In-paddock variability — a snapshot and lessons learnt

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Key points

- Electromagnetic (EM) zoning was strongly related to differences in pH at 10–30cm depth in three out of four paddocks.
- All four paddocks showed variability in chemical properties, with the EM zoning showing good separation of chemical properties between zones. This provides confidence that the zoning was suitable.
- Variability in plant growth needs to be examined 'holistically' rather than just focussing on one variable. While a paddock may show variation in plant available water (PAW), it may be that sodicity or subsoil acidity is the key limiter in plant performance, not water availability *per se*.
- Existing precision agriculture (PA) datasets, in conjunction with selected chemistry sampling, can be used to indicate relative change in PAW across paddocks, but not the actual volume of water storage.

Background

Grain growers have readily adopted PA technologies, such as GPS-guidance, controlled-traffic and yield mapping. As such, they are the custodians of large datasets, including EM38 surveys (EM), yield maps, normalised difference vegetation index (NDVI) maps and soil analytical results. The oft-heard question from early adopters of PA technology is "I have filing cabinets and hard-drives full of data, but what can I do with it?".

This project evolved from initial discussions with growers from the Riverine Plains region, with the aim of understanding if growers could use the existing datasets they are collecting to create something greater. This included developing predictions of in-paddock variability, with a strong focus on developing predictions for PAW variations within a paddock so growers could create meaningful zones for nutrient management (especially nitrogen).

To further this understanding, Riverine Plains Inc, through the PA component of the GRDC investment *Maintaining profitability of stubble retained systems in the Riverine Plains region* (*Stubble*) project, partnered with several organisations with a range of skills and expertise, to explore the value of this approach. Unique to this aspect of the project was the collegial approach, where all parties appreciated the value of the work, and contributed considerable in-kind support. Riverine Plains Inc supported this work by identifying the required inputs (through grower consultation), managing the data and driving the interpretation of results by connecting with organisations with specialist skills.

All of the field work and measurement for this work was completed during the 2017 season. While the end-goal of being able to predict in-paddock variability through utilising existing datasets is still in progress, the various datasets collected through this work tell an interesting story around in-paddock variability, as described below.

In addition to the research described in this report, the PA component of the GRDC *Stubble* project also included a series of small plot nitrogen response trials across contrasting EM zones (Report on page 42), and the economic and financial value of zoning for variable rate nitrogen, based on EM38 surveys (Report on page 66).

Aim

The aims of the PA component of the GRDC *Stubble* project were to:

- deliver a pilot project to understand how soil parameters, including PAW, vary across a paddock and understand whether current PA datasets can correlate with PAW
- connect variations in soil moisture with nitrogen supply
- demonstrate the use of NDVI to inform variable rate applications of nitrogen
- determine the economic value of variable rate nitrogen application across paddocks, based on zones

Methodology

Four Riverine Plains region paddocks were selected at Howlong (canola), Rutherglen (wheat), Telford (wheat) and Yabba South (wheat). Existing EM38 maps were used to generate three initial zones for each paddock, labelled the 'high, medium, and low EM zones'. A weather station was located in each paddock to provide local climatic data, with 1.4m depth capacitance soil moisture probes also installed into the 'high' and 'low' zones to determine the comparative depth and degree of moisture extraction by plants. Due to issues associated with the interpretation of technical data, the Telford results have been omitted from this report.

Sampling was done at common GPS-locations across each paddock. Incremental soil sampling was carried out to a depth of 0.6m for spatial soil chemistry, while intact cores were taken for PAW measurement. Incremental deep soil nitrogen (DSN) and dry matter (DM) sampling was carried out through the growing season and post-harvest.

Subsamples from all intact cores were used to measure PAW by water extraction from saturated samples at 10 and 1500kPa on ceramic pressure plates. Subsamples were also air-dried and processed through mid-infrared (MIR) spectral scanning and regression models to predict PAW directly from the spectra. The infrared spectra were recorded by diffuse reflectance for 10 seconds in a range from 8000–400cm^{-1} on <2mm, 0.5g subsamples, with the 4000–700cm^{-1} MIR region used to derive the partial least squares regression (PLSR) calibration models. This means the PAW of soils was tested directly and also predicted by MIR, which may provide a cost-effective alternative in the future.

Two sets of NDVI satellite images were taken across each paddock through the season to understand variability in plant 'greenness', which may be correlated to nitrogen supply. Where possible, yield maps were accessed from previous years, with yield map data also collected during 2017.

All these disparate datasets were then collated, aligned and interpolated in order to layer the data in a web-based mapping tool, and so interrogate and determine any relationships. This interrogation is still in-train, subject to ongoing funding.

Results

There is a huge dataset associated with this work, which cannot all be described in this report. As such, this report provides a snapshot of some key parameters.

The dates at which the various activities were carried out are listed in Table 1.

TABLE 1 Dates of activities at the Howlong, Rutherglen and Yabba South trial paddocks in 2017

Activity	Date
Soil chemistry sampling	16/5/17
Intact core sampling for PAW	7 and 8/6/17
End of tillering soil nitrogen, plant number, tiller number, DM cuts	29 and 30/8/17
Satellite NDVI	31/8/17
Satellite NDVI	15/10/17
Flowering DSN and DM cuts	24/10/17
Howlong harvest	7/12/17
Rutherglen harvest	15/12/17
Yabba South harvest	18/12/17

Paddock 1: Yabba South

Soil chemistry

Soil chemistry results from the Yabba South paddock show that soil pH was similar in the surface 0–10cm layer across the three zones, with values above pH_{Ca} 5.0 (Figure 1). However, the low zone showed a significant drop in pH in the 10–30cm depth compared with the other zones, which maintained their values.

