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FarmLink Research Report 2018

Towards Best Practice Soil Amelioration

Trial Site Location 'Oakvale', Ardlethan (Geoff Minchin)

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Introduction

With the growing availability of commercial precision agriculture (PA) data collection services and variable rate (VR) application technologies, an increasing number of producers within the FarmLink region are adopting site-specific soil amelioration practices for lime and gypsum inputs. This project examines the ability of a number of data collection methods including EM38, grid soil sampling and strategic segmented sampling to quantify horizontal and vertical spatial variability of soil constraints including soil acidity and dispersiveness within a pilot/test paddock located at Ardlethan, NSW.

Key findings:

- Identification of a highly stratified pH profile and subsurface acidity layer at this location (medium rainfall zone) suggests this problem may be more widespread than previously thought
- Topsoil (0-10cm) grid soil pH mapping in isolation would not have identified the subsurface acidity problem in this example and the result most likely would have been under-liming
- Subsurface acidity (10-20cm) varied within the paddock and was more severe (lower pH and deeper) in soils of lower buffering capacities, i.e. lower Cation Exchange Capacity (CEC)
- Both apparent electrical conductivity (EC_a) measured via EM38 and topsoil (0-10cm) grid CEC soil mapping correlated well with subsurface pH, indicating either data layer would be suitable to use to design strategic 5cm segmented pH tests. Further work is required to determine if this relationship extends to different management practices, soil types and liming histories
- Both EC_a and 0-10cm grid soil CEC/Exchangeable Sodium Percentage (ESP) mapping broadly correlated with sodium concentrations at depth, as well as dispersiveness as measured by Emerson's tests; indicating either data collection method could be used for site-specific gypsum applications in this example
- Quantifying and treating multiple soil constraints on a site-specific basis is complex. Investing in a one-off higher resolution EC_a data layer (e.g. EM38 survey) and deep ground-truth soil sampling before commencing variable rate practices has merit
- Advances in the following would be advantageous for progressing site-specific amelioration practices:
    - Liming calculators/decision support tools that can model the effect of liming rate, treatment depth, incorporation practices, productivity and average annual rainfall on a site-specific basis
    - Analysis methods to directly quantify soil dispersiveness as well as associated ameliorant calculators

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Introduction

The FarmLink region within southern NSW covers an area of highly diverse soil types with a range of soil constraints. In the higher rainfall eastern portion (Cowra, Boorowa, Gundagai, Holbrook); the dominant soil types consist of Kurosols, Kandosols and Chromosols, often typified by lighter (coarser) textures which can be erosion-prone. Subsoils in these areas range from neutral to strongly acidic, with varying concentrations of exchangeable aluminium. Transitioning westward (Temora, Ardlethan, Coolamon, Lockhart), soil types generally increase in clay content/ buffering capacity and include Chromosols, Sodosols, Kandosols, Kurosols, Dermosols and minor Vertosols. Many of these soils possess acidic topsoils which may partially extend into the subsurface (10-20cm) before transitioning to alkaline subsoils. These soils may be sodic in chemistry both in the topsoil and/or subsoil. In addition to these soil types, two key zones within the FarmLink region are dominated by heavier textured Vertosol soils (Urana in the south-west and Barmedman-Quandialla in the north). Whilst these soils are generally strongly alkaline in the subsoil (increasing with depth), they are typically neutral to slightly acidic in the topsoil. Marginal levels of salinity can also be present in the subsoil, whilst sodicity is reasonably common in the topsoil and almost always present (>15% ESP) below ~50cm depth.

In addition to these regional trends, soil type variation at the farm and paddock scale within the FarmLink region is commonly high. This is often related to the underlying soil formational processes; particularly the interplay between parent material, elevation and eluvial (in-situ/ gravity transported), alluvial (water transported) and aeolian (wind transported) processes. These inherent variabilities are compounded by human induced factors, particularly as paddock sizes have increased through the amalgamation of former management areas.

Over the past three to five years, the increased commercial availability of 'on-the-go' pH sensors (e.g. Veris®), apparent Electrical Conductivity (EC_a) sensors (e.g. Geonics EM38, Veris®) and grid soil mapping (typically pH $\pm$ CEC/Phosphorus) within the FarmLink region has given growers the ability to quantify and map within-paddock variability of a number of soil parameters at a relatively high spatial resolution. This has been accompanied by a substantial increase in the number of growers and contractors now equipped with Variable Rate (VR) capable spreaders, making site-specific soil amelioration an accessible and increasingly popular option for growers. Whilst this is overall a positive step, there are a number of considerations that require further research attention to ensure site-specific management approaches are scientifically robust, accurate and cost-effective. These points are discussed below in relation to amelioration of soil acidity and dispersiveness.

Soil pH

The current treatment of soil acidity in NSW is based predominantly on recommendations arising from rigorous research undertaken as part of the NSW Government Acid Soil Action (ASA) program (1997-2003). These recommendations were based on a surface application of lime to treat the 0-10cm layer via a presumed incorporation to a traditional cultivation depth of at least 10cm.

With considerable changes to farming practices over the previous two decades including widespread adoption of minimum or no-till systems, it has become apparent that these amelioration practices are no longer effectively treating soil acidity throughout the profile. Instead, the phenomena of pH stratification or 'subsurface' acidity has been identified in many paddocks.

pH stratification is the result of a number of combined processes; including 1) surface applications of lime without incorporation, 2) acidifying fertilisers banded below the soil surface, particularly ammonia-based products such as MAP and 3) uptake of alkali (OH-) from the soil by plant roots and removal or redistribution to the soil surface through plant litter and dung *(Paul et al., 2003)*.

Recommended sampling intervals for quantifying pH stratification are 0-5cm, 5-10cm, 10-15cm and 15-20cm *(Burns et al., 2017)*. Sample collection at these intervals is highly manual, time consuming and considerably more expensive than 0-10cm testing. For this reason it is not practical or cost-effective to perform segmented sampling on a grid basis. It is however more likely that an economically viable commercial solution to quantifying the spatial variability of subsurface acidity may come in the form of a proxy data layer that is ground-truthed using strategically designed 5cm segmented soil tests.

One potential option for this proxy data layer is apparent Electrical Conductivity (EC_a), most commonly acquired using a Geonics EM38 in eastern Australia. The rationale behind this theory is underpinned by the correlation between EC_a and a number of soil physical and chemical properties, including soil texture and Cation Exchange Capacity *(CEC; Rhoades et al., 1976)*. As these properties are in most cases positively correlated with soil buffering capacity, it is hypothesised that where sub-surface acidity exists, areas of lower EC_a (i.e., lighter soils) will display more extreme subsurface acidification than those of higher EC_a (i.e. heavier soils). This process would be further reinforced by the tendency of lighter soils to leach nitrate ions at a higher rate than heavier soils, an acidifying process.

