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CURRENT SOIL SAMPLING METHODS – A REVIEW

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Abstract

Soil testing ensures sufficient quantities of fertiliser and lime are applied to achieve crop and pasture yields, while limiting the potential of losses to the environment. Historically, fertiliser applications have been applied uniformly taking into account variability such as, soil type, topography and land management through soil sampling. A standard method has been outlined and widely adopted in New Zealand for obtaining soil samples. However, there is a growing trend driven by early adopting farmers and numerous agricultural consulting firms in New Zealand, to increase the sampling resolution determining the variability in soil fertility on farm. With current trends of farm expenditure on the rise relative to returns, and improved nutrient use efficiency driving change, a spotlight has been placed on soil testing practices.

The aim of this paper is to assess the current soil sampling protocol, review the literature and identify if there is a need to modify current soil sampling methods. The authors conclude that intensive sampling processes need to consider the specific nutrient or soil characteristic being analysed and that although one hectare grid sampling is commonly used, this may not be the most accurate for all nutrients or soil characteristics.

Introduction

In New Zealand agriculture, soil sampling has been recognised as the first step in generating customised zonal information on which to base lime and fertiliser decisions and in monitoring soil nutrient status over time (Edmeades et al. 1985). Interpretations of soil tests are based on years of calibration trials with pasture and crops grown on relatively small, uniform experimental plots (Edmeades et al. 2010). However, soils on farms vary within a paddock or block and struggle to be fairly represented by a composite soil test result (Roberts et al. 1987; Roberts et al. 2011). The composite sample results mask scattered areas of both higher and lower levels of soil nutrients. If nutrient status is highly variable, then a substantial portion of the paddock might respond to lime or fertiliser applications or both, even if a composite sample suggests no response. The Fertiliser Association of New Zealand (FANZ) have documented a protocol for performing soil sampling (FANZ, 2014), which aims to represent the potential variation in each management area, and this protocol has been widely accepted as the standard since the mid-nineties.

Due to the inherent variation in soils and advances in GPS (global positioning systems) and GIS (geographic information systems), farmers and farm consultants have been able to design more intensive soil sampling strategies, and use this information for lime and fertiliser management decisions (Corwin & Lesch, 2003). Consequently, new soil sampling strategies have been developed to better represent the potential variation in paddocks and blocks. With the more intensive soil sampling strategies it has given rise to question the current soil sampling protocol outlined by FANZ (2014) which is now being applied to the novel sampling strategies.

The aim of this paper is to outline the current soil sampling strategies used in the field and carry out a stocktake of processes for collecting the samples of each of the strategies. Attention is also given to the present and potential use of information technology (IT), particularly GIS platforms, as a means of storing, managing and displaying data.

'Traditional' Sampling Method

Since the mid-1990s, the widely adopted practice for soil sampling in New Zealand has followed the method detailed by FANZ (2014) and listed below:

- Conduct at least every 1-3 years
- Sample at the same time every year
- Sample along fixed transects
- Zone the farm based on soil type, topography and management history
- Collect composite samples made up of 15-25 cores collected at unbiased intervals
- Avoid atypical samples (around gates, troughs and shelter belts).
- Sample in subsequent years along the same fixed transect lines.

This method is referred to as the traditional sampling method (Dawson & Knowles, 2018). Therefore, if any further refinement were to be made to the method, it should maintain the principles outlined above and demonstrated in Figure 1. The advent of GPS and GIS, along with a reduction in their costs has seen an increase in their use in the agricultural industry for use with soil sampling. This has led to improved record keeping, ensures subsequent sampling is conducted along the same transect line, which has decreased some of the variation caused by human error, and allowed for more intensive soil sampling strategies.

Information Technology

GIS platforms

The use of GIS (geographical information systems) in agriculture was first used in the mid-1990s, with the developments and wider use of GPS (global positioning systems) (Corwin & Lesch, 2003). The use of GIS in farming occurred due to it being a necessary piece in the conception of precision agriculture of which intensive soil sampling has been an evolving management practice (Flowers et al., 2005, Van Schilfgaarde, 1999). Therefore, the use of GIS is now an integral component to the delivery and further refinement of novel soil sampling such as the strategies listed below.