No real differences between zones are seen in the soil electrical conductivity (EC) and exchangeable sodium percentage (ESP) values at the 0–10cm, 10–30cm and 30–60cm depths (Figures 2 and 4).

At the 0–10cm depth, organic carbon (OC) values show a decrease in the low zone (1.38%) compared with the medium (1.99%) and high (2.24%) zones, which is a difference of 0.86% (Figure 3).

The differences in pH and organic carbon levels across zones can be largely attributed to the cation exchange

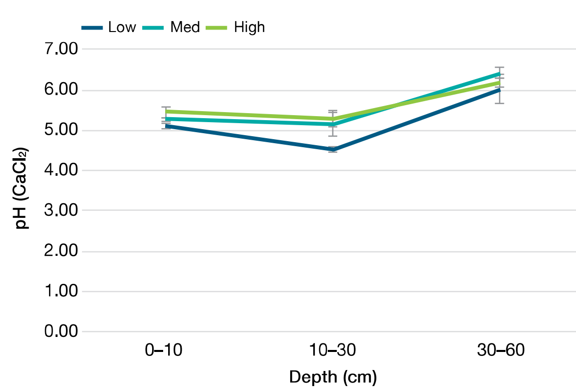

FIGURE 1 Soil pH_{Ca} across three zones to depth at Yabba South
The error bars are a measures of standard error.

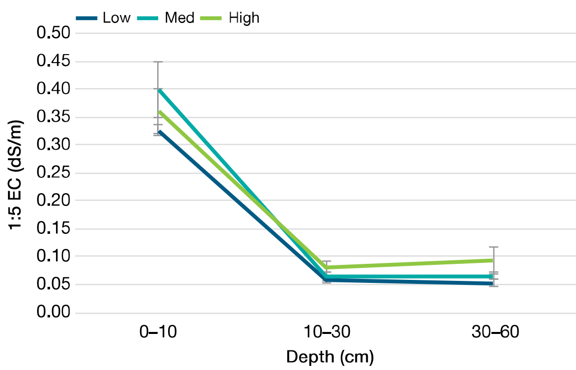

FIGURE 2 Soil EC across three zones to depth at Yabba South

Bars are measures of standard error.

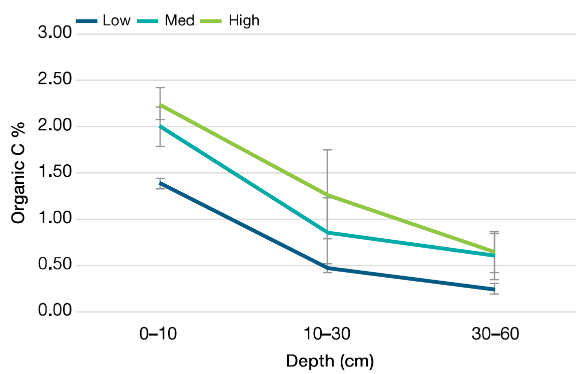

FIGURE 3 Organic carbon percentage across three zones to depth at Yabba South

Bars are measures of standard error.

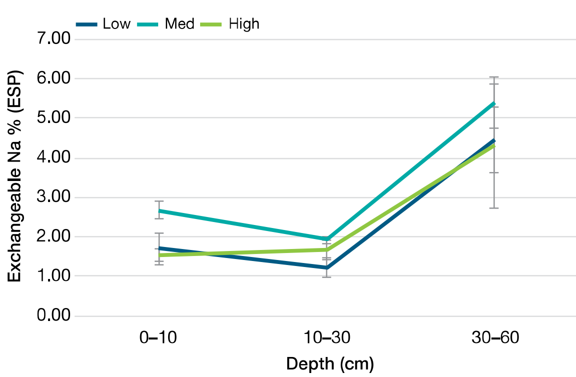

FIGURE 4 Exchangeable sodium percentage across three zones to depth at Yabba South

Bars are measures of standard error.

capacity (CEC) values across the zones (Figure 5). The CEC in the low zone is significantly less than the medium and high zones which means the low zone has less capacity to withstand chemical change, and so is likely to experience a greater rate of pH decline than higher CEC areas of the

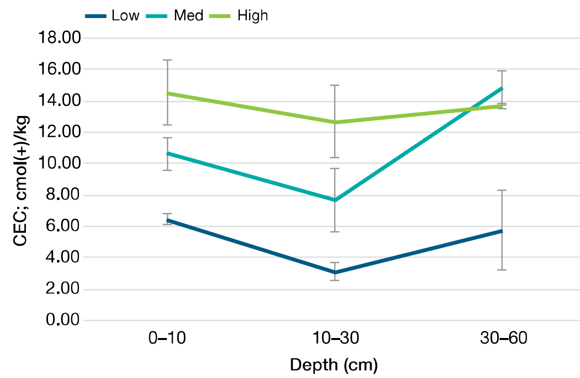

FIGURE 5 Effective cation exchange capacity across three zones to depth at Yabba South

Bars are measures of standard error

paddock. Clay content is indirectly measured by CEC, so soils with a higher clay content have a greater capacity to hold onto carbon through chemical interaction. This helps explain the differences in OC between zones.

Soil PAW

The decreased CEC of the low zone (which relates to decreased clay content) correlated well with the PAW measurements (Figure 6). Increasing clay content results in less PAW (as water is strongly absorbed onto clay surfaces), so it makes sense that the low zone, which has a lower CEC and less clay, has a higher PAW content on a mm/mm basis down to 30cm. This results in a 16mm increase in stored water in the profile in the low zone compared with the high zone (Table 2).