Soil dispersiveness

Dispersive soils have poor physical characteristics which result in problems including poor infiltration, high runoff/erosion, poor aeration, hard-setting/surface crusting upon drying and restricted plant establishment and growth *(Shainberg et al., 1989)*. To combat the effects of dispersive soils, strategies involving applying gypsum (or lime $\pm$ gypsum combinations on acidic soils) have been implemented successfully in southern NSW. Gypsum ($CaSO_4 2H_2O$) improves these soils in two ways. Firstly, through a (short term) electrolyte effect which causes flocculation of soil surfaces and secondly, through increasing the proportion of exchangeable Ca^{2+} on the exchange complex (i.e. decreasing Na, Mg, K) which increases soil particle aggregation *(Quirk & Schofield, 1995)*.

At present, the most commonly used method to develop site-specific gypsum input maps in southern NSW is apparent electrical conductivity (EC_a) surveying followed by soil zoning and strategic deep soil sampling. EC_a sensors such as the Geonics EM38 are used to collect dense datasets at high spatial resolution, which are calibrated by ground-truth soil sampling. Underpinning this approach is the correlation between EC_a and a number of soil physical and chemical properties including soil texture, moisture content and CEC *(Rhoades et al., 1976)*.

A second approach is through topsoil grid soil sampling for Cation Exchange Capacity (CEC) combined with strategic deep segmented sampling. This method relies on the assumption that properties in the topsoil (0-10cm) correlate with those in the subsoil. If this is the case, a direct soil measurement could be more accurate than using EC_a as a surrogate dataset. This method would also prove cost-effective to producers on acidic soils that could combine this work with grid pH testing. The disadvantage of this method is the loss of spatial resolution/data density through the nature of grid soil mapping versus a sensor-based method.

Both methods rely on soil testing to determine ameliorant rates, traditionally measured by their exchangeable sodium percentage (ESP), with values greater than 6% ESP in the topsoil termed 'sodic' *(Northcote & Skene 1972)*. More recent work however has highlighted the contribution of exchangeable Potassium (K) and Magnesium (Mg) to the dispersive nature of soils *(Rengasamy and Sumner, 1998; Rengasamy & Marchuk, 2011; Rengasamy et al., 2016; Bennett et al., 2016). Rengasamy et al. (2016)* proposed a 'net dispersive charge' concept whereby the dispersive powers of exchangeable cations are: $Ca^{2+} = 1$, $Mg^{2+} = 1.7$, $K^+ = 25$ and $Na^+ = 45$ (water soluble cations expressed as c.mol/kg, measured at a given pH).

Shifting our attention from quantifying soil 'sodicity' (Na content) to soil 'dispersiveness' (i.e. the symptom) will be an important step in developing mapping techniques to base site-specific gypsum ($\pm$ lime) applications on. This will be particularly relevant in the FarmLink region of NSW where high K concentration soils are common, owing to inherently high-K parent materials. The issue of variable soil EC and the contribution of magnesium would also be addressed by revised techniques based on direct measures of dispersiveness.

Objective

This project seeks to examine the accuracy, relevance and effectiveness of a number of data collection methods in determining site-specific lime and gypsum ameliorant inputs in a pilot/test paddock in the FarmLink region.

Method

Paddock selection and description

A 49ha paddock was selected as a pilot/test paddock based on the criteria that it had at least a moderate level of soil variability and a low ameliorant input history *(Table 1).*

Table 1: 'Gill Guy' paddock information

Size	48.9ha (arable)						
Location	146.995°E -34.525°S; 20km SSE of Ardlethan, NSW						
Annual rainfall	485mm (Ardlethan post-office, 1909-2019)						
Topography	258.9m-245.4m ASL Gradational ~1-2% slope from west to east (13.5m relief) Highest point in south-western corner, lowest point in south-eastern corner						
Cropping history	2012	2013	2014	2015	2016	2017	2018
	Wheat	Wheat	Canola	Wheat	Barley	Canola	Wheat
Liming/gypsum history	1t/ha lime north of creek in late 1990's, nil application south of creek Maintenance (400kg/ha) gypsum application pre canola						

'Gill Guy' is situated 20km SSE of Ardlethan on the eastern flank (1-2% slope) of the NNW-SSE trending Cowabbie Range, a sedimentary ridge composed predominantly of sandstones, siltstones and conglomerates. To the north and east of 'Gill Guy', the Walleroobie Volcanics outcrop intermittently forming a shallow valley between the two features whereby soils have been derived from mixed origin colluvium/ eluvium and alluvial sources *(Figure 1)*.

Soils within 'Gill Guy' are texture contrast, with silty loam/loamy topsoils (15-20% clay in top 20cm) and clay loam/clay subsoils (30-60% clay in 20-100cm). Soils range from red Chromosols in the northern half of the paddock to red/grey transitional Sodosols/Vertosols in the southern half of the paddock. Gilgai microrelief present in some areas within the southern portion of the paddock is indicative of shrink-swell soil behaviour.

Conversations with the grower suggest that the adoption of minimum till and retained residue farming practices has greatly improved the soil physical behaviour of 'Gill Guy', which can display dispersive characteristics when wet. The paddock has appeared responsive to pre canola low rate (400kg/ha) gypsum applications.

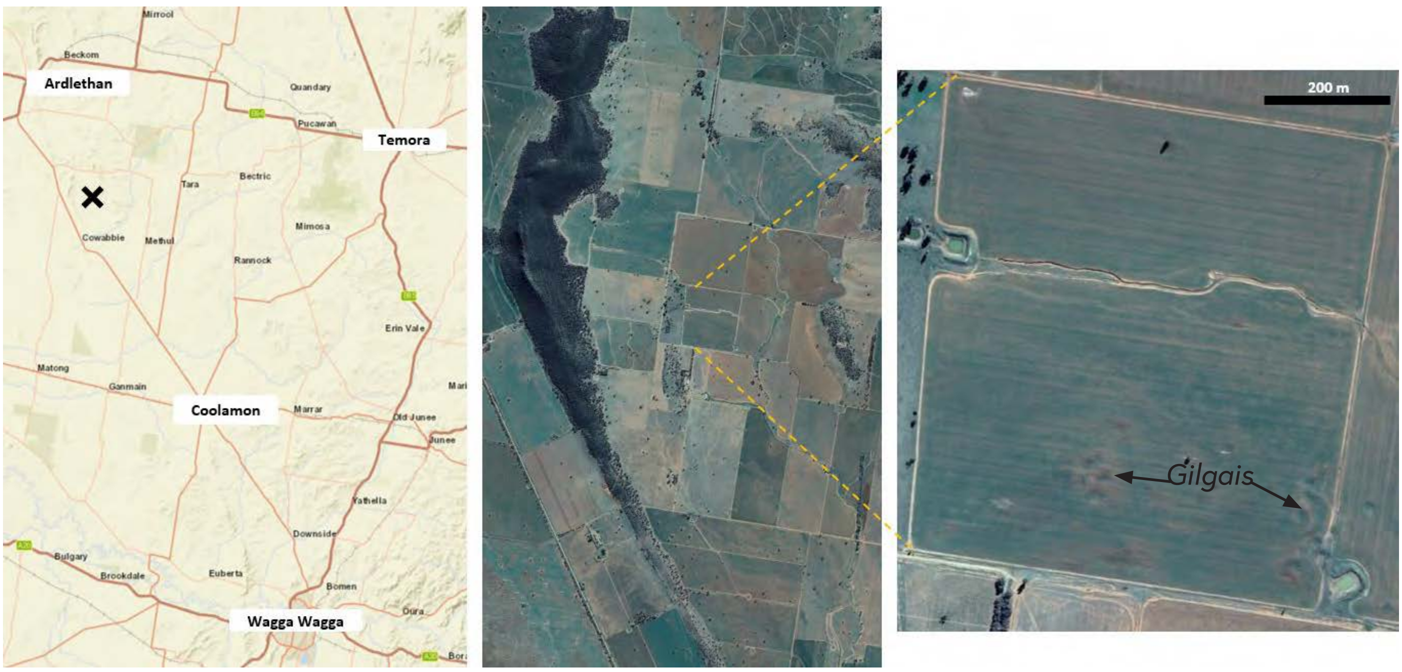


Figure 1: Location of 'Gill Guy' paddock and aerial imagery showing regional context and paddock plan view.

