Final Technical Report

Compaction mitigation options for growers in the Albany and Kwinana West port zones

Project code:	AVP00003-A
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REPORT SENSITIVITY

Does the report have any of the following sensitivities?

Intended for journal publication	NO
Results are incomplete	NO
Commercial/IP concerns	NO
Embargo date	NO

Abstract

An estimated 13 million hectares (70%) of Western Australia's agricultural soils have moderate to high susceptibility to subsurface compaction. These hard layers of soil slow or in extreme cases prevent root growth and access to water and nutrients resulting in an estimated annual cost of $333M from lost production.

Growers in the Albany and Kwinana West port zone RCSNs identified soil compaction as an issue though were concerned the impact/extent on profitability had not been quantified, wanted to understand the yield-limiting factors on their soil types, and use amelioration techniques that maintain/improve soil structure and increase profitability.

This project measured yield responses to various treatment designed to alleviate soil compaction at twelve trial and demonstration sites in the Albany and Kwinana West port zones in the 2017 and 2018 seasons. Sites were established two to four years previous and had not been continuously monitored. Yield responses to ripping were overwhelmingly positive (89% of treatments) across the sites, though economic benefits varied greatly (-$505/ha to +$655/ha) due to cost of treatments and crop establishment issues at some sites.

Understanding the physical and chemical constraints of a soil type are imperative to designing the most appropriate amelioration strategy and maximising economic benefit. Minimising machinery traffic after removing compaction is essential maintain benefits.

Key messages

1. Dramatically increased crop yields were observed when subsoil compaction was removed,
2. Compaction amelioration treatments returned an average wheat yield increase of 495kg/ha and an economic benefit of $195/ha across the sites,
3. Increased crop yield can still result in negative economic return for high-cost treatments,
4. Very deep ripping (to 700mm) gave the largest yield and economic results, especially when soil strength decreases to below 2500Kpa within 70cm of the surface.
5. Yield increases and economic benefits from deep ripping could still be observed after four years,
6. Acid subsoil (below 30cm depth) and soluble Aluminium appear to be continuing to depress yields despite significant amendment of subsoil pH between 10-30cm depth in treatments that have mixed or inverted lime to this depth.
7. A controlled traffic systems should be implemented to increase the longevity of benefits from removing soil compaction.

Executive Summary

Soil compaction is widespread, but the exact severity and trend is unknown (Department of Agriculture and Food Western Australia, 2006). The annual cost of compaction as lost production is estimated at $333 million across WA (Department of Primary Industries and Regional Development, 2018), with additional losses associated with soil structure decline. Subsoil compaction holds back crop growth on WA soils by restricting root growth and increasing the risk of waterlogging in the soil profile. Compacted soils can also restrict healthy activity of soil biology. These effects can reduce grain yield and increase costs.

The major aim of the project was to develop best-bet management options for growers of the Albany and Kwinana West port zones on (1) compaction and mitigation options for a range of soil types; and (2) how best to move into CTF technology for their farming situation.

The project had a mix of research, demonstration and extension activities on soil compaction in the Albany and Kwinana West port zones where growers identified compaction as an issue.

A compaction tour for growers and advisers was organised and took place in August 2017 and incorporated the National CTF conference in Perth and Bolgart plus visits to 4 farms. All the farms visited were dealing with multiple soil constraints and had taken steps to alleviate them. They also all had trial sites (either set up by themselves or by collaborating researchers) on their farms which were inspected. Three of the growers had adopted CTF. All of the attendees found the tour valuable as it gave them a number of ideas to trial on their farm. The interaction between the attendees and the hosts also produced some “what not to do’s”, which are equally if not more valuable than the “must do’s”.

A case study booklet was published in December 2021 and included the results of the demonstration sites monitored as part of the project (see below) as well six (6) case study articles on leading growers. These six case study articles were also published in Ground Cover magazine.

Nine (9) field walks were held at the demonstration sites throughout the life of the project and the results from some of the demonstration sites were presented at the GRDC Research Updates in Perth.