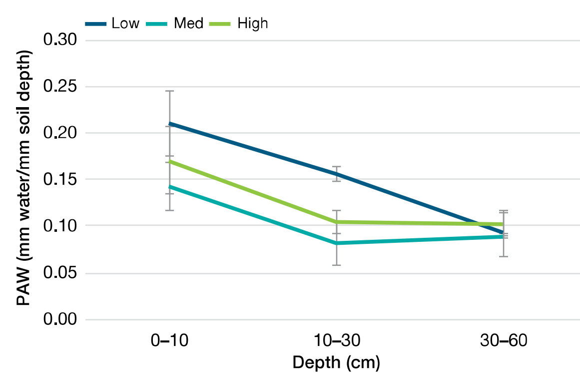

FIGURE 6 Plant available water across three zones to depth at Yabba South, measured as millimetres of water per millimetre soil depth

Note: These values increase when multiplied across the depth of sampling. For example, high zone 0–10cm depth = 0.17mm/mm x 100mm = 17.0 mm per 10cm depth.

Bars are measures of standard error



TABLE 2 Total PAW in the measured profile depth of 60cm across three zones at Yabba South, 2017

Zone	Total PAW/profile (mm)
High	68.1
Medium	65.5
Low	84.1

Dry matter and nitrogen

There were clear differences in DM between the low and medium–high zones (Figure 7). While the low zone has a higher PAW, and therefore a higher capacity to hold water, it will also dry out more quickly than heavier soils with a higher clay content. The dry spring conditions during 2017 likely meant the low zone 'ran out of puff' before the medium and high zones, which is reflected in the significantly lower DM results.

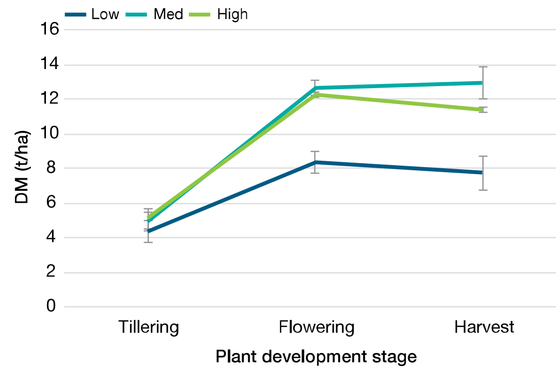

FIGURE 7 Dry matter across three zones to depth at Yabba South throughout the 2017 season

Bars are measures of standard error.

Comparison of measured PAW results and MIR predictions

The conventional method of measuring PAW is a slow, costly and laborious laboratory method using a series of pressure plates. The Australian Precision Ag Laboratory has been working with researchers to develop quick and cost-effective mid-infrared (MIR) predictions of PAW. The samples used for PAW analysis using pressure plate methodology were also used for MIR prediction.

Figure A and B show the strong correlation between the measured and predicted values for the Yabba South paddock. This means PAW may become a common-place parameter incorporated within a routine soil surface test, which would provide timely and highly valuable information.

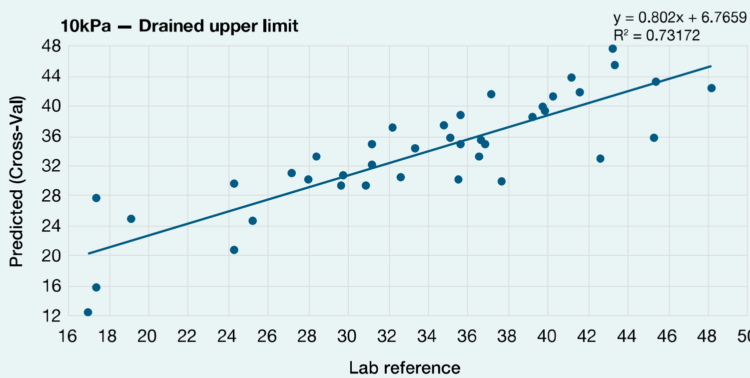

FIGURE A The relationship between the measured crop lower limit and the predicted value based on laboratory MIR analysis of the same samples

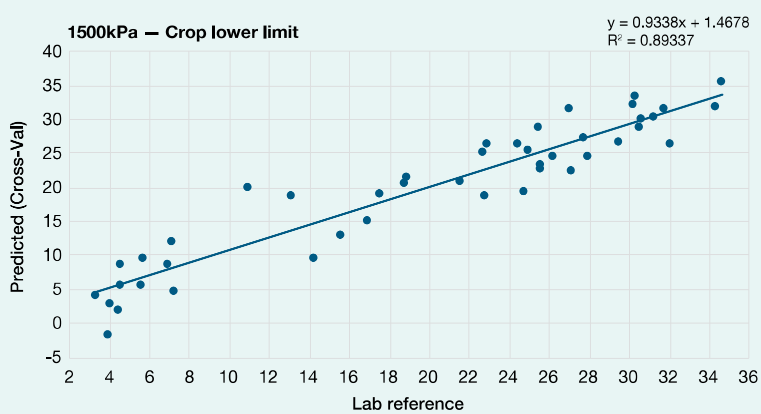

FIGURE B The relationship between the measured drained upper limit and the predicted value based on laboratory MIR analysis of the same samples

The mineral nitrogen numbers also reflect the variable production potential across the paddock (Figure 8). While all the nitrogen values at sowing are high (200–300kg N/ha) the high zone is lower, likely due to greater depletion of nitrogen from the previous crop.