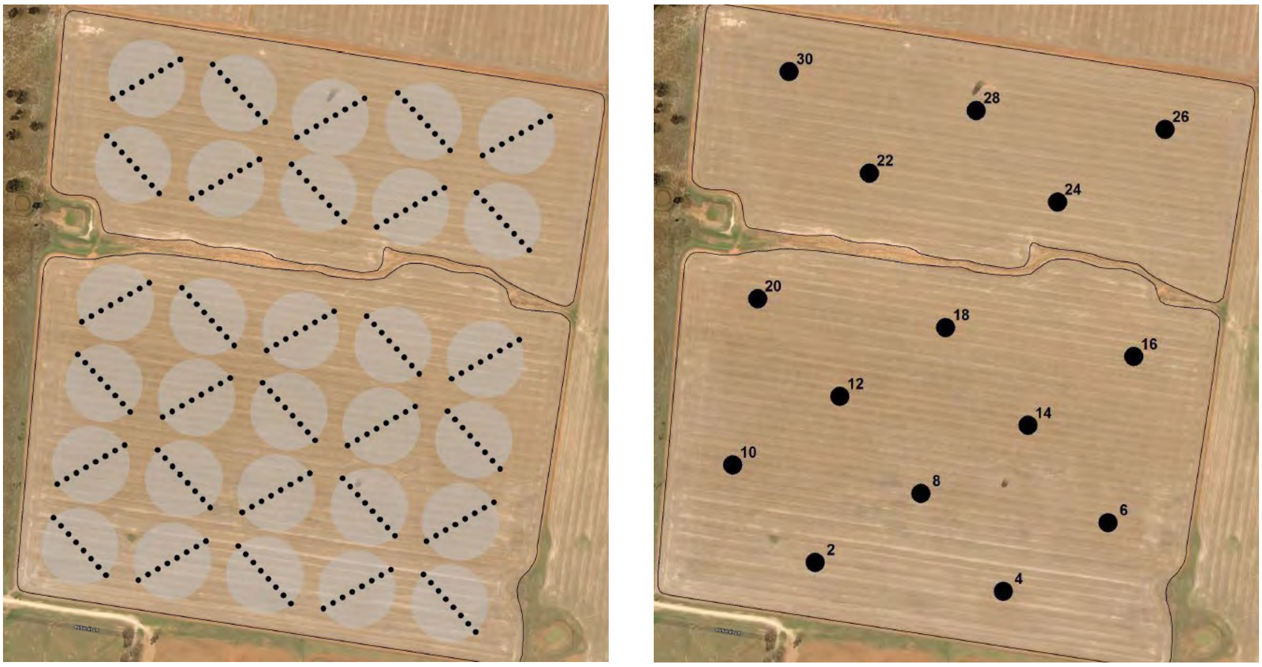


Figure 2: Grid soil sampling plan (left), showing the location of each 0-10cm 2ha soil test (grey circles) composed of 8 bulked subsamples (black dots). Right: Deep soil (0-10cm, 10-20cm, 20-60cm, 60-100cm) and shallow segmented pH (0-5cm, 5-10cm, 10-15cm, 15-20cm) sampling plan (25m diameter points).

Soil Sampling

Soil sampling was undertaken on August 4 2018. A standard 2ha grid soil sampling plan was designed in keeping with standard methodology of Precision Agriculture Pty Ltd (commercially available direct grid soil sampling service) (Figure 2, left). 0-10cm grid soil samples were collected as per Precision Agriculture's standard practice of collecting 8 sub-samples on a diagonal angle across a 100m transect for each sample point. Samples were collected using an Amity automated auger style sampler mounted on an ATV using a Trimble YUMA differential GPS signal. Sampling depth was checked with a ruler prior to and regularly throughout soil sampling.

Deep segmented soil samples were collected at every second sample point (Figure 2, right) using a ute-mounted Daybreak hydraulic soil corer and Trimble YUMA GPS unit. Sampling intervals were 0-10cm, 10-20cm, 20-60cm and 60-100cm. Three cores were taken at each point, with samples collected within 25m of the GPS location. An additional 0-10cm/10-20cm core was sampled immediately next to each of the deep cores to ensure adequate soil volume was collected (six sub-samples total).

A further deep core was collected at each point to collect soil aggregates from depths of 5cm, 15cm, 40cm and 80cm for Emerson's slaking/dispersion tests.

Two 0-5cm/5-10cm/10-15cm/15-20cm segmented cores were also collected immediately alongside each deep core sample (six sub-samples total) using an open sided manual soil sampler (Spurr probe or 'dig-stick'). A pH test kit was used in the field on a separate core to visualise the soil pH profile.

EM38 Mapping

'Gill Guy' paddock was EM38 and elevation surveyed in April 2017 by Precision Agriculture Pty Ltd using a Geonics EM38 unit operated in the vertical dipole. Soil EC_a in milliSiemens per meter (mS/m) was recorded on a 3-4m data spacing at a swath width of 25m. Data points were recorded using a Real Time Kinematic (RTK) portable base station correction signal.

EC_a data from the 1m coil (0-150cm depth) was processed into a 5m pixel grid output via an Inverse Distance Weighted (IDW) interpolation (50m search extent, 30 neighbours). EC_a values were derived for each sampling point by performing a weighted average on the EC_a values of the grid cells co-located within a 25m diameter of each sample GPS point *(Figure 3)*.