The impact of the project activities has been significant. One of the agVivo agronomists involved with the project now has 66% of his clients (21 out of 32) using some form of deep ripping and amelioration with most experiencing significant yield improvements as a result. Twelve deep ripping trial and demonstration sites were monitored in 2017 and 2018. These trials and demonstration sites were mostly on-farm sites established between 2014 and 2016 and had not been monitored after their initial project completed, two of the sites were fully replicated trial design. A total of 66 constraint removal treatments were examined at these twelve sites and included different tillage and ameliorant (i.e. lime) combinations (Table 1). Yield response and economic benefits were calculated for each treatment.

Positive yield responses to ripping were recorded at nine of the twelve trial and demonstration sites in either or both the 2017 and 2018 seasons. Yield responses to ripping were overwhelmingly positive across the sites, though economic benefits varied greatly (-$505/ha to +$655/ha) due to cost of treatments and treatment related crop establishment difficulties. Depth of ripping had an impact on the yield response, with deeper ripping providing a greater yield and economic return than shallow ripping or shallow mixing of soil.

Risks associated with compaction amelioration practices were also highlighted with negative outcomes recorded at some sites. Negative outcomes fell into three scenarios where treatment resulted in:

1. Reduced yield and negative economic return,
2. No yield difference and negative economic return,
3. Increased yield and negative economic return.

The reasons for the negative outcome were apparent in each situation and provided a learning opportunity for future management. Reduced yield and economic return in Scenario 1 were a result of poor seed germination due to the deep ripping treatment leaving the soil surface rough and seed placed too shallow or deep at seeding. Scenario 2 was due to the soil type not being responsive to deep ripping indicating that the practice was not appropriate in this location. Scenario 3 occurred when the value of the yield increase was not enough to outweigh the very high treatment costs.

Understanding the physical and chemical constraints of a soil type are imperative to designing the most appropriate amelioration strategy and maximising the economic benefit. Minimising machinery traffic after removing compaction is essential maintain benefits.

Table 1: Summary of each trial or demonstration examined in this project.

Albany

Grower	Location	Trial Description	Collaborators	Measurements	Treatment Benefit Avg. Yield (kg/ha)	Treatment Benefit Avg. Economic ($/ha)
Josh Goad	South Stirling	Ripping to 350mm, 700mm & 1200mm Replicated plots	Stirlings 2 Coast DPIRD	UAV NDVI Penetrometer Plant counts Grain yield Soil coring	415.2	72.0
Reece Curwen	South Stirling	Ripping to 300mm & 600mm Demo strips, unreplicated	Stirlings 2 Coast DPIRD	UAV NDVI Penetrometer Plant counts Grain yield Soil coring	255.9	115.2
Scott Thompson	Broomehill	Ripping to 300mm, 500mm, 500mm+Inc, Replicated plots	DPIRD	UAV NDVI x 2 Penetrometer Plant counts Grain yield Soil coring	185.6	177.4
Simon Zacher	Kojonup	Ripping to 350mm, 350mm + Inc, 550mm Replicated Plots	Southern DIRT DPIRD	UAV NDVI Penetrometer Plant counts Grain yield Soil coring	230.6	43.5
Ben Hobley	Nyabing	Deep rip to 500mm 5 paddock, Demo strips, unreplicated	N/A	UAV NDVI Penetrometer Plant counts Grain yield	106.3	272.2

Kwinana West

Grower	Location	Trial Description	Collaborators	Measurements	Average Net Benefit Yield (kg/ha)	Average Net Benefit Economic ($/ha)
Adam Smith	Beverley	Deep ripping to 500mm Demo Strips, unreplicated	N/A	UAV NDVI Penetrometer Plant counts Grain yield Soil coring	167.6	51.3
Charlie Boyle	York	Ripping to 350mm, Rip & Spade, Rip & MBP, Plozza, Offset Disc, Demo strips, unreplicated	agVivo, DPIRD	UAV NDVI Penetrometer Plant counts Grain yield Soil coring	1097	384
Warakirri	Quairading	Heliripper to 700m + Spading Demo strips, unreplicated	N/A	UAV NDVI Penetrometer Grain yield Soil coring	1097	270.6
Craig Jesperson	Wickepin	Deep ripping to 500mm, Spading to 300mm, +/- 2t/ha lime, Replicated trial	Facey Group	UAV NDVI Penetrometer Plant counts Grain yield Soil coring	136.4	-88.5
Ty Fulwood	Northam	Heliripper to 700mm 3 paddocks, Demo strips, unreplicated	N/A, DPIRD	UAV NDVI Penetrometer Plant counts Grain yield Soil coring	393	198.3