The spatial data in Figure 9 shows how the EM zones created at the start of the 2017 season align with the NDVI values collected in-crop as well as the yield map. The yield map clearly shows the variation in productivity across the paddock, to the degree that assigning average yield values for each zone would be of limited value. The NDVI imagery from October 2017 clearly shows that the lighter soils of the low zone in the middle of the paddock are running out of water (indicated by the dark red colouring), which has resulted in a DM decrease and the yield penalty as seen on the yield map.

Paddock 2: Rutherglen

Soil chemistry

Soil chemistry results for the Rutherglen paddock show that while the soil pH_{Ca} values are above 5.0 in the surface 0–10cm, they decline in the 10–30cm zone to a range of pH_{Ca} 4.2–4.5 units (Figure 10). This resulted in aluminium levels of between 10–25 %Al (data not shown), which is likely to have a negative effect on plant growth. The pH drop in the 10–30cm zone corresponds to a decrease in the CEC in that zone (Figure 14), with the lower CEC (and clay content) at that depth meaning the soil has less ability to withstand chemical change and making it liable to greater rates of acidification. Although the differences are small, the high zone has a slightly higher pH_{Ca} value and associated CEC value than the low and medium zones, which also corresponds to a slightly higher organic carbon value (Figure 12).

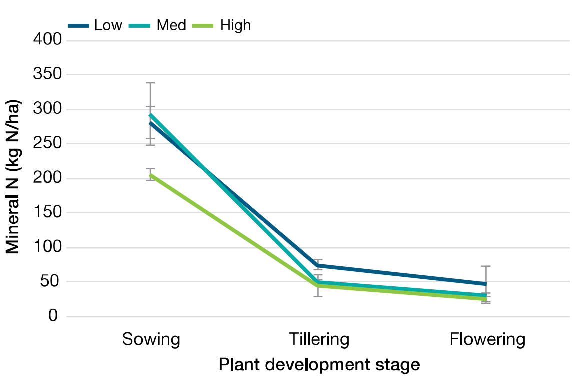

FIGURE 8 Mineral nitrogen to 60cm across three zones to depth at Yabba South throughout the 2017 season

Bars are measures of standard error

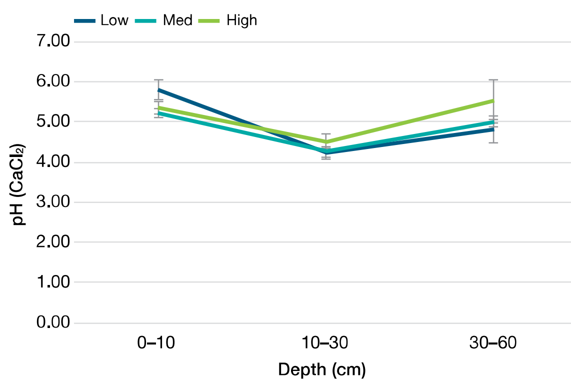

FIGURE 10 Soil pH_{Ca} across three zones to depth at Rutherglen

Bars are measures of standard error

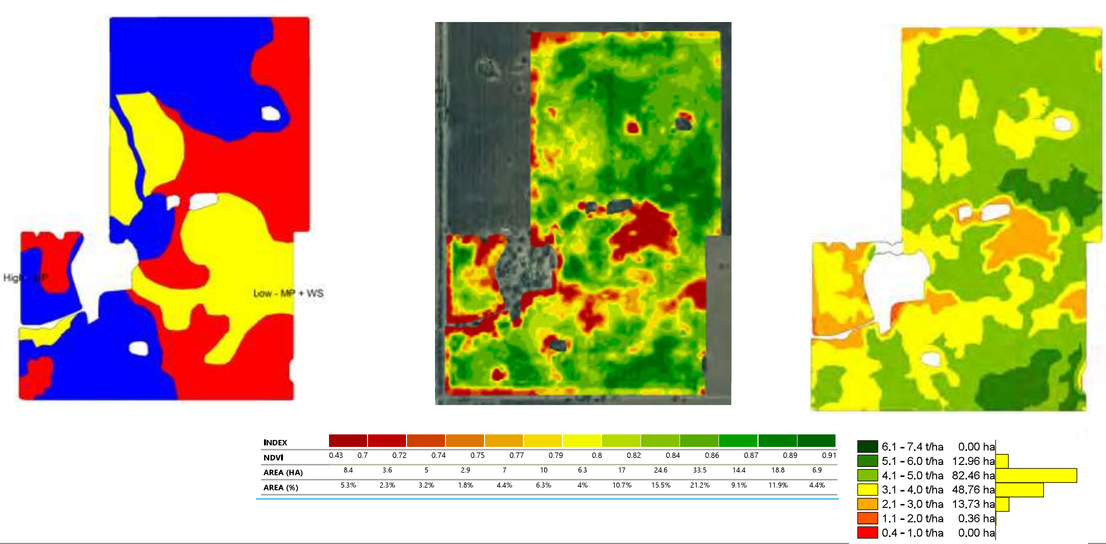

FIGURE 9 The allocation of zones and location of the weather station and soil moisture probes, NDVI satellite imagery collected 21 October 2017 and the Yabba South paddock yield map, 2017

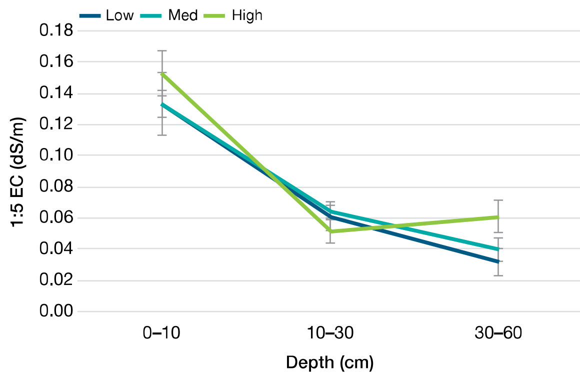

FIGURE 11 Soil EC across three zones to depth at Rutherglen
Bars are measures of standard error

