Soil mapping in modern high-density apple orchards

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Summary

The use of EM38 soil mapping prior to planting has potential to provide significant benefit to the apple industry through informing soil amelioration work to improve soil homogeneity across orchard blocks. Reducing soil variability increases the chances of growing a uniform block of trees, which is essential for optimal productivity and efficient labour-use. This project aimed to determine a) if there is a relationship between soil zones defined by EM38 mapping, and productivity in apple orchard blocks, and b) if a relationship does exist, investigate whether productivity might be improved by conducting EM38 mapping prior to planting. EM38 soil maps, soil samples and tree productivity maps were collected and analysed from two high-density orchard blocks in the Stanthorpe region of Queensland. The results showed existence of a broad relationship between EM38 mapping zones and areas of high and low productivity in both blocks. Further data investigation and discussions with growers, suggested that use of the EM38 soil maps, together with grower knowledge of the site history, would have likely led to improved soil amelioration work prior to planting and changes to block design. This may have resulted in reduced variability in productivity and therefore greater profitability. It was concluded that EM38 soil mapping could be a cost-effective technology for guiding decision making at the point of site preparation and has significant potential to add value to orchard businesses. The combination of EM38 soil mapping with yield, and Normalized Difference Vegetation Index mapping technologies will likely provide greatest value in the future, particularly in the preparation of apple orchards for the use of robotics.

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Background

Queensland is Australia's third largest apple producing State with an industry valued at over $90M (Tancred and McGrath 2013). Orchard productivity has increased significantly in Queensland in the last 30 years, primarily through the transition of the industry to high-density planting systems. Future gains in productivity are likely to come from the implementation of mechanization and precision technologies.

Achieving maximum productivity in high-density systems requires every tree canopy to fill its allotted orchard space, both in height and width, to optimise light interception for the block (Middleton and McWaters 2001). Rapid development of a full fruiting canopy after planting has been identified as an essential success factor for orchard profitability (Hornblow and Wilson 2011) and lack of tree uniformity across orchard blocks significantly reduces yields (Wilton 2016). Labour-use efficiency is also improved in uniform blocks as simpler guidelines for pruning, thinning and picking can be given to workers, and mechanised platforms can be employed more easily. Future use of robotics in tree cropping systems will rely on minimal variability between trees.

Achieving uniform blocks of trees, however, is a significant challenge for the apple industry as the primary causes of variability are not clearly understood or managed. Little research has been undertaken in tree cropping systems to investigate practices and precision technologies that could be used either prior to planting or during the life of the orchard block to reduce tree variability.

Precision technologies are widely used in broad-acre cropping systems to measure and manage plant variability (Corwin and Plant 2005). Soil variability, as determined through the use of electromagnetic (EM38) mapping, has been strongly linked with variation in yield in these crops, and soil mapping together with variable rate technologies (for nitrogen in particular) are commonly used to improve uniformity of yield (Corwin and Plant 2005). Recent studies for the wine-grape industry have found good correlations between EM38 mapping, soil variability and grape vine vigour in vineyard blocks in New Zealand (Bramley et al. 2011, Trought et al. 2008).

It is likely that variability in soil characteristics is also an important driver of tree canopy and yield variability in apple orchards (Wilton 2016). Unlike broad-acre crops which are planted annually, there are few opportunities for intervention to amend soil variability once the trees have been planted, and careful preparation of blocks prior to planting is essential. The use of EM38 soil mapping prior to planting could potentially provide significant benefits through informing soil amelioration works to improve soil homogeneity, increasing the chances of growing a uniform and productive block of trees.

Project Objectives

This project aimed to investigate the research question *"could EM38 soil mapping be used in the preparation of apple orchard blocks prior to planting to improve uniformity, productivity and profitability?"* Specifically the project objectives were to:

1. Determine in apple orchard blocks if there is a relationship between soil zones defined by EM38 mapping and productivity,
2. If a relationship does exist, investigate whether productivity might have been improved by conducting EM38 mapping prior to planting to inform appropriate soil amelioration work.

The project sought to obtain preliminary data for the apple industry to inform future research directions in the areas of precision horticulture and soil management.