Results

EC_a

EC_a as collected by EM38 *(Figure 3)* demonstrated a high degree of spatial variability across 'Gill Guy' (n = 6099, CV = 31.4%). Highest EC_a values were present in the southern half of the paddock, coinciding with areas containing gilgai microrelief and the grower's knowledge of soils more prone to dispersive symptoms. EC_a values were lowest

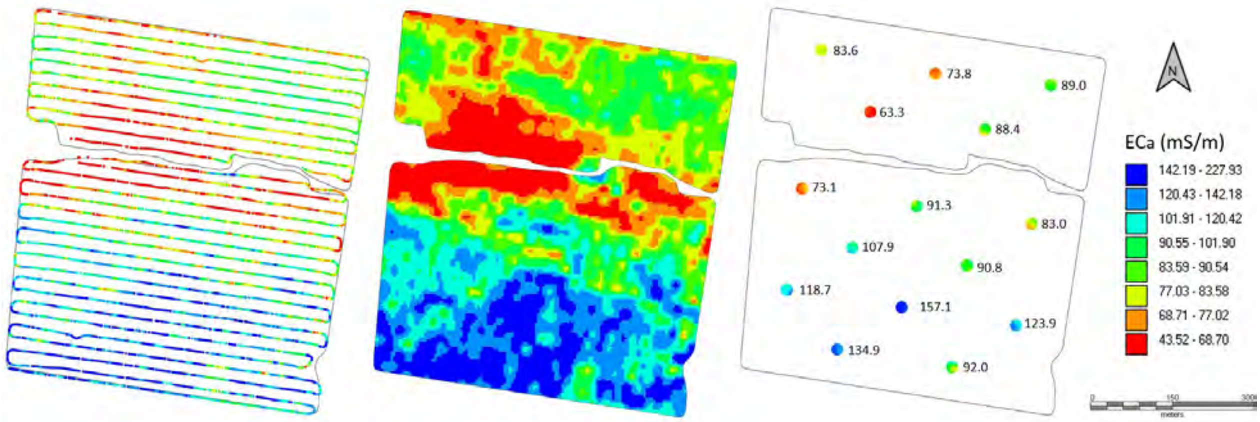


Figure 3: EC_a (mS/m), as collected by EM38 in the vertical dipole, 1m sensor (0-150cm depth). Left = raw data; middle = 5m grid Inverse Distance Weighted interpolated EM38; right = 25m diameter sample points used to derive average EC_a values.

around the drainage feature in the middle/northern half of the paddock whilst intermediate zones were located in the north-east corner and in the transitional area between the high and low zones. Linear regression analyses revealed positive correlations of varying strengths between EC_a and 0-100cm weighted average 1:5 EC, chlorides, MIR clay percentage and eCEC values *(Figure 4).*

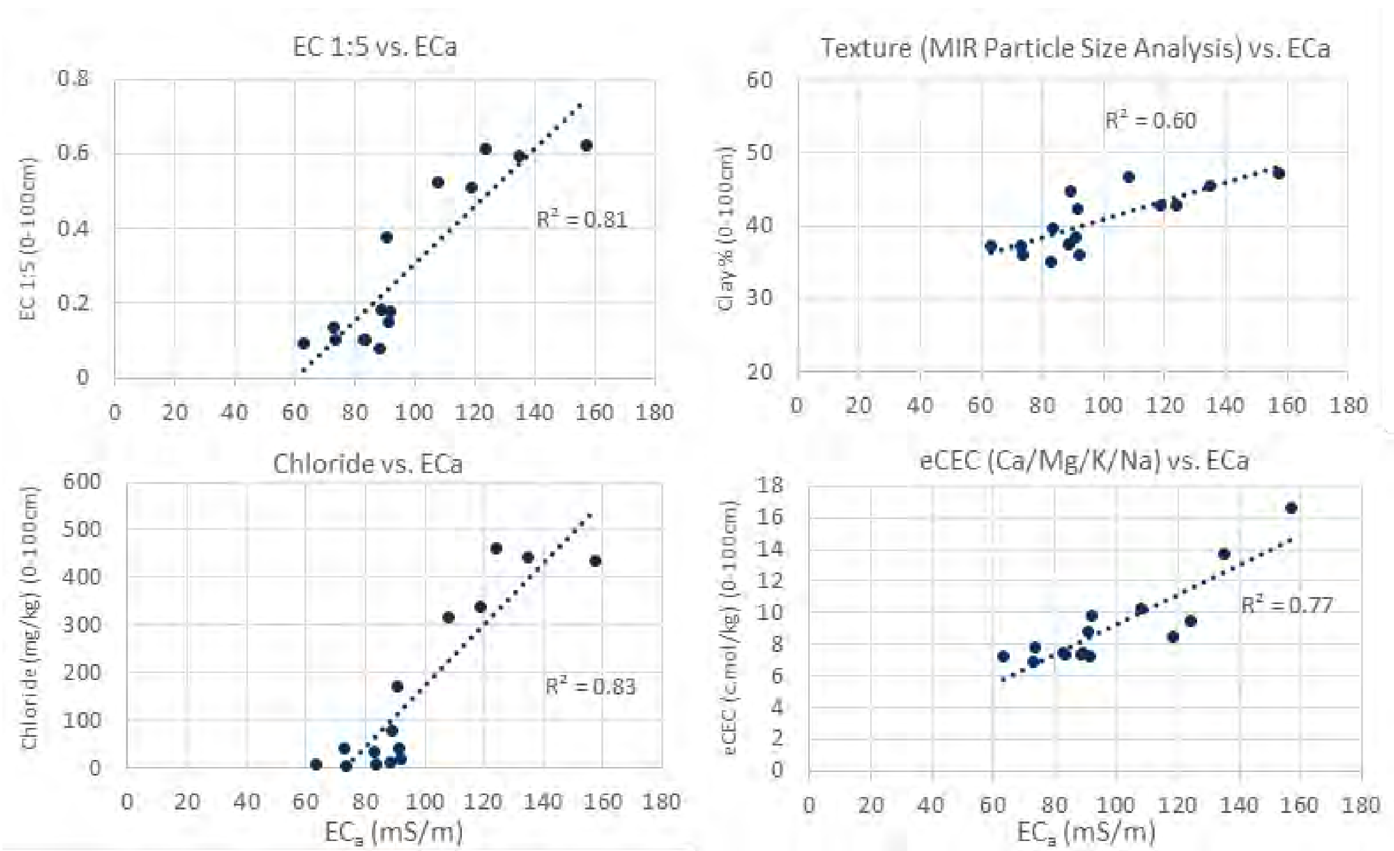


Figure 4: Linear regression analyses comparing EC_a as collected by EM38 mapping in the vertical dipole, 1 m coil (0-150cm) to weighted average values for 0-100cm depth of a number of key soil parameters; EC 1:5, Chloride, Clay % and eCEC.