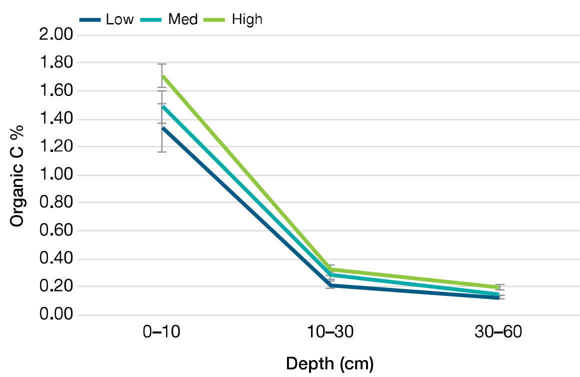

FIGURE 12 Organic carbon across three zones to depth at Rutherglen
Bars are measures of standard error

The soil EC values show limited differences between the zones (Figure 11), while the exchangeable sodium percentages (ESP) does show an increase in ESP (sodicity) at depth in the high zone (Figure 13).

Soil PAW

The higher CEC value of the high zone (Figure 14) correlates well with the plant available water (PAW) measures. This is based on the assumption that the high zone has a higher clay content at depth, which is supported by MIR predictions (data not shown). These PAW results show that the low and medium zones maintain a relatively constant PAW at depth, however the high zone PAW decreases significantly at depth (Figure 15), with approximately 40mm less water storage to 60cm depth compared to the low and medium zones (Table 3).

Dry matter and nitrogen

The DM cuts from the Rutherglen paddock show little variation between the zones throughout the season (Figure 16). This is aligned with the high starting mineral nitrogen values, which become relatively uniform as the season progressed (Figure 17).

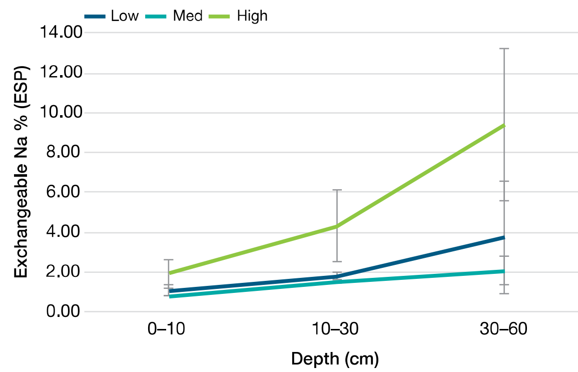

FIGURE 13 Exchangeable sodium percentage across three zones to depth at Rutherglen
Bars are measures of standard error

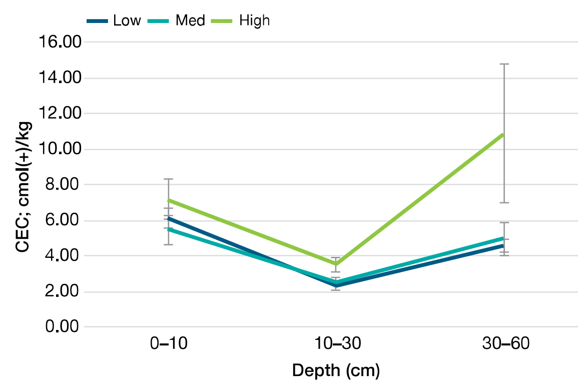

FIGURE 14 Effective cation exchange capacity across three zones at Rutherglen
Bars are measures of standard error

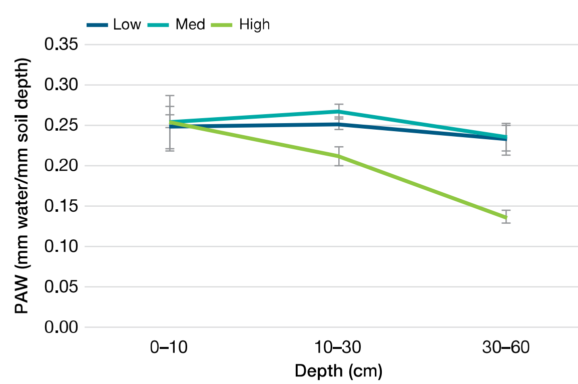

FIGURE 15 Plant available water across three zones to depth at Rutherglen, measured as millimetres of water per millimetre of soil depth
Note: These values increase when multiplied across the depth of sampling. For example, high zone 0–10cm depth = 0.17mm/mm x 100mm = 17.0mm per 10cm depth.

TABLE 3 Total PAW in the measured profile depth of 60cm across the three zones in the Rutherglen paddock

Zone	Total PAW/profile (mm)
High	108.4
Medium	148.9
Low	145.0

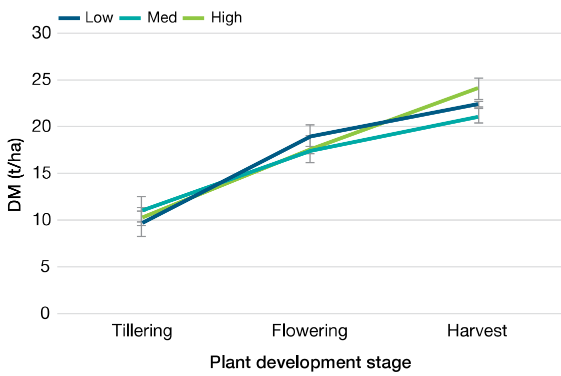

FIGURE 16 Dry matter across three zones to depth at Rutherglen throughout the 2017 season
Bars are measures of standard error