GIS enables the ability to construct a base map that delineates the farm into management zones or paddock boundaries in a digitised format. The digital information can be correlated to georeferenced co-ordinates using GPS, which can provide accuracy to within 5 meters or less (Flowers et al., 2005). The user can map any recognisable paddock or subunit boundaries, if they are to be used in the design of soil sampling strategies. Relevant paddock subunits could include units from soil survey maps, areas with distinct management history, or consistently different crop yields, as demonstrated in Figure 1G (Crozier & Heiniger, 2015). These strategies will be further outlined in later sections but gives an indication of the use and requirement of GIS when the management practice of novel soil sampling is followed.

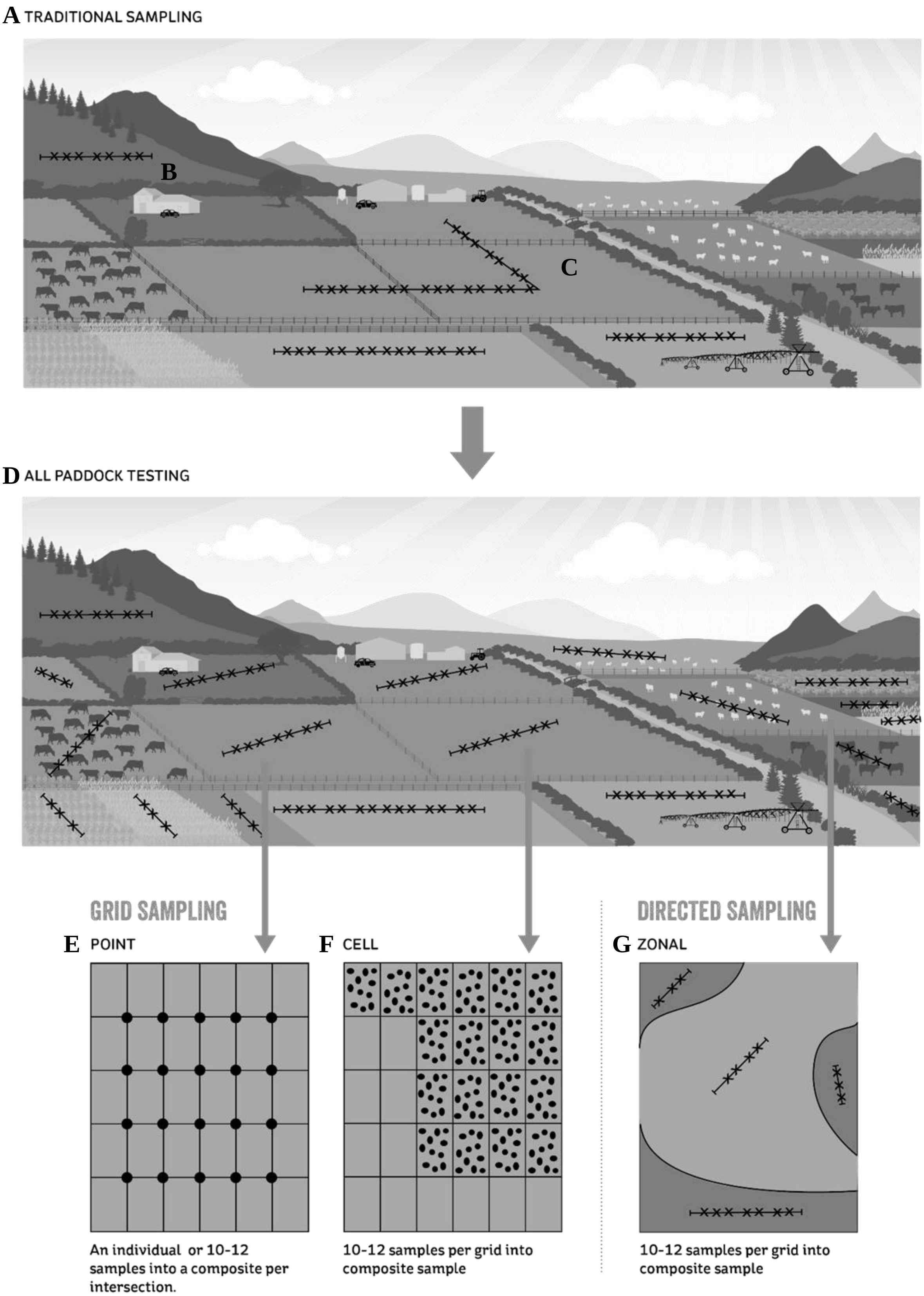

Figure 1. Soil testing transects. Areas with different soil types and/or different uses must be sampled separately. On hills (B), transects should run horizontally across the hill, rather than vertically up and down. A composite paddock test (C) can also be performed if desired.

Emerging Soil Sampling Strategies

There are currently a range of sampling strategies, which have been developed and defined in the industry, which are briefly outlined below. For a more detailed understanding of the various strategies, refer to Dawson and Knowles (2018).

All paddock testing

All paddock testing (APT), has samples obtained from all paddocks on the farm with the aim to understand individual paddock soil fertility demonstrated in Figure 1D. All paddock testing identifies the lower and higher soil fertility sites and allows tailored recommendations, down to individual paddocks if required. Typically, the range of soil test values will be larger in APT in comparison to traditional soil sampling due to a larger sample size; however, the average of the soil tests may be the same (Dawson and Knowles, 2018).

Grid soil sampling

As briefly referred to above grid soil sampling is an in depth analysis of in-paddock soil fertility. Describing nutrient variability across a paddock was difficult until the introduction of GPS and GIS (Flowers et al., 2005). There are two methods of grid soil sampling, cell sampling and point sampling.

