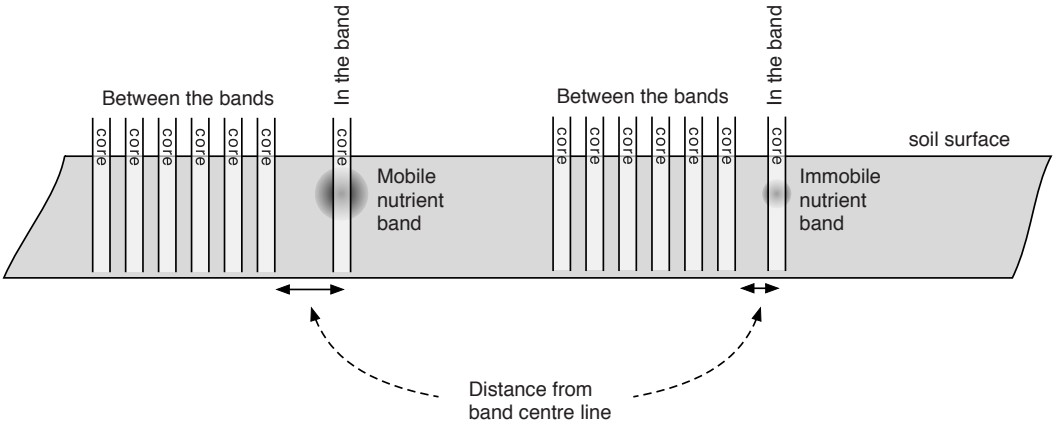

Figure 13. Sampling cross section showing a core in the band and cores between the bands for mobile and immobile nutrients.

Farming practices to manage issues such as non-wetting and disease control may also result in precision placement of fertiliser close to, but not coincident with existing fertiliser bands.

Where band or fertigation locations are known (i.e. where previous fertilised crop rows are visible), the sampling protocol should satisfy several criteria. This includes estimation of the distance away from the band centreline to commence between-band cores, and how many between-band cores should be collected for each core collected in the band.

6.5.1 Distance from band centreline

The distance away from the band centreline can be estimated as follows, rounded up to the nearest 10mm (Table 4).

For less mobile nutrients (phosphorus) the diffusion factor is affected by soil texture, soil buffering capacity and soil water status, and nutrient concentration in the band.

The diffusion factor for mobile nutrients (nitrogen) will be affected by pore space and water movement.

Use a diffusion factor of 1 where diffusion of nutrient from the band is limited, and a diffusion factor > 1 where there is a likelihood of increasing diffusion.

Distance from band centreline (mm) = Band diameter (mm) × Diffusion factor × 1.5

Table 4. Suggested minimum distance (mm) away from fertiliser band centreline to commence between-band cores as a function of band diameter and nutrient diffusion factor.

	Diffusion factor (mm)		
Band diameter (mm)	1 • less mobile nutrients such as phosphorus • clays	1.2 ⟷	1.5 • more mobile nutrients such as nitrogen • sands
10	20	20	30
20	30	40	50
30	50	60	70
40	60	80	90
50	80	90	120

Image courtesy Bede O'Mara, Incitec Pivot Fertilisers.

6.5.2 Estimating between band cores

When the fertiliser band location is known, and tillage has not disturbed the soil (Figure 14) the following formula can be used to estimate the number of between-band cores required for each in-band core collected. Examples are shown in Table 5. These ratios of 'in-the-band' to 'between-the-band' are similar to those reported by Kitchen et al (1990) of 1:8 for a 30 cm row width, 1:16 for a 61 cm row width and 1:20 for a 76 cm row width. Between-band sampling could occur perpendicular to bands, horizontal to bands or randomly between the bands (Figure 14).

$$\textit{Between–band cores} = \frac{\textit{Row spacing (mm)}}{\textit{Band diameter (mm)} \times \textit{Diffusion factor}} \div \frac{\textit{Core diameter (mm)}}{\textit{Band diameter (mm)}}$$

Table 5. Number of 'between-the-band' cores required for each 'in-the-band' core sample for a range of row widths (cm) and core diameters (mm) and diffusion factor of 1.2. Based on equations in section 6.5.1 and 6.5.2 (pers. comm. Chris Dowling Back Paddock).