Methodology

EM38 soil mapping was used to distinguish broad zones of soil variability in five high-density commercial apple orchard blocks in the Stanthorpe region of Queensland, with two of these chosen for detailed investigation. Soil sampling and analysis was undertaken to investigate possible causes of the different EM38 readings and to 'ground-truth' the soil maps. Tree productivity was assessed across blocks to determine the relationship, if any, between tree productivity and the EM38 soil mapping zones. To investigate the second objective, growers were asked how the soil maps might have changed (or not) the process of site preparation undertaken prior to planting.

Site details

Orchard mapping sites were chosen based on the criteria that they were high-density blocks with a history of good productivity, and that they were representative of the modern plantings in the Stanthorpe region. Growers were invited to volunteer for the project through the 'black-spot warning bulletin' in 23 November 2015. Site details are shown in Table 1.

Table 1 – Orchard mapping site details

Site No.	Location	GPS coordinates	Size (ha)	Cultivar
1*	Cottonvale	28°30'33.91" S 151°56'31.08" E	3.3	'Cripps Pink'
2*	Fleurbaix	28°31'10.06" S 151°54'16.59" E	0.6	'Alvina Gala'
3	Pozieres	28°31'16.92" S 151°53'59.39" E	3.5	'Cripps Pink'
4	Pozieres	28°32'35.36" S 151°54'28.00" E	0.6	'Cripps Pink'
5	Pozieres	28°31'29.94" S 151°53'43.04" E	2.7	'Cripps Pink'

Notes:
Soils in the area are typically shallow to deep siliceous sands over a clay subsoil. All blocks were mature tree plantings trained with a central leader under hail netting. 'Cripps Pink' apples are marketed as Pink Lady™.
*Detailed results are presented for blocks 1 and 2.

EM38 soil mapping

EM38 soil mapping is used to create zones within paddocks and orchard blocks according to soil type (Davis et al. 1997). The EM38 sensors measure electrical conductivity. As the EM38 unit is pulled over the surface of the orchard floor, it takes thousands of point readings which can be interpolated to produce a zonal map. The readings have been correlated to clay content, soil moisture and salt levels (Johnson et al. 2001). The size of the EM38 values may be determined by one, two or all three of these soil characteristics.

EM38 soil mapping was undertaken by Precision Agriculture Pty Ltd (precisionagriculture.com.au) using standard methodology based on Davis et al. 1997. Maps were overlaid on Google Earth for interpretation.

Soil sampling and analysis

Soil samples were taken using a hand auger. Samples were placed in plastic snap-lock bags and delivered directly to the Vintessentials laboratory (Stanthorpe) for testing. Two sampling sites were located for each orchard block (using a smart phone GPS application) - one in the 'high' and one in the 'low' EM38 zone. Samples were taken across two depths, 1 - 30 cm and 30 - 60 cm. Soil samples were tested for particle size analysis (texture), pH, conductivity, organic matter, effective cation exchange capacity, phosphorous, nitrogen, sulphur, calcium, magnesium, potassium, sodium, aluminium, zinc, manganese, iron, copper, boron, chloride and labile carbon.

An additional seven soil samples were taken (at the 1 -30 cm depth only) in 'Site 1', and eight in 'Site 3' for assessment of nutrient variability. The same suite of soil tests was undertaken on these samples, with the exception of the particle size analysis.

Productivity mapping

An orchard productivity map was created for Site 1 by developing a 'productivity rating' system (Figure 1) specific to the orchard block. Tree ratings were based on potential productivity, as determined by tree size (whether or not the canopy filled the allotted space), vigour, and quality and quantity of fruiting wood. Walking up and down the orchard rows, a rating was given to every fifth tree in every second row. Using these ratings a simple productivity map was created in Microsoft Excel.

Figure 1 – Productivity rating for 'Cripps Pink' apple trees in orchard block 1, 2016.

Results and discussion

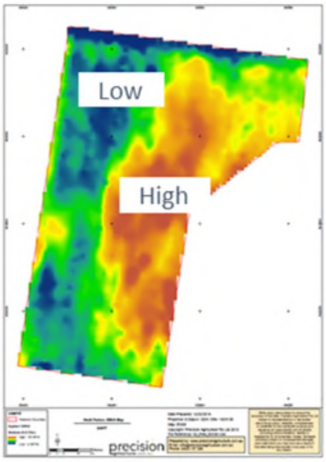
Detailed results and analysis for sites 1 and 2 are presented in this report as representative case-studies. EM38 soil maps and soil test results for all five sites have been provided to the growers.