Cell sampling, outlined in Figure 1F, is a subunit of a whole paddock where soil cores (10-15 cores) are randomly collected from locations throughout a cell. The samples are mixed to generate a composite sample for the cell. The resulting lime and fertiliser rates will be applicable to this entire cell. The entire paddock is represented by a checkerboard pattern of different recommendation rates (Crozier & Heiniger, 2015, Dawson and Knowles, 2018).

Point sampling is better for detecting patterns of paddock variability because all core samples are collected near georeferenced points (located at grid line intersections), rather than scattered throughout the cell. Construction of delineated maps of each soil test parameter can be created through calculating soil test parameters between sampling points, as outlined in Figure 1E. For point sampling the closer the sample point spacing the more reliable the correlation and interpolation between the soil testing points, because of this there has been much discussion around the appropriate grid spacing (Flowers et al., 2005; Franzen and Peck, 1994; Wallenhaupt et al., 1994). Franzen and Peck (1995) recommend that grid density should be decided by the uniformity of the field, soil types, past management and perceived economic benefit.

Directed Sampling

Directed sampling, is underpinned by GIS software to enable simple map creation and interpolation of sample results. Through homogenous sub regions within a field, directed sampling has shown to give a similar result to grid sampling, but with less cost in developing the prescription map due to lower sampling costs (Cline, 1944, Fleming et al., 2000; Flowers et al., 2005). Directed sampling uses an understanding of paddock variability to delineate zones that have similar yield limiting factors (Buttafuoco et al. 2009) as indicated by Figure 1G. Variability could be caused by inherent soil properties (soil texture, drainage, etc.), and some are due to management (treading damage, land shaping, spreader patterns, etc.). Directed soil sampling zones can be created by soil maps (Wibawa et al., 1993) yield mapping (Flowers et al., 2005), aerial footage of crops (Fleming et al., 2000), digital elevation maps (DEM), electrical magnetic (EM) maps or soil series maps (Mallarino and Wittry, 2004). Clay and soil organic matter (OM) content as a proxy for soil type has also been used (Nanni et al., 2011, Rossato et al., 2015). Creating homogenous zones within a paddock reduces the number of samples while still recognising areas of differing nutrient status.