Further data interrogation comparing the correlation between eCEC and texture as measured by MIR spectroscopy revealed two distinct data populations present within 'Gill Guy'. Soil samples collected from the southern section of the paddock possessed higher eCEC levels at a given clay percentage than soils from the northern half of the paddock *(Figure 5).*

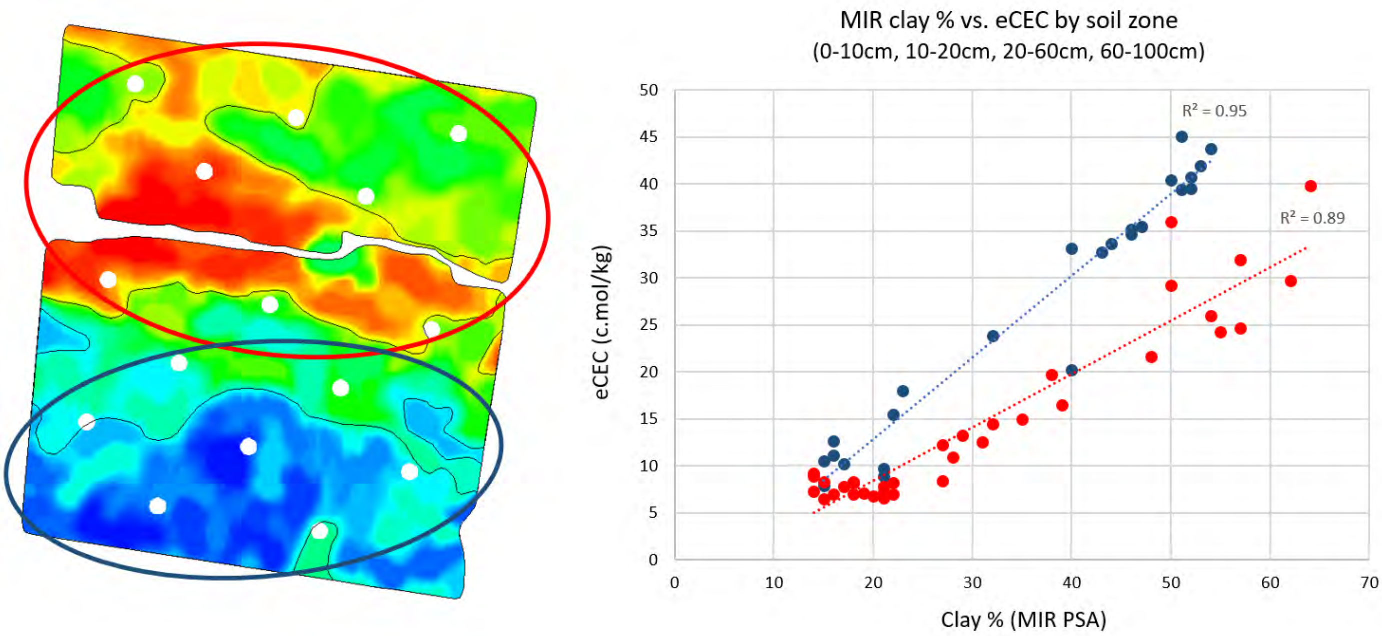


Figure 5: Left: EC_a as measured by EM38 at 'Gill Guy' where red = low EC_a, green = intermediate EC_a and blue = high EC_a. Right: eCEC (cmol/kg) versus clay % (as measured by MIR spectroscopy) for 0-10cm, 10-20cm, 20-60cm and 60-100cm samples taken at the 15 deep sample sites across 'Gill Guy'. Sample points are colour coded red or blue correlating with their location in the paddock as circled on the EC_a map.

These relationships are indicative of differing clay mineralogy between the two zones, which may be due to alternate parent lithologies/ sediment sources or weathering histories. In the northern half of the paddock, clays are most likely dominated by illite (K-mica), which has a CEC value of 20-40cmol/kg. In the southern half of the paddock, clays are most likely smectite dominated, which has a higher CEC of 80-120cmol/kg *(Shainberg and Levy, 2005)*. The presence of gilgai microrelief in the southern half of the paddock is supportive of a smectite dominated clay mineralogy due to its shrink/swell characteristics. Visual assessment of deep cores also reveals the contrasting nature of the two zones *(Figure 6).*

Figure 6: Contrasting 0-100 cm depth soil cores collected from the low EC_a zone (sample ID 22) and high EC_a zone (sample ID 8). Soil surface (0cm) is on right hand side.

Soil pH

0-10cm grid soil pH mapping returned an average pH of 5.3 ($CaCl_2$) across the paddock, ranging from 4.8-6.9 pH_{Ca}. 0-20cm averaged pH results from 5cm segmented sampling returned a pH_{Ca} range of 4.7-6.3, with a mean pH_{Ca} of 5.1 *(Figure 7).*

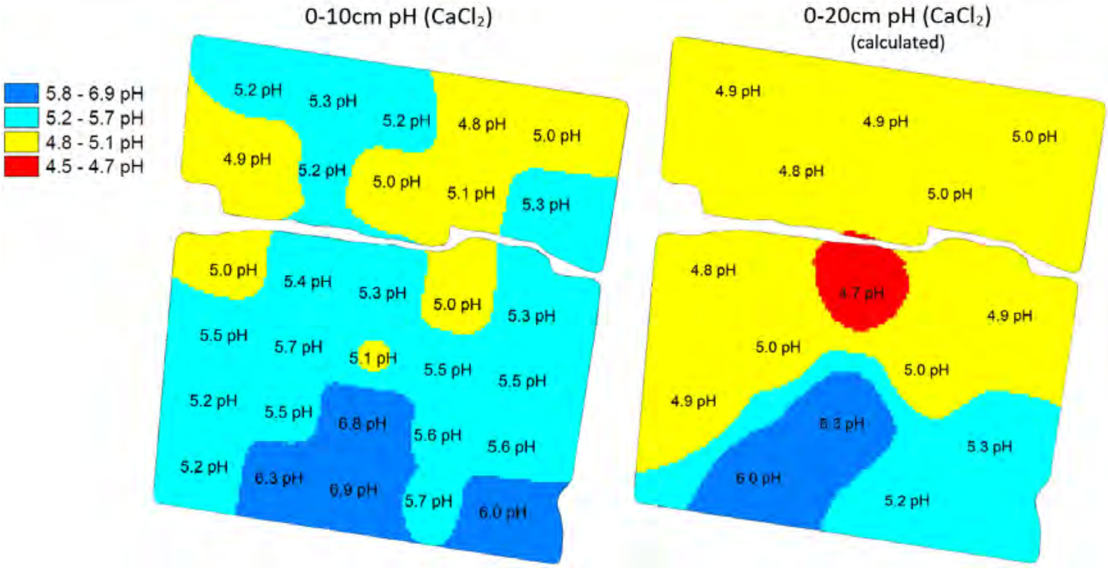
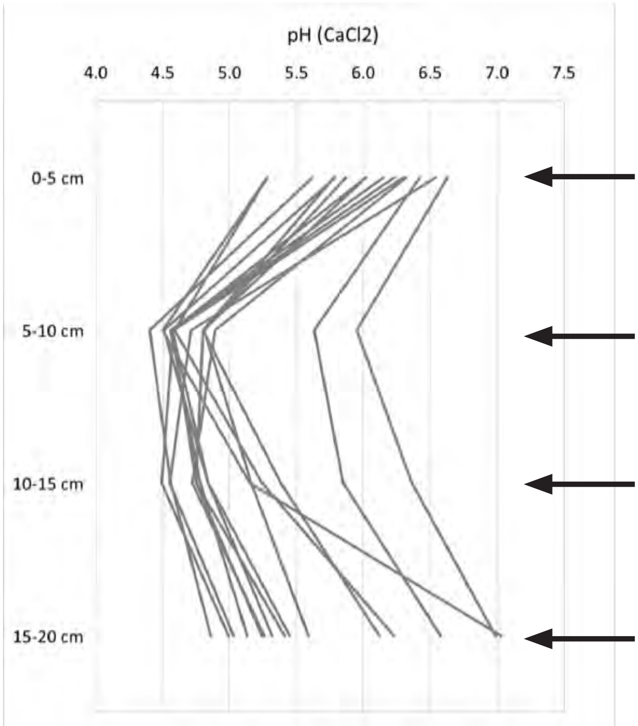


Figure 7: IDW interpolated 2ha grid soil sampling (0-10cm) results (left) and 4ha 0-20cm pH ($CaCl_2$) results (right).