Site 1 – 'Cripps Pink'

EM38 mapping showed the presence of two distinctive soil zones - a 'high' and a 'low' zone (Figure 2a). Analysis of soil samples taken from the two depths in each of these zones was undertaken to investigate the causes of these differences in EM38 readings. There were no differences in soil conductivity or soil moisture between the 'high' and 'low' EM38 zones at either the 1 - 30 cm or the 30 - 60 cm depth (Figure 2b). However, there was a significant difference in the clay content, with 22% clay measured in samples from the 'high' zone and 5.5% in the 'low' zone when averaged across the two sampling depths (Figure 2b). Consultation with Precision Agriculture Pty Ltd indicated that this difference in clay content alone, is significant enough to explain the differences between EM38 soil mapping zones in this orchard.

Figure 2 – ‘Site 1’ soil mapping showing (a) EM38 soil map with ‘high’ and ‘low’ EM38 zones identified, and (b) texture, conductivity and soil moisture analysis for soil samples taken at two depths from each zone.

a



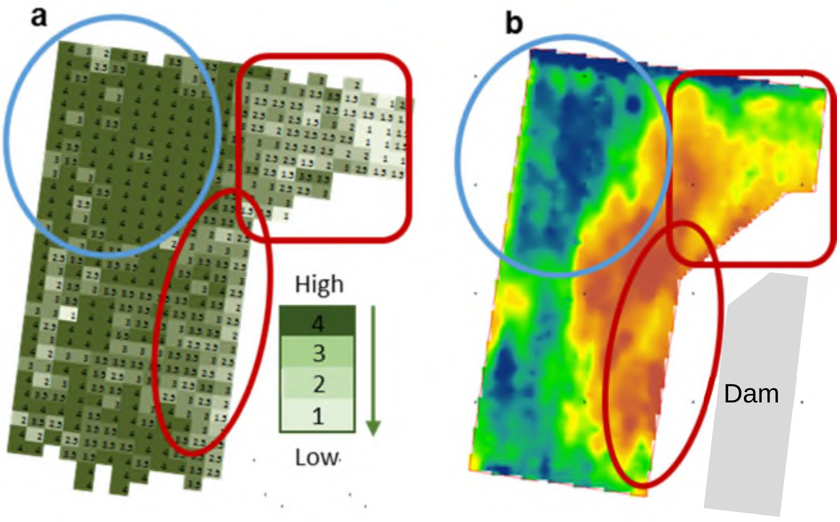
b

EM38 zone (soil depth in cm)	Texture	Conductivity (dS/m)	Moisture (%)
High (1 – 30)	20% clay 59% sand	0.068	14
High (30 – 60)	24% clay 53% sand	0.106	15
Low (1 – 30)	6% clay 75% sand	0.086	9
Low (30 – 60)	5% clay 80% sand	0.125	7

To determine if there was a relationship between the EM38 soil zones and tree productivity in this block, a productivity map was developed using the ‘Cripps Pink’ rating system described in Figure 1. Productivity varied across the orchard block (Figure 3a) and correlated broadly with the EM38 mapping zones. The least productive parts of the block were in the ‘high’ EM38 mapping zones near the dam, and the most productive part of the block was in the ‘low’ zone (Figure 3b). Investigations into the cause of poor tree growth in the ‘high’ zones suggested the problem was associated with proximity to the dam. Clay in the ‘high’ EM38 mapping zone is likely to have resulted from movement of bulk materials during dam construction. While the clay content itself was not great enough to be the primary cause of weak tree growth, poor soil physical structure resulting from the movement of materials may have had a negative impact. Water seepage from the dam into surrounding orchard could also have caused stunted tree growth in wet years.

The relationship between EM38 zones and productivity did not hold closely for all parts of the block. For example, the section of the block with the poorest tree productivity was in the far north-eastern corner (top-right in Figure 3a), but this section did not show the highest EM38 mapping values (top-right in Figure 3b). At the time of EM38 soil mapping, the dam was at about two-thirds capacity. Mapping undertaken in a wet season might show a closer relationship with tree productivity. There were no significant differences in organic matter content, pH or nutrient levels across the block (data not shown). Spatial analysis would be required to further investigate relationships between productivity and soil fertility.