	Row width (cm)					
Corer (mm)	**15**	**25**	**35**	**45**	**55**	**65**
20	6	10	15	19	23	27
25	5	8	12	15	18	22
30	4	7	10	13	15	18
50	3	4	6	8	9	11

When band locations are unknown, but row widths are known, a paired sampling approach can be used (Kitchen et al., 1990). One set of cores (at least 30) are collected randomly and composited. A second set of cores, 50% of the row width away from and perpendicular to the first set of cores is collected and composited. The soil sample with the lower soil test value is likely to be the most representative since one of the composite samples will have over sampled the in-the-band zone.

Image courtesy Bede O'Mara, Incitec Pivot Fertilisers.

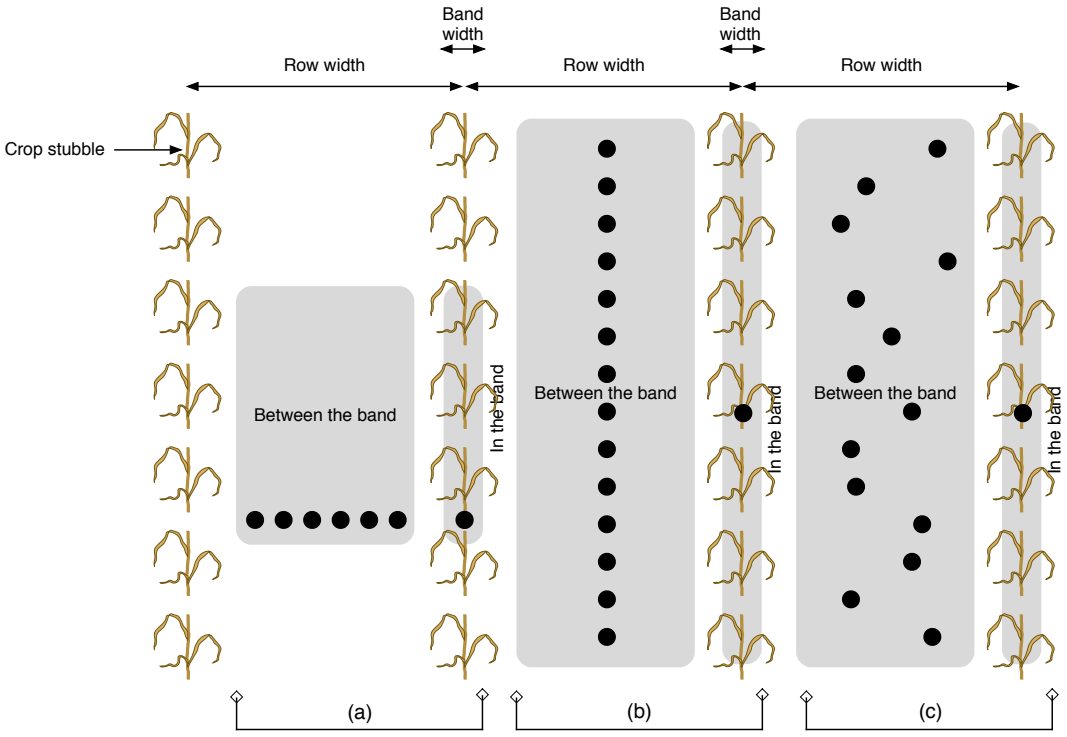

Figure 14. Sampling strategies with banded fertiliser when the bands are known where cores are collected (a) perpendicular (b) parallel or (c) randomly between the bands (adapted from https://communities.grdc.com.au/crop-nutrition/soil-sampling-banded-fertiliser/) .