5cm segmented pH tests showed the presence of a highly stratified pH profile (Figure 8), with a consistent trend of higher pH in the 0-5cm layer, lower pH across the 5-15cm depth and increasing pH in the 15-20cm zone. Variability across the site was least at the 5-10cm depth, with 13 out of 15 samples returning results between 4.4-5.0 pH_{Ca}. Within the 10-15cm depth, pH_{Ca} ranged from 4.5-6.4 whilst at 15-20cm, pH_{Ca} ranged from 4.9-7.0 pH *(Figure 9).*

There was a moderate to strong correlation at the 10-15cm depth between pH_{Ca} and EC_a via EM38 (R^2 = 0.82; *Figure 10*) and interestingly, an even stronger correlation between pH_{Ca} and 0-10cm grid soil eCEC (R^2 = 0.94; *Figure 11*). These relationships were also maintained at the 15-20cm depth (R^2 = 0.81 and 0.88, respectively).

A notable feature of the data was the tendency for the lower CEC samples to decrease in pH between the 5-10cm and 10-15cm layers, in contrast to the moderate and higher CEC samples which all began to increase in pH below the 5-10cm depth.
This indicates that the acidification front has moved deeper in the profile in soils of lower CEC (lower buffering capacities).



Average	Minimum	Maximum
6.02	5.28	6.63
4.79	4.40	5.95
5.03	4.49	6.36
5.68	4.86	7.03

Figure 8: Segmented (0-5cm, 5-10cm, 10-15cm, 15-20cm) pH ($CaCl_2$) results for 4ha resolution point locations within 'Gill Guy'

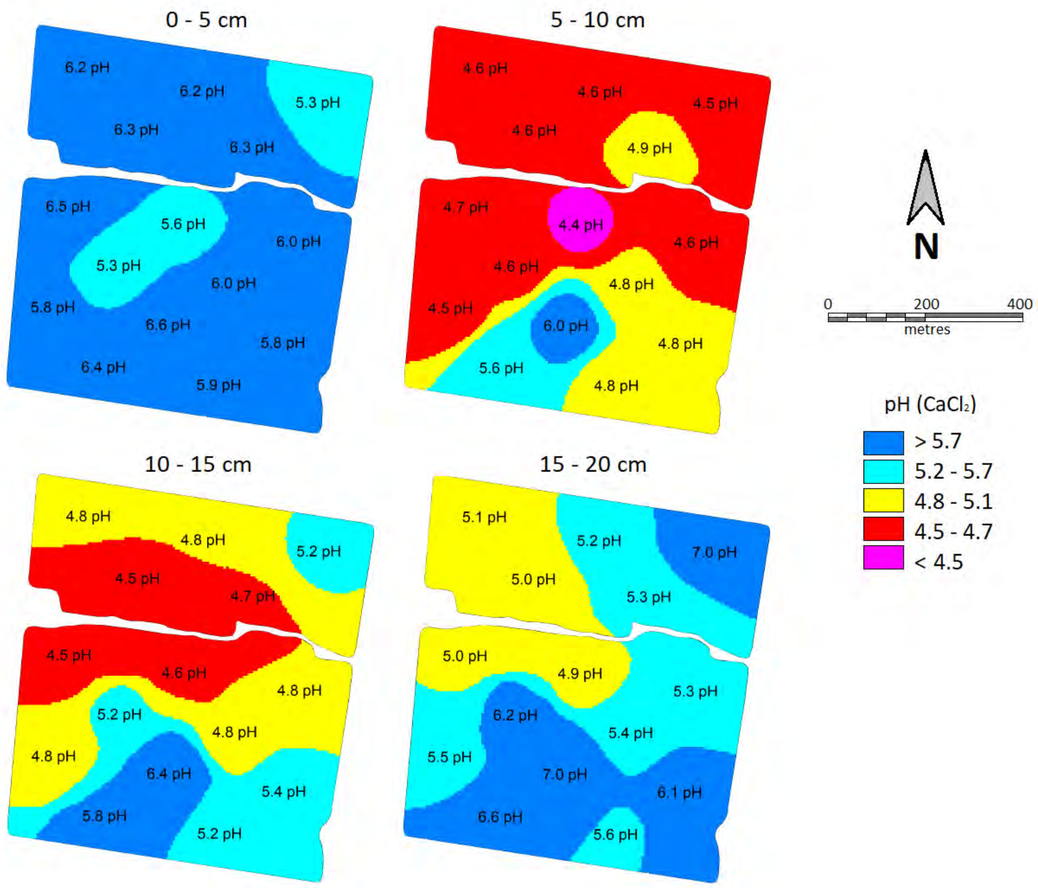


Figure 9: Segmented 5cm increment pH ($CaCl_2$) results for 4ha resolution point locations within 'Gill Guy'.