Figure 3 – Relationship between (a) the productivity map of 'Site 1' and (b) the EM38 soil map. Blue outline is the region of highest productivity, red outline are regions of lowest productivity.



If EM38 mapping had been undertaken prior to planting in 'Site 1', would it have led to soil amelioration work that could have reduced variability in productivity across the block? The map indicated the presence of two soil distinctive zones; one a sandy clay loam, the other a sandy loam. Without any knowledge of how these zones are related to tree growth or yield, the EM38 map was not meaningful. Combination of the map with knowledge of previous block history on the other hand, could have provided valuable information. Results of the EM38 and productivity mapping undertaken in this project have provided the grower with useful information that could be applied to future plantings in this block, as well as to future dam construction in the orchard more generally. With regards to the latter, consideration should be given to disposal of soil from dam construction and the potential for seepage of water into adjacent trees.

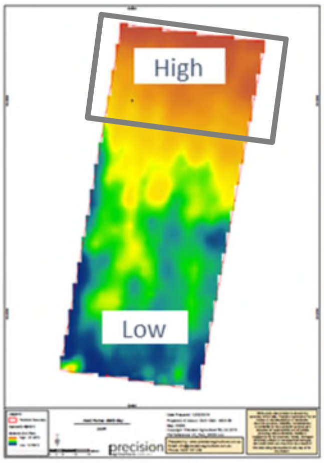
Site 2 – 'Alvina Gala'

There was a clearly defined section of orchard at the northern end of 'Site 2' where productivity was severely reduced through poor growth and stunting of trees. The grower was uncertain about the cause of the failure to thrive in this part of the block, however there was some concern that it might be the result of soil salinity. Productivity in the rest of the block was uniformly good.

EM38 soil mapping of 'Site 2' showed clear 'high' and 'low' zones which aligned well with the zones of variability in productivity (Figure 4a). That is, there was a well-defined relationship between low productivity and a 'high' EM38 mapping zone for this block of trees. Soil sampling and analysis however, showed no clear differences in clay content, conductivity or moisture between these zones at either the 1 – 30 cm or 30 – 60 cm depths (Figure 4b). Therefore, soil salinity did not appear to be the cause of poor productivity in this block, at least down to 60 cm soil depth, and further investigation of possible causes for differences in the EM38 readings and productivity was required.

Figure 4 – 'Site 2' soil mapping showing (a) EM38 soil map with 'high' and 'low' EM38 zones identified, and (b) texture, conductivity and soil moisture analysis for soil samples taken at two depths from each zone. The grey box indicates the section of the block with low productivity.

a



b

EM38 zone (soil depth in cm)	Texture	Conductivity (dS/m)	Moisture (%)
High (1 – 30)	1% clay 87% sand	0.251	13
High (30 – 60)	3% clay 84% sand	0.148	11
Low (1 – 30)	3% clay 81% sand	0.224	9
Low (30 – 60)	6% clay 81% sand	0.125	9

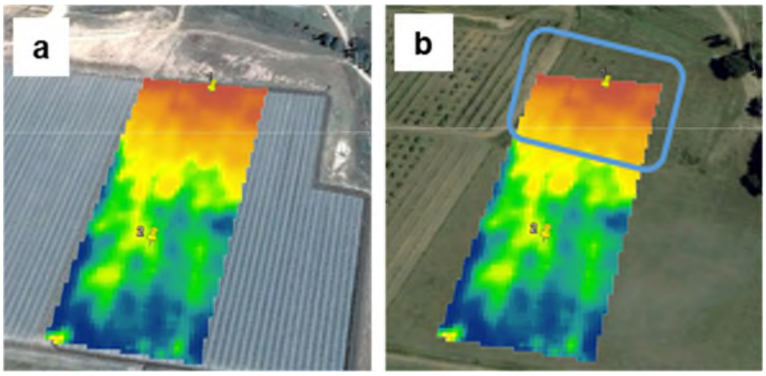
Discussions with the grower indicated that 'Site 2' was established in 2008 by joining together two sections of land with different land-use histories. The southern part of the block had a history of apple orchard while previous land-use of the northern section was unknown to the grower (other than that it was cultivated). It was feasible that the land-use history might provide information that could help determine the cause/s of the 'high' EM38 readings and poor productivity at the northern end of the block.