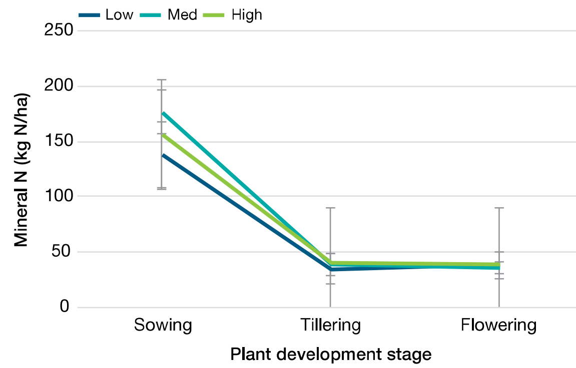

FIGURE 17 Mineral nitrogen to 60cm across three zones to depth at Rutherglen throughout the 2017 season

Zoning, NDVI and yield

The NDVI and yield maps show only limited variation in growth across the site (Figure 18), with the main variance being seen in the top half of the images. These images show that the lighter soil type in the low zone may be starting to run out of moisture, while the high zone may still have moisture available. Although the high zone has less total PAW (Table 3), the heavier clay content means that it will continue to supply PAW longer through a drying period than the low zone.

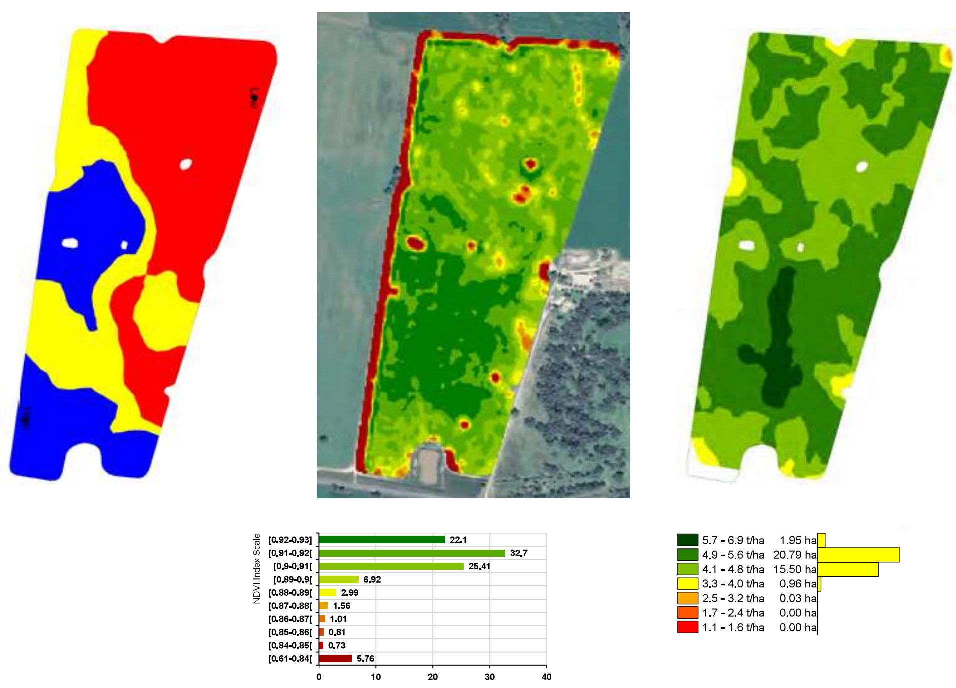

FIGURE 18 The allocation of zones and location of the weather station and soil moisture probes, NDVI satellite imagery collected 15 October 2017 and the Rutherglen paddock yield map, 2017

Paddock 3: Howlong

Soil chemistry

The Howlong paddock soil chemistry results tell a similar story to the other paddocks. The soil pH_{Ca} values are consistently lowest in the low zone, with the lowest values for all zones found at the 10–30cm depth (Figure 19). The EC and organic carbon values were also lowest in the low zone (Figures 20 and 21), as was ESP (Figure 22) and CEC (Figure 23).

Soil PAW

In conjunction with the MIR predictions of decreased clay content in the low zone (data not shown), these results indicate that the low zone has a lighter textured subsoil with a low capacity to buffer against chemical change. This means that the rate of subsoil acidification is likely to be higher in the low zone. It also means that the low zone has a slightly larger capacity to store PAW (Figure 24 and Table 4), however it is also likely to be the first zone to run out of water.

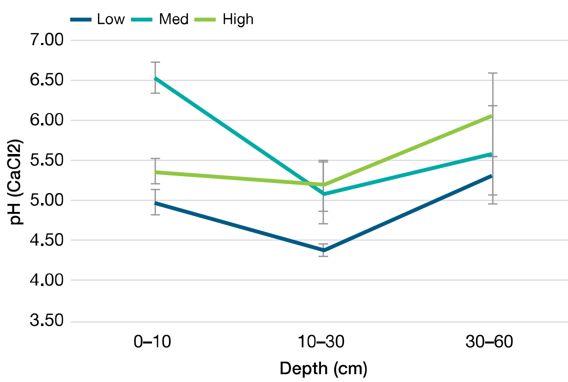

FIGURE 19 Soil pHCa across three zones to depth at Howlong
Bars are measures of standard error.