Sampling Methods

Once the soil sampling strategy has been chosen the next step in the process is to follow a method for obtaining the soil samples. This is where there is large variation in the methodology used to carry out what used to be a relatively straightforward exercise. The aim of the initially designed process as outlined previously from the fertiliser code of practice by FANZ is to limit the variability of the sample through an unbiased methodology. Therefore, the following sections will discuss the relevance of soil sampling intensity concerning the required number of samples to fairly represent a designated area. Also investigated is how the sampling strategy may reflect a more accurate representation of the soil nutrient or characteristic under investigation.

Spatial Scale and Intensity of Sampling

Although there is limited, New Zealand based trial work investigating the understanding of sampling intensity, there has been some research overseas which can guide the methodology in the interim of this lack of research. From early work in soil sampling methodology, it was realised that the limit of accuracy is typically caused by sampling not the analysis (Cline, 1944). As with all soil sampling, attention to sample depth and collection of sufficient cores are critical. The North Carolina Department of Agriculture & Consumer Services (2015) recommends that samples from cultivated paddocks be collected to the depth of the plough or cultivation layer, generally 15 cm. For established no-till paddocks and fallowed paddocks, samples should be collected to a depth of 7.5 cm with reason for variable depth on sampling relating back to what the plant will initially have access to, through their root system. Traditionally composite soil samples of 10 hectares or less have consisted of 15 to 20 cores, or approximately 2 cores per hectare. With a precision soil-sampling scheme based on 1 hectare, 5 to 10 cores have be collected. This aligns to Cline (1944) who reviewed soil-sampling methods and assessed the applicable nature to novel strategies (which at the time was in relation to the strategies outlined above) with the conclusion that finer resolution sampling methods can reduce possible errors equating to three to six times the true value.

Although the above sampling methodology is being universally adopted there is research demonstrating that the intensity of sampling can be estimated by a simple calculations. There have been many equations developed over the years to calculate the required number of samples best representing the variation in a designated area. One such example is below (Equation 1) which suggest the range in available nutrient indicated by a sample can provide an acceptable estimate of the size of sampling required. The issue with these equations is the requirement to have an understanding of the current variability of the area under investigation. However, with the typical farm following best practice, carrying out some form of soil sampling already, there should not be a lack of data to carry out this calculation. Therefore, the best place to start is a soil sample, which will guide the need of whether further intensive sampling is required or if the status quo will suffice (Cline, 1944).

$$Sample\ size = \frac{(r_n - r_1)}{C}$$

Equation 1. Calculation to establish an approximate sample size where C is a constant – which will typically be four to represent 25 sampling units – and r_n and r_1 are the extremes of the range (Hossack, 1936, Cline, 1944).

Sampling pattern

Soil sampling pattern has also been identified as a key area potentially leading to bias in understanding the variability of nutrients in a paddock. The reason for soil sampling pattern leading to bias is that if there is either insufficient area being sampled to represent the sample or potential bias caused by other anthropogenic or environmental factors the actions taken based on the sample results may be inaccurate. As summarised by Crozier and Heiniger (2015) the methodology outlines that concentrated core samples along with core samples taken in parallel with row crops should be avoided (Figure 2c and d) due fertiliser bands and areas disturbed by vehicle traffic (Swenson, et al., 1984). Alternatively, when an intensive sampling strategy is followed either random core samples should be obtained or systematically arranged sampling which may align to vehicle access portrayed in Figure 2a and b.

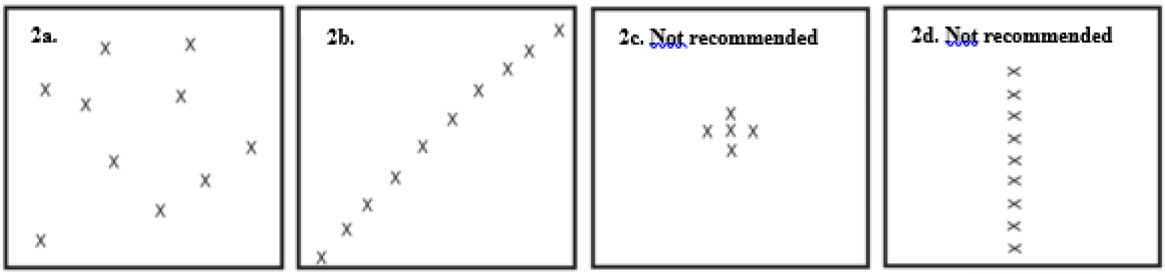

Figure 2. Base cell-sampling patterns on (a) random core samples or (b) systematically arranged core samples to facilitate sampling vehicle access. Avoid (c) highly concentrated core samples and (d) core samples parallel with crop rows (Crozier & Heiniger, 2015).

