A guidance document for agronomic best practice soil sampling in Australia.

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Abstract
Fertiliser recommendations for agriculture should be supported by soil analysis and interpretation, the basis of which is underpinned by collected field samples which accurately represent the plant root environment, and calibration experiments. Field variability of soil characteristics can exist horizontally and vertically, with induced soil nutrient variations 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, nutrient mobility, waterlogging, mechanical disruption and nutrient placement. A third dimension of variation is that of temporal change; between years, between seasons or even more rapidly from applied fertiliser or animal manure. Agricultural practices such as minimal tillage, deep soil amendment, row cropping, raised beds, precision fertiliser and ameliorant placement, and variable rate applications, can all impact on soil conditions and nutrient availability within the root zone. Nutrient additions may involve organic, liquid and granular forms. Technological advances now allow for immediate and easy access to site-specific aerial and satellite imagery, capture of geo-coordinates, real-time access 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. The purpose of this paper is to introduce the new Fertcare® soil sampling guidance document which describes 'fit for purpose' soil sampling approaches with the aim of improving consistency and accuracy of on-farm in soil sampling.

Key Words
Soil sampling, nutrient availability, soil analysis, plant nutrition, spatial variability.

Introduction
The purpose of the Fertcare® Accredited Advisor program is to provide farmers and other stakeholders with confidence that farm managers are receiving soil management and fertiliser advice based on soil and or plant testing of a high standard. Soil analysis measures nutrients and physio-chemical parameters in collected soil samples. These measures indirectly predict how plant growth and farm produce product quality will respond to additional nutrient supply throughout a growing season. 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.

The Fertcare® soil sampling guide aims to take a pragmatic approach which recognises there are many factors which impact on plant nutrition responses and nutrient losses, be relatively simple and not highly technical but also defendable from a science perspective, applicable across a broad range of agricultural industries and referenced in industry codes of practice.

Issues addressed in the Fertcare® soil sampling guidance document include:

- Defining the purpose of collecting soil samples
- Farm level sampling strategies
- The number of soil cores to achieve a representative composite sample
- Sampling patterns at the paddock scale
- Dealing with previous fertiliser banding
- Sampling to the correct depth
- Documenting and recording soil sampling location and pattern
- Selecting the right sampling tools
- Soil sample handling, dispatch and quarantine issues.

Defining the purpose of soil sampling

Analysis of soils can be undertaken for a variety of reasons including describing the inherent characteristics of soil types, matching specific plant species and cultivars with soil characteristics, assessing organic and inorganic contaminants and accumulation, determining nutrient availability, monitoring changes due to inputs, diagnosing differences in production, and management and assisting to identify environmental risk. In some cases, there may be multiple purposes in mind when collecting soil samples from a farm.

Predictive sampling aims to assess nutrient availability and chemical constraints in the root environment for a current or proposed crop or pasture type and is 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. Gourley et al 2007) 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 which may account for variations in soil fertility and chemical conditions, the establishment and reuse of specific sampling locations which represent the key crop system and soil types, and sample collection in the same way, at the same depth, at the same time of year, with analysis derived from the same laboratory.

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 paddocks should be sampled at multiple depths to help define differences in soil nutrient supply and/or the incidence of soil limitations such as salinity, acidity, and sodicity.

Compliance sampling aims to provide soil analytical data to aid environmental and/or human health risk assessment (Standards Australia 2005). 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. 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.

Farm and paddock soil sampling strategies

It is essential to know the locations and characteristics of specific soil types within a farm to make sound soil and fertiliser management decisions. 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.

Paddocks or blocks that have differing management regimes (i.e. tillage, previous cropping histories, irrigation systems, fertiliser, ameliorants and bi-product inputs), need to be identified and categorised. Similarly, areas with observed or measured yield performance differences should also be identified and categorised. 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 (Cotching et al. 2019).

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 paddocks or blocks in that group.

With site-specific management being implemented on many farms, there is a growing need to characterise 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. The sampling approach should have an organised and systematic pattern to characterise 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, but ultimately collected samples must 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.

The correct number of soil cores to achieve a representative sample. Collecting an adequate number of cores to account for lateral and vertical variability is critical to achieving a representative soil sample. 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. 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 1. 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.

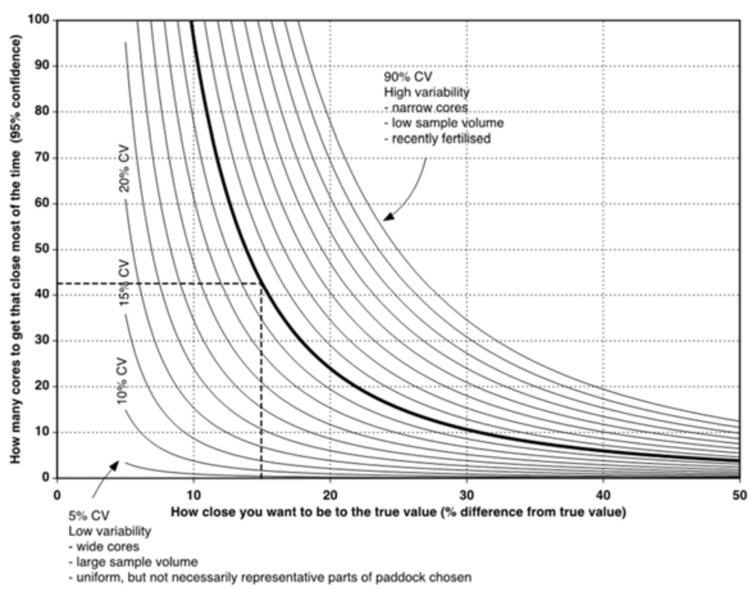

Figure 1. Number of cores required to be 95% confident that the collected sample has a specified % difference from the true value for situations of different variability. Figure developed using statistical procedures described by Gilbert (1987).

Sampling patterns for 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 unfertilised 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 for 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 (Norton 2018). This approach can be modified for soil sample collection for fertigated tree crops within the root zone. Where band or fertigation locations are known (i.e. where previous fertilised crop rows are visible), the sampling protocol should satisfy several criteria including determination of a specified 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.

The diffusion of nutrients will impact on the volume of soil influenced by the previous fertiliser placement. For less mobile nutrients (i.e. 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. A diffusion factor of 1 is used where diffusion of nutrient from the band is limited, and a diffusion factor > 1 where there is a likelihood of increasing diffusion.

When the fertiliser band location is known, and tillage has not disturbed the soil, the number of between band cores required for each in band core collected can be estimated (Table 1). 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.

Table 1. Number of 'between-the-band' cores required for each 'in-the-band' core sample for a range of row widths and core diameters and diffusion factor of 1.2.

	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

Conclusion

Agronomists provide soil and plant nutrition advice to encourage optimum crop / pasture yield and quality, whilst considering risks such as weather, offsite nutrient impacts and food safety matters. The nutrient management approach Fertcare® endorses is to use objective measures such as soil or plant testing, appropriate analysis and interpretation methods to arrive at evidence based, site specific nutrient management plans at a paddock level. Soil and plant sampling practice forms the foundation of this approach. The updated Fertcare® Soil Sampling Guide seeks to guide and support agronomists in the soil sampling decisions they make and forms part of the Fertcare® training program and Accredited Advisor Performance Standards.

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