Using Google Earth, the EM38 map was overlaid on aerial photos of the orchard from 2013 (Figure 5a) and 2003 (Figure 5b). In the 2013 photo, the orchard block appears as it does in 2016, complete with netting. The photo taken in 2003, however, shows the area of land prior to establishment of the 'Alvina Gala' block. The map overlay clearly showed a tight relationship between the 'high' EM38 zone and an area of land with a distinctly different history from the adjacent part of the block (Figure 5b).

The causes of poor productivity at the northern end of the block are still un-clear. Organic matter, pH and nutrient analysis did not show any large differences between the EM38 zones (data not shown). Material was brought in to build-up the northern end of the block during site preparation and a drain was placed underneath, in line with the junction between the 'high' and 'low' EM38 zones. Drainage problems could be a causal factor here, particularly in wet years when tree growth could have been impacted.

It is common practice for apple orchard businesses to develop and re-develop blocks over time for the purposes of planting new varieties and changing to new planting systems. This process often involves joining together pieces of land with different land-use histories which, as the results here suggest, has potential to result in a lack of soil homogeneity across the new site.

Figure 5 – Relationship between historical land-use and the EM38 soil map of ‘Site 2’. The EM38 soil map is overlaid on historical Google Earth maps from (a) 2013 and (b) 2003. Blue outline indicates overlap between the ‘high’ EM38 zone and the alternative land-use history.



If EM38 mapping had been undertaken prior to planting this ‘Alvina Gala’ block it would have identified two distinctive soil zones with no clear differences in fertility. It is unlikely that this information alone would have benefitted ‘Site 2’ preparations as it gives no indication of the future productivity problems. The inclusion of historical land-use records, however, has added value to the soil map interpretation. EM38 mapping more widely to take in adjacent established orchard blocks could have provided further useful information about relationships between EM38 readings and potential productivity at ‘Site 2’. The grower noted that he would not have planted in the northern end of the block if this relationship between ‘high’ EM38 readings and low productivity had been established prior to planting.

Conclusions

To determine whether the use of EM38 soil mapping prior to planting may inform decision making and lead to improved apple tree uniformity and orchard productivity, it was necessary to demonstrate that differences in soil type measured with EM38 are significant drivers of growth and yield. Results from both ‘Site 1’ and ‘Site 2’ showed good correlations between ‘high’ and ‘low’ EM38 soil zones and variability in tree productivity suggesting that soil type was an important determining factor in tree productivity at these sites. While ‘high’ zones were related to poor productivity at both sites assessed here, this is unlikely to be the case on all orchard blocks. These relationships need to be established for each particular location and soil environment.

For EM38 soil mapping to provide benefit for apple growers, it needs to inform soil amelioration work that leads to improvement in tree growth and uniformity across orchard blocks. At both ‘Site 1’ and ‘Site 2’, EM38 mapping in isolation prior to planting would have provided little benefit. However the addition of information related to orchard block history, and productivity-soil relationships established in surrounding orchard blocks, would have informed grower decisions in the design of new plantings and necessary remedial actions. The combination of soil and yield maps with normalized difference vegetation index (NDVI) technologies is likely to provide the greatest value in the future by enabling the causes of poor productivity to be more easily defined.

The high capital cost of developing orchard blocks means that returns are needed on the investment in the first few years, to cover the cost of orchard establishment. Therefore there is a significant cost to long-term profitability when trees do not rapidly develop full fruiting canopies uniformly across the block, and commence cropping by their second or third year. EM38 mapping has potential as a cost-effective method for improving soil preparation prior to planting to reduce the risks associated with variable tree growth. Soil mapping technology could add more relative valuable to the apple industry than it has in broad-acre cropping systems due to the nature of orchard site establishment (which often involves joining together pieces of land with different land-use histories) and the longevity of the crop.