Rob Dempster	Goomalling	Deep ripping to 500mm, 500mm + Inc Helipper to 700mm, delving to 1000mm Plozza plough to 300mm Replicated trial	agVivo, DPIRD	UAV NDVI Penetrometer Plant counts Grain yield Soil coring	451.8	-21.25
Tim Cusack	Narembeen	Deep ripping to 500mm, Spading, Offset Discs, +/- lime @ 3&6t/ha, Replicated trial	agVivo, Landcare	UAV NDVI Penetrometer Plant counts Grain yield Soil coring	215	-31.09

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Background

The majority of agricultural soils in Australia have developed subsoil physical constraints, in particular compaction. An estimated 13 million hectares (70%) of Western Australia's agricultural soils have moderate to high susceptibility to subsurface compaction (Department of Agriculture and Food Western Australia, 2006). Subsurface compaction is caused by compression from agricultural machinery traffic with the compacted layer forming between 10 and 40 centimetres. In contrast, compaction from stock trampling is confined to the surface 15 cm of soil. In addition to compaction, hard layers can form as a result of natural soil packing and chemical cementation processes and these may occur throughout the soil profile. These hard layers slow or in extreme cases prevent root growth and restrict root access to water and nutrients (www.soilquality.org.au)

Soil compaction is widespread, but the exact severity and trend is unknown. Annual cost of compaction as lost production is estimated at $333M with additional losses associated with soil structure decline. Subsoil compaction holds back crop growth on WA soils by restricting root growth and increasing the risk of waterlogging in the soil profile. Compacted soils can also restrict healthy activity of soil biology. These effects can reduce grain yield and increase costs (Crop Updates paper 2015: **Belford,** Even, White)

Optimum compaction management strategies include traffic control and deep ripping. Previous research and development in WA by DAFWA, Grains Research and Development Corporation (GRDC) and Northern Agricultural Catchment Council (NACC) have reported benefits of about 10% more yield ($60/ha benefit for a 2t/ha yield and $300/t price) and better quality in a controlled traffic farming (CTF) system on deep sand with suitable amelioration of compaction, and 20-30% grain yield increase by deep ripping without a hard finish to the season.

DAFWA research notes that deep ripping is most effective in deep sandy-textured soils where roots need to grow deeper to access subsoil moisture. Deep ripping is of particular benefit when it is used to break through a compacted pan or distinct constraining layer, allowing root access to unconstrained soil water beneath this layer. If the soil below the depth of ripping contains other constraints, such as acidity, poor structure from sodicity or subsoil salinity, the benefit of deep ripping will be limited.

Compaction has long been considered an issue, particularly in the Northern Agricultural Region (NAR). To this end, a significant volume of research has been developed to address compaction issues in the NAR. Some of this research and on-farm demonstration work has occurred further south, but not to the same extent.

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Project objectives

Aims

The major aim of the project was to develop best-bet management options for growers of the Albany and Kwinana West port zones on (1) compaction and mitigation options for a range of soil types; and (2) how best to move into CTF technology for their farming situation. The project had a mix of research, demonstration and extension activities on soil compaction in the Albany and Kwinana West port zones. Twelve deep ripping trial and demonstration sites were monitored in 2017 and 2018. These trials and demonstration sites were mostly on-farm sites established in previous years but had not been properly monitored. One of the sites was a fully replicated trial site.

Methodology

Kojaneerup site:

Deep ripping treatments were established at this site between 2014 and 2016. All treatments were aligned with existing 12 metre Controlled Traffic Farming (CTF) run lines (Figure 1).

Treatment summary:

2014: 16 ripping strips to a depth of 350mm were setup on alternative run lines using a Grizzly Deep Digger

2016: 4 strips originally ripped to 350mm in 2014 were ripped to a depth of 700mm using a Heliripper on 500mm tine spacing. An additional 4 strips originally ripped to 350mm in 2014 were ripped to a depth of 1200mm using a bulldozer on 1000mm rip spacing.