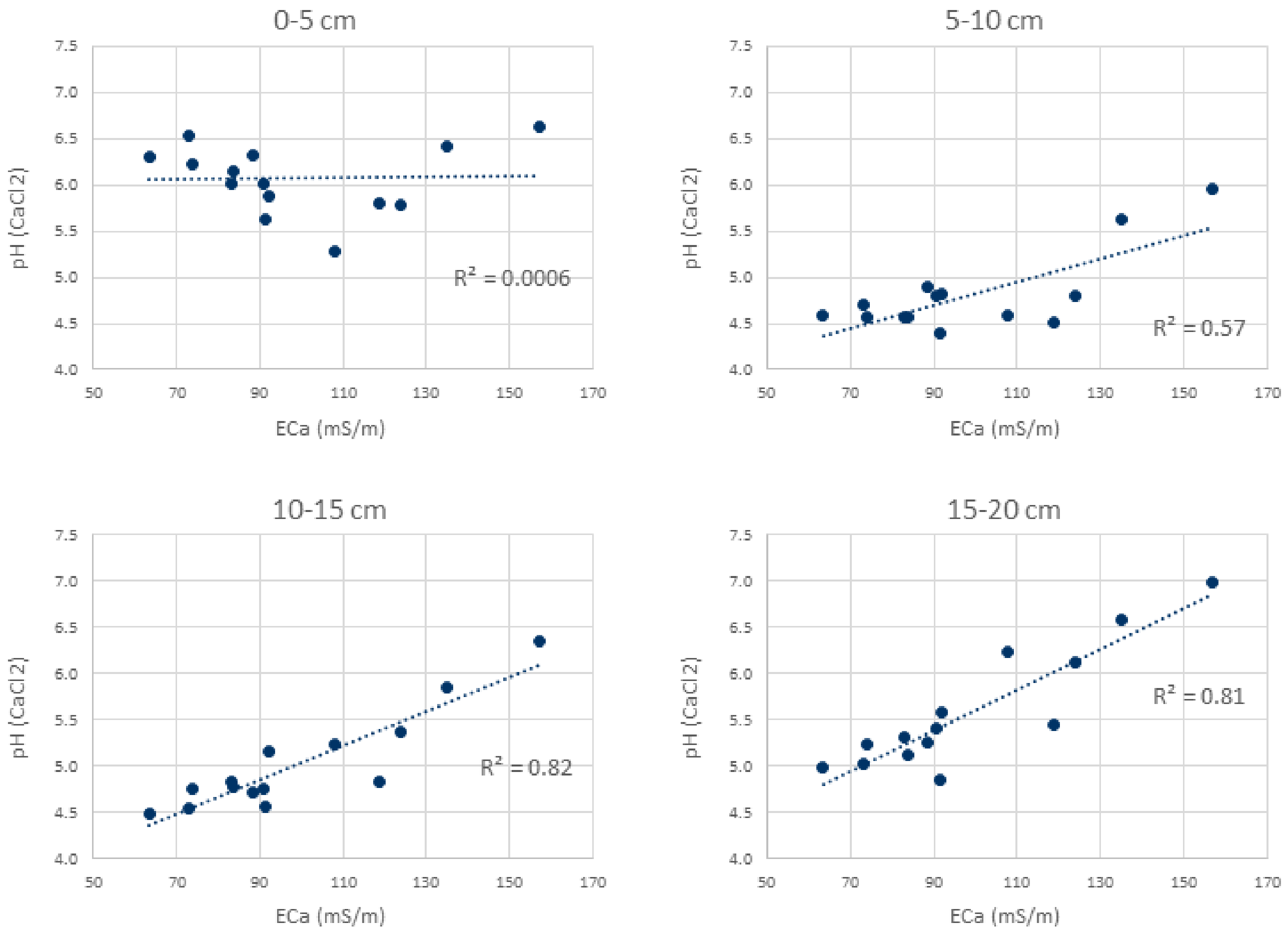


Figure 10: Correlation between pH ($CaCl_2$) and EC_a (as measured by EM38) at four depths (0-5cm, 5-10 cm, 10-15cm, 15-20cm) from 14 samples taken across 49ha paddock 'Gill Guy', Ardlethan, NSW (one outlier omitted).

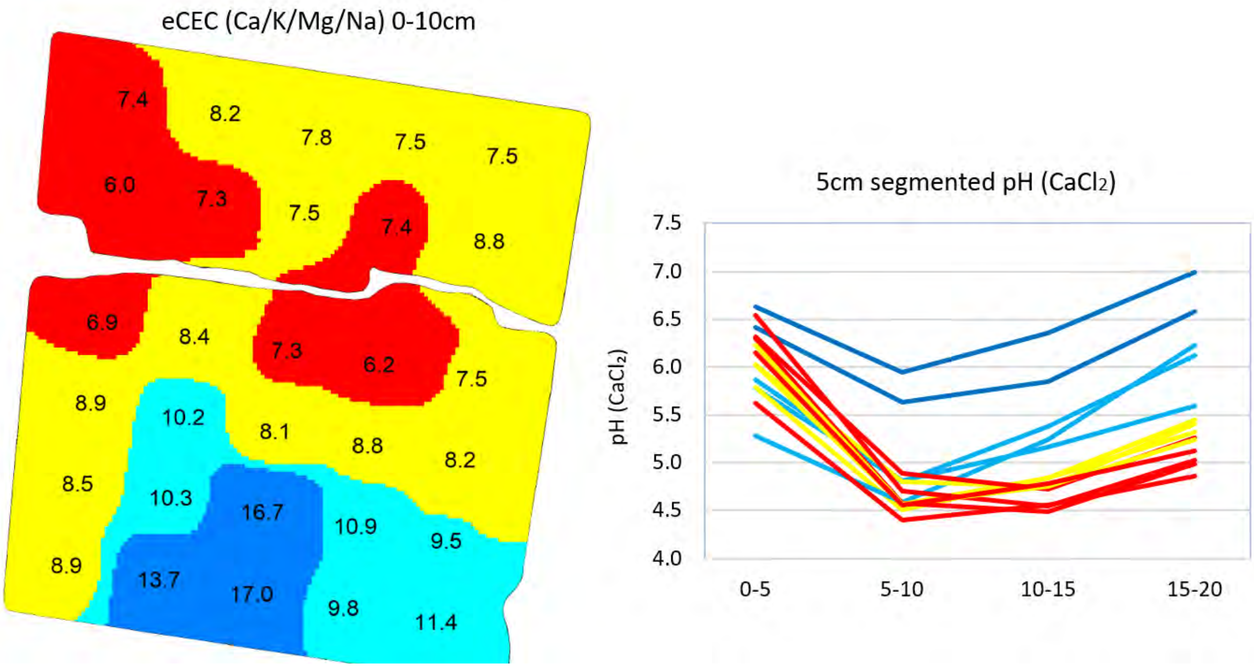


Figure 11: 0-10cm grid eCEC mapping (left) and 5cm segmented pH results (right), colour coded to match the 0-10cm eCEC value at that location (Red = eCEC less than 7.5cmol/kg; yellow = 7.5-9.4cmol/kg, light blue = 9.5-11.4cmol/kg, dark blue = greater than 11.5cmol/kg). Note the very poor correlation of eCEC to pH in the 0-5cm depth, reasonably poor correlation at 5-10cm depth and reasonably strong correlation at 10-15cm and 15-20cm depth.

Sodicity / dispersiveness

Within the 'Gill Guy' test paddock, EC_a was a good predictor of soil sodicity at the 0-100cm depth *(Figure 12)*.

There was also a reasonably strong correlation between sodium concentrations in the topsoil (0-10cm) and deeper in the profile (0-100cm) (R^2 = 0.78 and R^2 = 0.75 respectively for exchangeable sodium in cmol/kg and ESP).

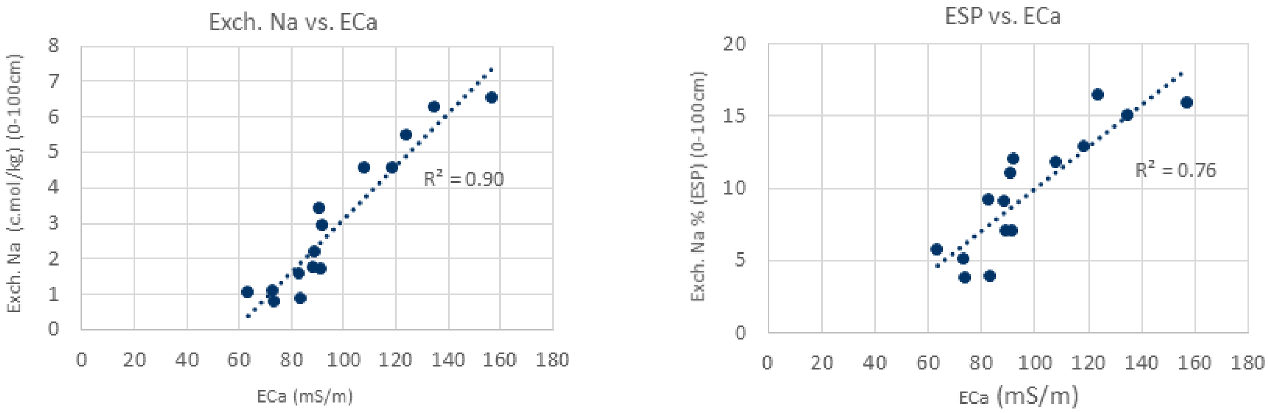


Figure 12: EC_a as measured by EM38 (vertical dipole, 1m coil) versus exchangeable sodium charge in cmol/kg (left) and Exchangeable Sodium Percent (ESP) (left). Exchangeable Sodium and ESP values are weighted averages of 0-100cm soil test (n = 15).