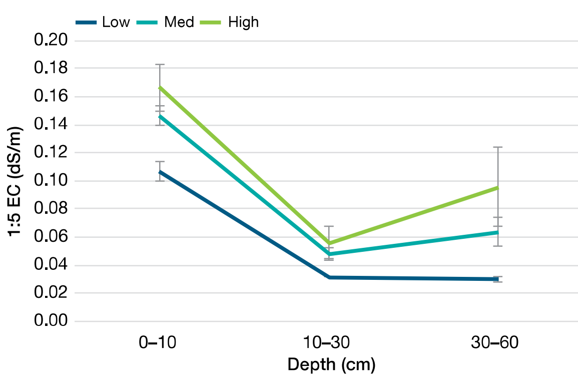

FIGURE 20 Soil EC across three zones to depth at Howlong
Bars are measures of standard error

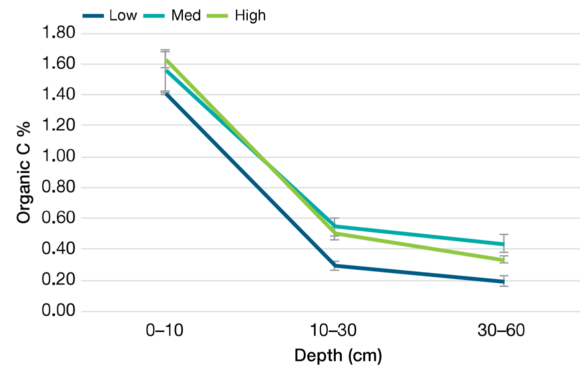

FIGURE 21 Organic carbon across three zones to depth at Howlong
Bars are measures of standard error

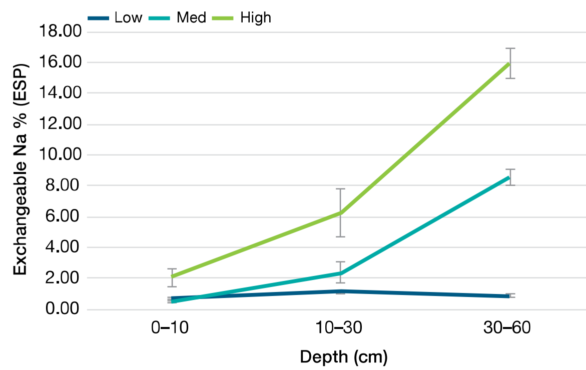

FIGURE 22 Exchangeable sodium percentage across three zones to depth at Howlong
Bars are measures of standard error

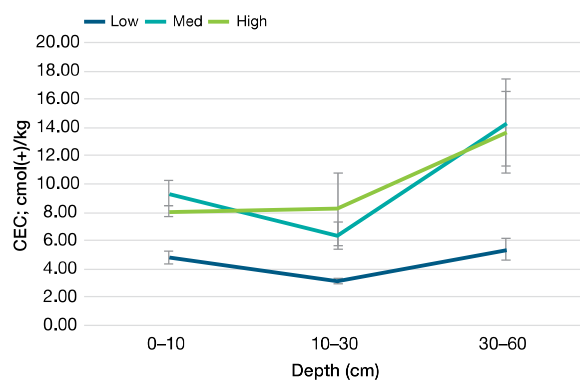

FIGURE 23 Effective cation exchange capacity across three zones to depth at Howlong
Bars are measures of standard error

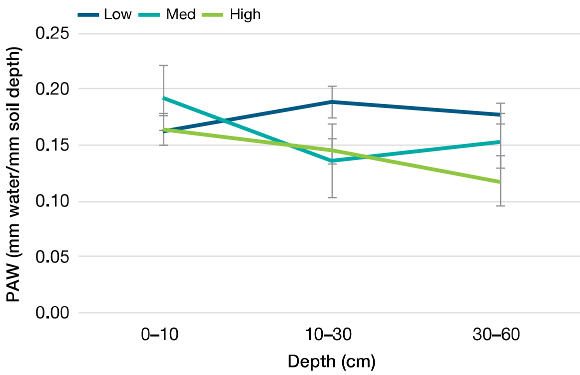

FIGURE 24 Plant available water across three zones to depth at Howlong, measured as millimetres of water per millimetre of soil depth

Note: These values increase when multiplied across the depth of sampling. For example, high zone 0–10cm depth = 0.17mm/mm x 100mm = 17.0 mm per 10cm depth.

Bars are measures of standard error

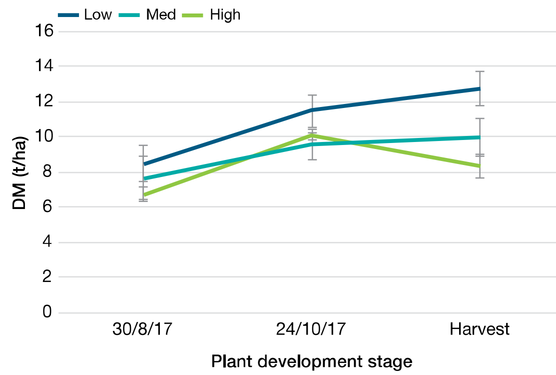

FIGURE 25 Dry matter across three zones to depth at Howlong throughout the 2017 season

Note: Dates are used rather than growth stages, as this crop was canola. While they were sampled at the same time as the wheat trials, the sampling date was not clearly aligned with crop stage; except for harvest

Bars are measures of standard error

TABLE 4 Total PAW in the measured profile depth of 60cm across the three zones in the Howlong paddock

Zone	Total PAW/profile (mm)
High	80.8
Medium	92.7
Low	107.5

While the low zone has a lighter texture, with a lower clay content than the high zone, the high zone has a significantly higher ESP value at depth (Figure 22). This means that the high zone has more clay and a greater ability to hold water as the profile dries out. However, higher sodicity at depth will mean that the plant roots cannot easily extract all the water from that zone due to poor structure. As such, the actual plant-extractable water content may be relatively even across the paddock, with differences in DM between zones likely due to the slight effects of aluminium toxicity on canola roots in the low zone (Figure 25).