6.6 Sampling to the correct depth

The soil sampling depth for any crop should reflect the zone of root activity and align with nationally accepted soil test calibration experiments. It is important therefore to adhere to the recommended soil sampling depths for each crop in each state (Table 6, Table 7) so that soil test results can be interpreted meaningfully.

The practices of deep tillage, spading, mouldboarding and slotting may markedly increase the variability in surface and subsurface nutrient concentrations and potential rooting depth. Sampling approaches should account these practices as discussed in Section 6.5.

Recommended sampling depths should always be 'fit for purpose'. Standard sampling depths may not necessarily be appropriate if the investigator has a different question or purpose in mind. For example, if attempting to understand nutrient runoff in a sensitive catchment, it may be more appropriate to collect shallow surface soil samples (0 - 2 cm) that align with the major hydrological pathways for nutrient loss (Kleinman, 2017).

Distinct soil textural transitions within a duplex soil profile can also be used to define sampling sections at depth.

Soil test results commonly show a vertical gradient in the soil profile

If you only get soil from part of the sampling depth, don't throw it in with the composite sample. Near enough isn't good enough.

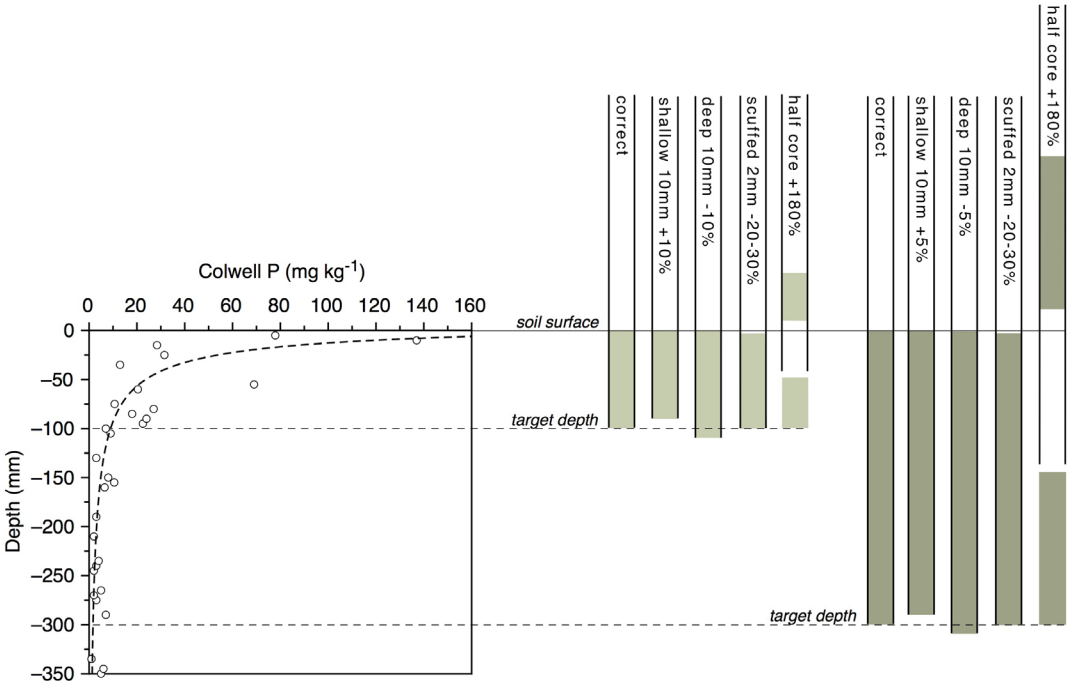

Figure 15. Generalised vertical gradient of available P and impact on determined P availability from different sample depths.

Once the correct depth has been chosen, it is important to ensure that collected samples are taken uniformly and not shallower or deeper than recommended. In soils with a strong vertical gradient, for example rapid decrease in soil P with depth (Figure 15), surface scuffing as little as 2mm of soil from a 0 - 10 cm sample may reduce soil Colwell P by 20-30%. Sampling to 9 cm or 11 cm when a 10 cm sample was intended in a soil with a strong vertical gradient can vary Colwell P by ±10%, whereas sampling to only 5 cm through the loss of the bottom half of a soil core from a sampling tube can increase Colwell P by 180%.