Soil Nutrient and Characteristic Associations

Research over the years, has identified certain soil nutrients and characteristics e.g. soil texture, are better represented by differing soil sampling strategies i.e. traditional, cell and directed sampling. The consensus is relatively wide spread (Cline, 1944, Franzen et al., 2002; Franzen, 2008; IPNI, 2012; Kerry et al., 2010; Mallarino and Wittry, 2004; Roberts et al., 2011; Wollenhaupt et al., 1994) which has all concluded that the ideal soil sampling strategy can vary from one soil nutrient or characteristic to another in the same sample zone. Although it may not always be practical, the best management practice would be to carry out a sampling strategy applicable to the nutrient or characteristic under investigation.

Outlined below are the strategies, which are most applicable to each soil nutrient or characteristic and are summarised in Table 1.

pH & Nitrogen

Soil pH and nitrogen (N) sampling have been recommended to be sampled less intensively than other soil nutrients and characteristics. The current understanding is the return on investment from a more intensive sampling strategy is decreased for soil pH, while the variability in soil N compared to crop yield is too high therefore, hard to demonstrate with confidence the return on investment from more intensive soil sampling would deliver (Franzen and Cihacek, 1998, Mallarino and Wittry, 2004). That being said Brouder et al. (2005) summarised traditional soil sampling strategies are insufficient therefore a more intensive strategy should be adopted to investigate soil pH. However, as Franzen and Cihacek (1998) and Mallarino and Wittry (2004) portrayed this would not have to be to the extent of grid soil sampling.

Table 1. Summary of soil analysis (nutrients and characteristics) best represented by various soil sampling methods (Franzen and Cihacek, 1998; Franzen et al., 2002; Franzen, 2008; IPNI, 2012; Kerry et al., 2010; Mallarino and Wittry, 2004; Nanni et al. 2011; Roberts et al., 2011; Stamper et al., 2014; Wollenhaupt et al., 1994).

Soil analysis	Traditional Sampling	APT	Grid Sampling		Directed Sampling
			Cell	Point	
pH	☑	☑			☑
Nitrogen	☑	☑			☑
Phosphorus		☑[c]		☑[a]	☑[b]
Potassium		☑		☑	☑
Sulphur	☑	☑[c]			☑
Magnesium	☑				☑
Zinc*			☑	☑	
Organic matter	☑				☑
Texture	☑				☑

[a] for heavily phosphate fertilised areas, [b] for lower soil phosphate values or modest to low amounts of phosphate fertiliser, [c] depends on the type of nitrogen or sulphur test carried out e.g. inorganic nitrogen should be on a finer resolution while organic nitrogen should be carried out on a coarser scale.

Phosphorus & Potassium

Phosphorus (P) and potassium (K) have been found to be highly variable with traditional soil sampling strategies (Roberts et al., 2011). Therefore, a greater intensity of sampling was investigated and found that the likes of grid soil sampling could represent the end yield of the crop better than the less intensive soil sampling strategies (Kerry et al., 2010, Nanni et al. 2011, Stamper et al., 2014). This was further summarised by Franzen (2008), Mallarino and Wittry (2004) and Wollenhaupt et al. (1994) through grid-point sampling is better than traditional soil sampling once variability was identified.

Sulphur

As the variability of sulphur (S) is high in relation to predicting yield response (Edmeades, 1985, Korb et al. 2002) in relation to traditional soil, sampling it is hard to justify the expense of increasing the intensity of sampling. As Korb et al. (2002) stated when it comes to soil sampling for S it helps determine potentially deficient soils but as herbage sampling is more beneficial in the instance of this nutrient it is best to be left at a less intensive sampling as the same result can be achieved with less cost associated from soil sampling.