Nitrogen

Availability of mineral nitrogen through the season was similar across EM zones (Figure 26), with no clear zonal effects on NDVI or yield (Figure 27). This suggests that nutrition was adequate across zones, with any differences in PAW not enough to cause yield differences as a result of the dry spring conditions of 2017.

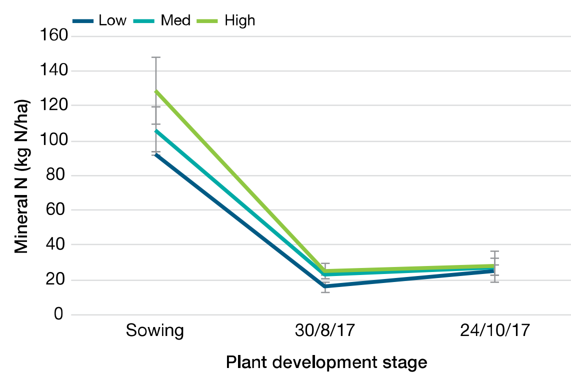

FIGURE 26 Mineral nitrogen to 60cm across three zones to depth at Howlong throughout the 2017 season

Bars are measures of standard error

Observations and comments

The field sampling from this project was intensive in order to attempt to validate the accuracy of the EM zoning for changes in soil chemical properties and to understand the relevance of that zoning for in-paddock PAW variance.

The results from this work show a clear delineation of soil chemical properties between zones, with significant differences being seen across a range of properties. The PAW measurements provided the link between these soil chemical parameters, and what that means for effective water uptake, with soil chemical parameters such as pH or sodicity sometimes acting to restrict plant uptake.

A key element of this project was the use of GPS-located sampling points, with all spatial datasets collected from the same locations within the paddock, somewhat reducing the spatial variance. The use of GPS-assisted sampling also means that these sampling points can be revisited in future to monitor change over time.

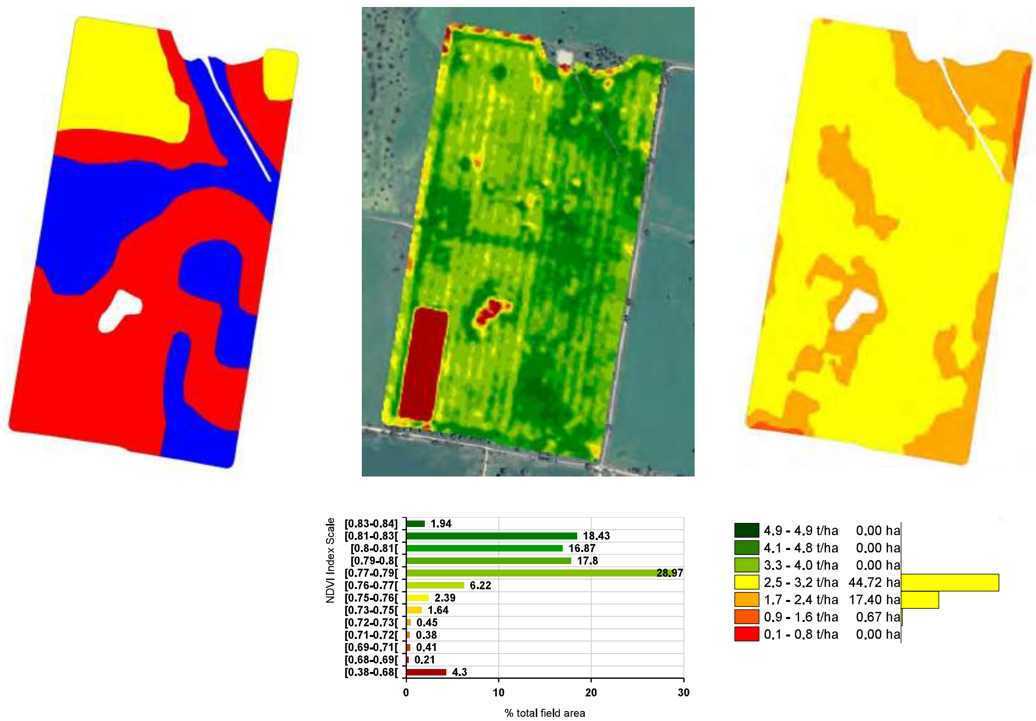

FIGURE 27 The allocation of zones and location of the weather station and soil moisture probes, NDVI satellite imagery collected 15 October 2017 and the Howlong paddock yield map, 2017

Note: The red rectangle is a small plot trial zone not related to this project, with fertiliser burn due to seeding issues also evident on the image right-hand side. Note also that canola NDVI will decrease in value with flowering due to decreased visible green area.

This research continues to evolve, on the basis that when this project commenced, the potential to use this approach to understand PAW variation in-paddock was unknown. Therefore, the methodology was designed to collect all datasets which may be of value in answering this question.

While this project has not yet achieved the end-point goal of using existing spatial datasets to predict in-paddock variation in PAW, and so inform variable rate zoning for in-crop nitrogen application, it has contributed to new knowledge around in-paddock variability as well as an understanding of the key drivers of change. Moreover, the spatial data analysis component of this work (still in development) has challenged existing approaches around management of spatial data, and how disparate datasets can be processed to enable 'cross-scale analysis'. This is likely to contribute to further learnings in future work.

Most importantly, this project has demonstrated that effective project learning can be achieved through partnerships built on a common vision of what could be, and an appreciation that sometimes you need to just make a start on a problem, in order to learn what you need to know.

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