Scuffing can have greater impacts than sampling slightly deeper or shallower than the specified depth because surface P concentrations are much higher than concentrations at depth. In Figure 15 for example, the top 1 cm of soil contains 60% of the Colwell P in the top 10 cm whilst the bottom 1 cm contains only 2% of the top 10 cm Colwell P.

The degree of vertical nutrient gradients varies for different analytes. While phosphorus levels usually decline sharply down the profile, potassium and sulphur may decrease, increase, or bulge with depth; often aligned with increasing clay content. Hence the influence of incorrect sampling depth on differing soil test results may vary.

Table 6. Surface soil sampling depths (cm).

Crop	Qld	NSW	Vic/SA	Tas	WA
Pasture	**0 - 10**	**0 - 10**	**0 - 10**	**0 - 7.5**	**0 - 10**
Cereal, Oilseed and Grain Legumes	0 - 10	0 - 10 (North) 0 - 10 (South)	0 - 10	0 - 10	0 - 10
Cotton	0 - 10 (rain) 0 - 15 (irr., flat) 0 - 30 (irr., bed)	0 - 30	Not Grown	Not Grown	Not Grown
Vegetables / Horticultural Row Crops	0 - 15	0 - 15	0 - 15	0 - 15	0 - 15
Bananas	0 - 20	0 - 15	Not Grown	Not Grown	Not Grown
Sugar Cane	0 - 20	0 - 20	Not Grown	Not Grown	Not Grown
Tree Crops (Establishing)	0 - 30	0 - 30	0 - 30	0 - 30	0 - 10
Tree Crops (Bearing)	0 - 15	0 - 15	0 - 15	0 - 15	0 - 10
Vines	0 - 15	0 - 15	0 - 15	0 - 15	0 - 15

Deep or subsurface sampling is commonly used for cotton and cereal crops to measure the nitrate nitrogen status and sometimes potassium and sulphur status of the profile. When establishing a new crop, consider sampling the sub-surface as well as the surface, to identify any salt or structural problems at depth. Sub-surface sampling may also be necessary to check for salinity, sodicity, acidity, alkalinity, acid sulphate soils and nutrient deficiencies or toxicities that may affect growth, particularly of deep-rooted species.

Table 7. Sub-surface soil sampling depths (cm).

Crop	Qld	NSW	Vic/SA	Tas	WA
Pasture	**10 - 30**	**10 - 30**	**10 - 30**	**7.5 - 30**	
Cereal, Oilseed and Grain Legumes	10 - 30 30 - 60 60 - 90 Or combined 10 - 60	10 - 30 30 - 90 Or combined 10 - 60	10 - 30 30 - 60 60 - 90 Or combined 10 - 60	10 - 30 30 - 60 60 - 90 Or combined 15 - 60	10 - 30 30 - 60 60 - 90 Or combined 10 - 60
Cotton (sometimes extended to depth of estimated water extraction)	0 - 10 (rain) 0 - 15 (irr., flat) 0 - 30 (irr., bed)	10 - 30 30 - 60 or 90	Not Grown	Not Grown	Not Grown
Vegetables / Horticultural Row Crops	15 - 60	15 - 60	15 - 60	15 - 60	15 - 60
Horticultural Tree Crops (Establishing)	30 - 90	30 - 90	30 - 90	30 - 90	10 – 60 in 10cm increments
Horticultural Tree Crops (Beaing)	15 - 90	15 - 90	15 - 90	15 - 90	10 – 60 in 10cm increments
Vines	15 - 30 30 - 60	15 - 30 30 - 60	15 - 30 30 - 60	15 - 30 30 - 60	15 - 30 30 - 60

6.7 Documenting and recording soil sampling location and pattern

With the ubiquity of mobile devices, recording the location of paddocks, sample routes and even individual 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 location of sampling cores representing a sampling site within each representative paddock, block or management zone, so that you can return to the same spot, transect or pattern, and identify trends in the fertility status site over time (Figure 16).