Magnesium, Organic Matter & Texture

There has been little investigation on the impact of soil sampling intensity predicting yield response from magnesium (Mg) however from one such trial, Kerry et al. (2010) found in a case study Mg demonstrated little variation between sampling strategies. Gualberto et al. (2016) reinforced this where they demonstrated there was little variation when samples were taken between 50-173 m apart from each other. The conclusion from Kerry et al. (2002) was that a more intensive sampling strategy would not be justified with the return on the higher costs involved.

Numerous pieces of research have found a similar result for organic matter (OM) and soil texture as they can be explained by both an intensive soil sampling strategy and less intensive strategy therefore the less intensive solution was recommended due to a lower expense on soil sampling (Mallarino and Wittry, 2004, Nanni et al., 2011).

Novel soil sampling methods

There are new soil sampling strategies being developed as time goes by, which will all have their pros and cons of ability to predict yield response. Although they may state an improved return on investment, one caution with these strategies and the methods used would be their calibration to predict yield response. As the current soil analysis methods e.g. Olsen P have been calibrated to yield response it is important to note that any new method should also have this, to demonstrate its relevance. Furthermore, if the sampling strategy used were outside the scope of the methods described above then there would need to be a fair justification for the change.

There are numerous soil sampling techniques e.g. ‘on-the-go’ using machines to sample the soil, along with non-destructive soil sampling methods being developed. As these start, being used in the market, the review carried out here should be repeated to ensure its robustness and relevance to making nutrient use on farm more efficient.

Conclusion

Both grid and traditional soil sampling are valid soil sampling strategies — each has advantages and disadvantages (Dawson and Knowles, 2018). Unless the grid is dense enough, grid sampling may miss patterns and boundaries that are evident from looking at soil surveys or yield maps. As Flowers et al. (2005) stated grid sampling is very expensive — both to collect and to analyse the samples. Directed sampling uses other sources of spatial information to make informed decisions on where to sample, however, there may be patterns in soil fertility, which are not detectable except with grid sampling. Other sources of spatial information to add more detail to the variability in a paddock are yield maps and aerial photographs (Mallarino et al. 2006). Furthermore, there are also situations where traditional sampling strategies are less advantageous than grid sampling. Traditional sampling strategies might suggest that paddocks do not need phosphorus fertiliser; however, precision sampling using a grid strategy might show that most of the paddock tests well below the target range and phosphorus fertilisation should significantly increase yield potential. On the reverse of this, if the landscape is extensive e.g. a high country farm, traditional soil sampling will be more advantageous due to the cost, time and ability to apply the information.

If the ability to analyse soil nutrient from non-destructive means e.g. sensing utilising wave lengths beyond the visible light spectrum, this document should be reviewed to ensure the procedure for any innovative way of soil sampling is understood in terms of the advantages and disadvantages it may deliver on farm. Further to this, if the crop establishment method of limited or no-till is more widely adopted this management practice should also be assessed. The reason for reviewing the impact of limited or no-till is due to fertiliser being banded with seed and if these rows are consistently used, the banded rows will indicate different levels of nutrient as opposed to the inter-row areas.

Although it is simple to summarise that soil nutrients and pH are best determined from more intensive soil sampling (Nanni et al. 2011) there are straightforward ways and means to justify if the change in soil sampling strategy is required in the first place as demonstrated by Cline (1944). As the agricultural industry is moving towards an era, where greater attention is being placed on efficient use of nutrient and resources as a whole on farm, it is the authors conclusion, that soil-sampling strategies should be assessed based on known variability. Furthermore, if there is high variability in soil sampling or greater return on investment in soil sampling can be achieved, then the opportunity of more intensive sampling should be investigated. Whether the sampling is carried out on a nutrient basis, or as a suite of nutrients the decision should be determined by the return on investment from the yield of the crop.

Recommendations for future work

It is the recommendation of the authors to investigate further work in outlining and document an appropriate soil sampling protocol for each of the sampling strategies. This will need to include the consideration of the varying soil characteristics and nutrients in the soil as these have been shown to vary from one sampling strategy to the next.

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