Recommendations

Industry

- Where possible, EM38 soil mapping should be trialled in orchard blocks prior to planting to improve industry knowledge around the use and value of this technology in a range of environments. Cost-benefit analyses need to be undertaken to determine the value of this technology.
- Variations in productivity across blocks should be recorded prior to tree removal to enable relationships between productivity and EM38 soil zones to be established. Such information is likely to be valuable in informing soil amelioration required prior to re-planting.
- EM38 soil mapping should be used in conjunction with yield and NDVI mapping to improve uniformity of orchard blocks in preparation for the introduction of robotic technologies.

Scientific

- Spatial analyses are needed to further investigate relationships between productivity, EM38 readings and soil nutrient status across orchard blocks.
- Research is needed into the options for management of soil variability during the productive life of an orchard block through the use of soil mapping and variable rate technologies.
- Investigations are needed into potential relationships between tree death caused by soil-borne disease and EM38 soil mapping zones. Is EM38 mapping a valuable tool in the management of soil-borne diseases of apple orchards?
- Investigations should be considered into the potential for matching rootstocks to soil types for improved tree uniformity.

Key Messages

- There was a broad relationship between EM38 mapping zones and areas of high and low productivity in the orchard sites assessed.
- The use of EM38 soil maps together with additional knowledge would likely have led to improved soil amelioration work prior to planting of the orchard blocks, potentially reducing variability in productivity.
- All EM38 maps require ‘ground-truthing’ and interpretation. The soil mapping itself provides little information until it is combined with a productivity map, and/or previous grower knowledge.
- The level of benefit to the grower from use of EM38 mapping is likely to be different for each site and circumstance. The value of the mapping may improve as the area of orchard mapped increases.

- The more information the better. Mapping over larger distances (including surrounding land) and time would have significant longer term benefits.
- The combination of soil maps with yield maps and NDVI, technologies will provide greatest potential value.
- EM38 soil mapping has potential to add value to orchard businesses at the point of site preparation for planting as a cost-effective technology for guiding decision making around potential soil amelioration work and block design.
- Soil mapping technology could add more relative valuable to the apple industry than it has in broad-acre cropping systems due to the nature of orchard site establishment (which often involves joining together pieces of land with different land-use histories) and the longevity of the crop.

Where to next

- Outcomes from this project were communicated to local Queensland industry at the Horticulture Innovation event in Stanthorpe 1 June 2016 where Heidi Parkes presented '*Uniformity in high-density apple orchards: how important is managing soil variability?*'. Project outcomes will be communicated more broadly to the national apple and pear industry through submission of an article to the *Australian Fruitgrower* magazine in September.
- Opportunities will be investigated for developing a multi-disciplinary across-industry project around soil management and the application of sensing and mapping technologies. Potential for collaboration with sensing technology and software providers such as The Yield, to improve application of new technologies to tree cropping industries will be considered.

Budget Summary

Project budget $9,600
Project expenditure $9,625
Final budget balance $25 deficit

Table 2 – Details of project expenditure

Item	Description	Invoice date	Cost
1	**EM38 mapping**: Collection of EM38 data on five orchard blocks, production of soil zone maps, assistance with interpretation of results (Precision Agriculture Pty Ltd)	16 Feb 2015	$2,200
2	**Soil testing:** 10 samples (collected 25 Feb 2016) tested for the standard suite of nutrients, pH, conductivity, labile carbon, PSA.	7 Mar 2016	$2,376
3	**Soil testing**: 10 samples (collected 1 Mar 2016) tested for the standard suite of nutrients, pH, conductivity, labile carbon, PSA.	23 Mar 2016	$2,376
4	**Soil testing**: 7 samples (collected 3 Mar 2016) tested for the standard suite of nutrients, pH, conductivity, labile carbon, PSA.	23 Mar 2016	$1,247.40
5	**Soil testing**: 8 samples (collected 8 Mar 2016) tested for the standard suite of nutrients, pH, conductivity, labile carbon, PSA.	23 Mar 2016	$1,425.60
Total expenditure			**$9,625**

Notes:
Soil testing service provided by Vintessentials Laboratories Pty Ltd. PSA is particle size analysis.

Acknowledgements

Thank you to Stanthorpe apple growers, Trent Vedelago and Daniel Nicoletti for use of their orchard blocks to undertake this project and their willingness to discuss and assist with the interpretation of the outcomes, to Allan McWaters for his assistance with the tree productivity rating methodology and data collection and to Simon Middleton for reviewing the report prior to submission.

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