Recording of geo-coordinates and associated meta data provides numerous benefits:

- Allows sampling pattern to be repeated at a later date
- 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 test results with additional information from producers
- Metadata allows for later analysis to assist with detection of systematic sampling issues, and identify more efficient sampling approaches.

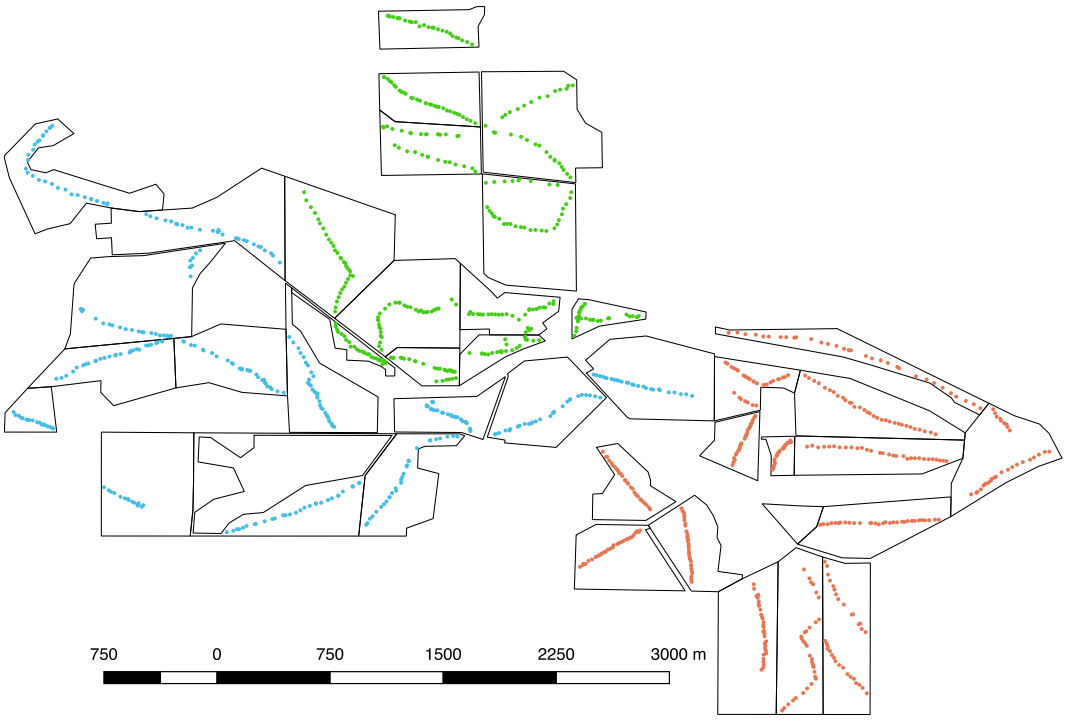

Figure 16. Example map showing sampling pattern of individual paddocks using geo-coordinates of individual soil cores using a mobile device. Colours indicate samples collected by different sampling staff.

7. Soil sampling equipment

7.1 Selecting the right sampling tools

A range of soil sampling equipment that can simplify sampling, reduce labour and time requirements, increase accuracy and reduce the possibility of contamination is currently available.

> It is important that selected equipment is 'fit for purpose' – providing representative samples which address a specific question and are suitable for the specific field conditions.

Sampling tools should be:

- able to take a small enough equal volume of soil from each sub-sampling site so that the composite sample will be of an appropriate size to process for analysis,
- easy to clean,
- rust resistant,
- free of contaminating materials such as galvanising with zinc,
- robust and durably constructed to resist bending or breakage,
- relatively easy to use,
- satisfy OHS requirements.