Emerson's dispersion/slaking tests performed at 5cm, 15cm, 40cm and 80cm on each soil test revealed the following qualitative observations:

- The most dispersive soil samples were from high EC_a / high Na zones at depths of 40cm or 80cm (southern side of the paddock, typically ESP 10-25%),.
- Samples from depth in lower EC_a zones displayed weak levels of dispersion (northern side of the paddock, typically 3 – 8 % ESP)
- Calcium Carbonate (free lime) nodules at depth in some samples in the high EC_a zone likely caused flocculation (i.e., prevented dispersion) despite ESP levels of $\geq$ 20% in some cases
- Only two samples showed substantial dispersion at 15cm depth, both were from higher EC_a / Na zones
- No samples displayed substantial dispersion at 5cm depth

Discussion

At 'Gill Guy', two key soil constraints were identified; soil acidity at 5-15cm depth and soil dispersiveness at > 20cm depth. Both of these constraints varied considerably in magnitude across the paddock, making a site specific input strategy highly warranted.

Segmented pH sampling within the top 20cm at 'Gill Guy' revealed that the 5-15cm depth layer was consistently more acidic than the 0-5cm and 15-20cm layers for the same location, however the severity and magnitude of the difference varied across the paddock. In the top 5cm, the range in pH_{Ca} was high (5.3-6.6) and correlated poorly with other soil characteristics. This is typical of minimum/no-till farming systems where accumulation of organic matter at the soil surface results in a relatively more alkaline band in the top few centimetres (regardless of liming history). At the 5-10cm depth, a sharp drop in pH was consistent among all soil samples except the two samples from gilgai areas with much higher CEC/buffering capacities. pH_{Ca} was reasonably tightly confined to around 4.4-5.0 at this depth, irrespective of soil CEC/buffering capacity (outside of the gilgai area).

When sampled in a single segment (0-10cm 2ha grid, Figure 7), this acidic layer was masked by the more alkaline/buffered surface layer, with all sites returning pHCa values of ≥ 4.8. This pH level would not generally be considered yield constraining to most major broadacre crops grown in southern NSW (wheat, canola, barley) and it is therefore likely that lime inputs based on this sampling alone would be low or potentially delayed until subsequent seasons.

Transitioning to the 10-15cm and 15-20cm depths, the correlation between pH and EC_a/CEC increased substantially, with results indicating that in this example the acidification front is deeper in areas of lower buffering capacity. These findings support the use of EC_a (via EM38 or equivalent) and/or grid CEC mapping to strategically select sites for 5cm segmented soil sampling. The severity of subsurface acidity identified at 'Gill Guy' was relatively surprising being in a medium rainfall zone and further follow up work in different soil types, management practices and rainfall regimes will be necessary to both a) understand the regional extent of this problem and b) confirm if the relationship between EC_a and subsurface acidity identified at 'Gill Guy' is maintained in other settings and thus can be exploited as a more cost-effective way to map pH stratification.

Whilst this strategy may improve our ability to map the spatial variability of subsurface acidity, the treatment of stratified pH layers remains problematic. Findings arising from GRDC project *DAN00191 – Nitrogen fixing break crops and pastures for high rainfall zone acid soils* recommend targeting a lime rate of > 5.5 pH_{Ca} at the 0-10cm depth and using a full cultivation to incorporate lime and mix soil layers (Burns et al., 2017). The rationale behind this approach is that if a pH_{Ca} of at least 5.5 is not achieved within the top 10cm, lime will be entirely consumed in the topsoil and will not contribute any alkalinity to the subsurface. By raising the 0-10cm pH_{Ca} to 5.5, it is thought that this will prevent further acidification of subsurface layers.

If the subsurface (10-15cm) has already acidified however, a higher rate of lime will be required if an increase in the subsurface pH is desired. There is a great deal of work still to be done to determine best practice methods of treating subsurface acidity. Firstly, the development of a more sophisticated liming rate calculator that could be incorporated into a spatially referenced platform/software would be highly beneficial. In the 'Gill Guy' example, liming rates were determined using the NSW DPI liming chart (Upjohn et al., 2005) based on 5cm segmented results to 15cm depth on zones derived from EC_a and grid soil mapping. This is an intensive task, and the development of a calculator would be of great value to automate and simplify the process.

In addition to advancements in developing liming rates, further work is also required to determine the most effective (and economic) method to deliver the liming effect to subsurface layers. Lime is a highly insoluble product, and moves very slowly through the profile, particularly on heavier (finer textured) soils. Insolubility is even greater in high pH (alkaline) environments, such as those that occur on the soil surface if lime is not incorporated. Further studies to compare tillage methods (e.g. offset disc, scarifier, speed tiller, deep ripper), tillage timing (in relation to erosion risk and moisture loss), the effect of rainfall/soil type and potential alternative methods and products would be beneficial.

Taking a broader look at the soil properties across 'Gill Guy', the results of this study showed a reasonable (however not strong) level of correlation between EC_a, eCEC, sodium concentration, ESP and dispersiveness as observed through Emerson's dispersion tests. This suggests that in this example any number of these properties could be used to generate zones for variable rate gypsum applications.

This relationship has not been universally observed in the FarmLink region however and a larger study within southern NSW on a range of soil types is required to further refine best practice data layers to base variable rate gypsum inputs on. One promising potential method is measuring the turbidity of a soil/water solution via Optical Density (OD) to directly measure soil dispersiveness (see method outlined by Rengasamy, 2002).

The development of an objective, quantitative test of this nature that could be undertaken quickly and at low cost would be a great advancement for site-specific management of dispersive soils in southern NSW. In addition to more objective analysis methods, more defined gypsum rate recommendations will be required to perform more targeted, site-specific treatment of dispersive soils. As with liming, consideration of treatment depth and delivery method will be crucial. These factors are currently being explored by GRDC project *DAV00149 Understanding the Amelioration Processes of the Subsoil Application of Amendments in the Southern Region*, which also includes alternative treatments such as subsoil manuring.

The results of the 'Gill Guy' test paddock highlight the potential level of complexity that can be involved in quantifying and treating multiple soil constraints on a site-specific basis within the FarmLink region. They also highlight the value of multiple data layer types and a higher level of investment toward targeted soil sampling and analysis beyond the regular 0-10cm approach.

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