Sampling tools can consist of blades, tubes or augers operated either manually or with mechanical assistance. Tools can vary in width or diameter, although most sampling tools are around 20 - 30 mm in diameter, allowing for ease of penetration into the soil, and ensuring that the final combined sample is not too large. It is important to avoid shovels, or other tools that result in the collection of tapered samples, as all depths intended in the sample should be equally represented (see section 6.5).

Work undertaken in WA comparing various soil sampling tools (Weaver et al. unpublished) found no systematic differences between equipment for a range of analytes. The study compared 8 sampling tools including hand and power-driven augers, tube samplers and vehicle mounted equipment in 3 soil types on a monthly basis over 12 months. On a few occasions, differences were identified when operators of the equipment changed. In most cases, within laboratory variation exceeded variation between equipment. The work highlighted the importance of 'fit for purpose sampling tools' (Table 8). For example, hydraulic corers were suitable for soils with sufficient moisture, whilst some augers did not handle wet clays well.

Table 8. Sampling tools

Sampling tool	Image	Comment
Pogo stick or tube		Suitable for taking surface samples from a wide range of soil conditions, to depths of up to 30 cm. The depth should be marked on the side of the tube or may be set by a fixed or adjustable foot to the required level. In dry sandy soils or cultivated land, the tube may need to be forced into a near-horizontal position while still in the ground before being lifted out. Need to be checked for wear to ensure desired sampling depth is maintained.
Compressor driven auger		Suitable for taking samples from a wide range of soil conditions, in 10 cm increments to depths of up to 20 cm. Surface and sub surface samples can be split automatically at each core location. Use of mirrors required to ensure dung or other hazards are avoided. Satisfies OHS requirements during hot weather. Useful for soils that are hard to penetrate. Auger can bind on wet clays or where there is tall biomass. Auger wear can reduce sample volume and integrity over time. Check depth is calibrated to desired sampling depth.
Hydraulic driven tube		Suitable for taking samples from a wide range of soil conditions to 10 cm, but mostly suited to moist soils and irrigated paddocks. Tube is extracted vertically. Beware that soil "cores" can be incomplete in dry sandy soils. Provides access to a wider range of terrain.
Battery drill driven auger		Suitable for taking samples from a wide range of soil conditions up to 20 cm. Useful for soils that are hard to penetrate. Auger can bind on wet clays or where there is tall biomass. Check depth is calibrated to desired sampling depth. Auger wear can reduce sample volume and integrity over time. Can make use of all-terrain vehicles to traverse sampling area.
Hydraulic driven auger		Suitable for taking samples from a wide range of soil conditions to depths of up to 20 cm. Useful for soils that are hard to penetrate. Auger can bind on wet clays or where there is tall biomass. Auger wear can reduce sample volume and integrity over time. Check depth is calibrated to desired sampling depth. Not preferred due to increasing OHS concerns of quad bikes.
Multi-purpose soil mapping and depth sampling		Undertakes zonal mapping of paddocks prior to identifying the most typical and suitable locations for the collection of deep soil cores. Maps electromagnetics, soil moisture, compaction etc. to identify best locations for samples.

7.2 Using soil sampling tools correctly

- Select the most suitable 'fit for purpose' sampling equipment and undertake a number of test samples to verify complete sample extraction and appropriate sampling depth.
- Check that tubes and augers are not worn and are not compromising the extraction of a sample that represents uniform width at all depths.
- Ensure your hands and equipment are clean before commencing sampling.
- If conditions change and the chosen equipment is no longer 'fit for purpose' during the sampling pattern, change equipment as needed.
- Capture geo-coordinates and other metadata as you go.
- Gently remove, push to one side or part any obvious surface plant debris such as crop litter and undecomposed stubble, but do not scuff the soil surface.
- Suitable non-contaminating lubricants that do not contain organic carbon may be used if samples are compressed and retained in the sampling tube. WD-40, silicone and canola oil spray have been suggested as suitable for macro-nutrient testing in wet clayey soils, with WD-40 as the best choice when testing micro-nutrients.
- Collect the appropriate number of cores in a vessel that will not contaminate the sample (not galvanised) to the same depth across the area of concern, using a nominated pattern.
- Break up cores into small crumbs and mix them thoroughly into a composite sample. Not all laboratories mix and sub-sample appropriately upon receival.
- Transfer a representative sub-sample into the soil sample bag, ensuring visible label or barcode, supplying the amount of soil required by the laboratory.
- If the sample is too large for the bag provided, select a representative sub-sample by taking 100 g (a small handful) of the sample, placing it in the sample bag, remixing the remainder, then taking another 100 g subsample, continuing the process until the required amount (typically 500g) is obtained.
- Complete the Field Information Form if required. Send the completed pack to the laboratory via a reliable Courier service or mail for prompt delivery to the laboratory.

7.3 Hygiene

Weeds, pests and diseases can be spread on soil, crop residues and sampling equipment and may be transferred between and within farms during the process of soil sampling. Specific hygiene requirements when sampling, in addition to normal practices, may be required in areas where certain plant diseases or noxious weeds have been identified.

For example, in cotton areas infested with Fusarium oxysporum, equipment may need to be sprayed with recommended disinfectant before moving between farms. Similarly, in areas infested with noxious weeds, special requirements on vehicle movements may be in force.

- Ensure clean soil sampling probes and other sampling gear.
- Ensure clean boots (especially soil from farm previously visited).
- Ensure clean vehicles (check tyres, wheels and underneath vehicle for weeds, seeds (Figure 17), soil, etc.).
- Ensure clean surfaces where samples are bagged and prepared for dispatch.
- Arrange to make use of on-farm wash down facilities

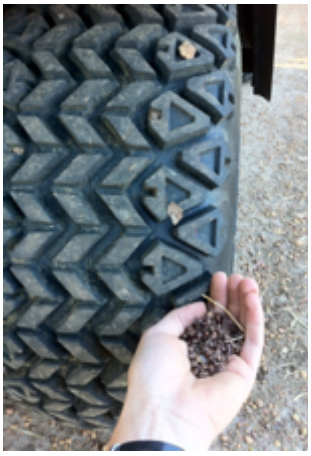

Figure 17. Collecting double gee seeds from tyres following soil sampling of infected paddocks

8. Soil sample handling and dispatch

8.1 Submitting samples

Sample submission forms should be filled in, recording the details required by the laboratory. This information is essential to identify the samples and order the suite of analyses required. Other key information about the crop to be grown, previous fertiliser and crop protection history, irrigation type, etc. should be captured and recorded via on-line or paper-based systems, to assist with the interpretation of results.

> Once a sample is collected, dispatch it to the laboratory quickly, so that it is representative of field conditions.

Soil samples are best kept in plastic bags, but because most samples contain moisture, microbial activity will continue while suitable temperatures prevail.

Change in temperature can influence chemical properties in collected samples; this is particularly relevant to nitrate nitrogen and sulphate sulphur. Bagged soil samples should be transferred to a cool box, containing frozen cooler bricks or ice, as soon after sampling as possible. Samples can be transferred to a refrigerator for storage overnight or until ready to dispatch.

Do not expose collected samples to extreme heat, e.g. storing on the dashboard, in the back of a utility or truck, or in a locked-up vehicle during the heat of the day.

Avoid posting samples late in the week as they may be held up in transit over the weekend. Soil samples taken late in the week, should be store in a refrigerator (~3 - 5°C) over the weekend.

If dispatching samples quickly is not possible, collected samples may be air-dried in a cool and dry environment. The collected sample should be well-labelled, adequately crumbled into small particles and spread out on a clean plastic sheet or bag, away from any likely contamination.

8.2 Quarantine issues in soil and plant sample movement

Staff collecting and submitting soil samples should be aware of State and Commonwealth Government regulations that apply to the transfer of soil and plant samples. Regulations vary between states and change over time. Restrictions include movement of samples, or requirements for treatment of soil from areas known to be infested with particular pests or diseases.

Sales staff, advisers and farmers working in areas known to be infested with the following pests or diseases will need to contact the laboratory providing their analysis, and obtain details on requirements for sample treatment, or restrictions on sample movement.

Some examples of these pest and disease may include:

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

More information can be found at State and Commonwealth Government biosecurity websites 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: **http://agriculture.vic.gov.au/agriculture/horticulture/moving-plants-and-plant-products/importing-plants**
- Western Australia: **https://www.agric.wa.gov.au/biosecurity-quarantine/quarantine/importing-western-australia/importing-plant-and-plant-products**

9. Work Health and Safety

Occupational work, health and safety (WHS) risks are associated with sampling. Employers and employees have a duty of care in identifying possible risks and managing the situation for the health and safety of those involved (Table 9).

Table 9. Some WHS issues and actions to consider

WHS Issues	Considerations to address
What **WHS hazards** may be associated with performing soil sampling?	Hazards may include disturbance or interruption of underground services, solar radiation, dust, noise, soil and water-borne microorganisms, chemicals and hazardous substances, sharp hand tools and equipment, manual handling, moving machinery and machinery parts, falling objects and uneven surfaces. Check Dial Before You Dig (https://www.1100.com.au) particularly if sampling to depth.
What **safety equipment** may be required?	Safety equipment may include signage and barriers.
What **Personal Protective Equipment** may be required to perform a soil sampling?	May include broad-brimmed hat, boots, overalls, gloves, goggles, respirator or facemask, face guard, hearing protection, sunscreen lotion and hardhat.
How may a **clean and safe work area** be maintained?	Tasks may include disabling unused tools, equipment and machinery and storing neatly out of the way of surveying activities; safely storing materials on site; using signage and safety barriers during and removing after surveying activities are completed; backfilling soil survey holes and pits; and swiftly and efficiently removing and processing debris and waste from the work area.
What **WHS requirements** may be relevant to this standard?	WHS requirements may include identifying hazards; assessing risks and implementing controls; cleaning, maintaining and storing tools, equipment and machinery; machine guarding; appropriate use of PPE including sun protection; safe operation of tools, equipment and machinery; safe handling, use and storage of chemicals and hazardous substances; correct manual handling; basic first aid; personal hygiene and reporting problems to supervisors.
Remote work	Inform and update co-workers/ manager of work location, any identified hazards and expected time requirements, particularly where mobile phone reception is limited.

10. Soil sampling checklist

		Relevant Sections
PLANNING		
1.	Develop a 'fit for purpose' soil sampling plan that identifies the reasons for sampling and uses a stratified approach.	3, 5, 6
2.	Select a sampling pattern that provides a representative sample, is repeatable and efficient.	6.4, 6.5
3.	Schedule sampling at the same time each year and to align with future fertiliser decisions.	3, 4
4.	Avoid sampling during climatic extremes and 2 - 3 months after ameliorant and fertiliser applications.	4
SAMPLE COLLECTION		
5.	Check and select 'fit for purpose' sampling equipment	7.1, 7.2
6.	Follow work health and safety guidelines, and ensure cleanliness throughout the sampling and handling procedure.	9, 7.3
7.	Collect at least 30 - 40 surface cores using a 20 mm corer, 20 - 30 surface cores using a 25 mm corer per bulked sample (~1 - 1.5 kg fresh soil).	6.3
8.	Sample the correct depth for the crop or pasture and issues addressed.	6.6
9.	Avoid areas that are atypical for your representative sample such as stock camps, fence lines, tree lines.	6.2
10.	Record geo-coordinates of sample patterns, sampling equipment used, depth, date and field conditions.	6.7
HANDLING AND DISPATCH		
11.	Protect collected soil sample from heat, sun and contamination.	8.1
12.	Send to the laboratory shortly after collection. Samples may be briefly stored in a refrigerator at 3 - 5°C prior to dispatch.	8.1
13.	Correctly fill out all details on the sample submission forms.	8.1
14.	Follow relevant biosecurity requirements with respect to movement of samples within and across state borders, and within and between farms.	8.2

11. References and Further reading

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