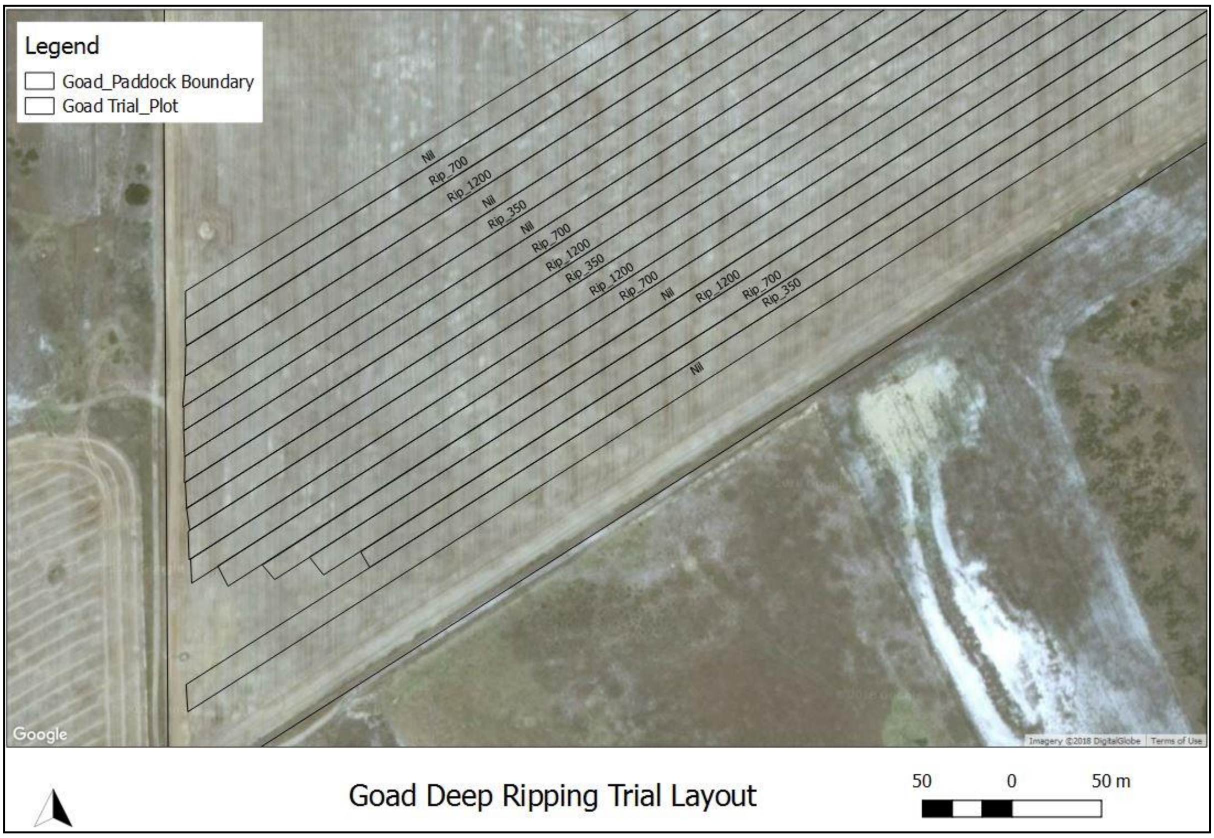


Figure 1: The deep ripping trial design on Josh and Tony Goad's farm near Kojaneerup was finalised in 2016. The trial consisted of three ripping treatments at 350mm, 700mm and 1200mm in 12 metre wide plots. Undisturbed 'Nil' plots allowed yield comparisons to be made in barley, canola and barley crops in 2016, 2017 and 2018.

Yield measurements

The paddock was sown to barley in 2016, canola in 2017 and barley in 2018. Yield data was recorded in the harvester yield monitor, extracted using Ag Leader SMS and statistical analysis carried out using Past3 software (Hammer et al, 2001).

Soil and plant measurements

A number of soil and plant measurements were collected during the 2017 and 2018 season in addition to yield.

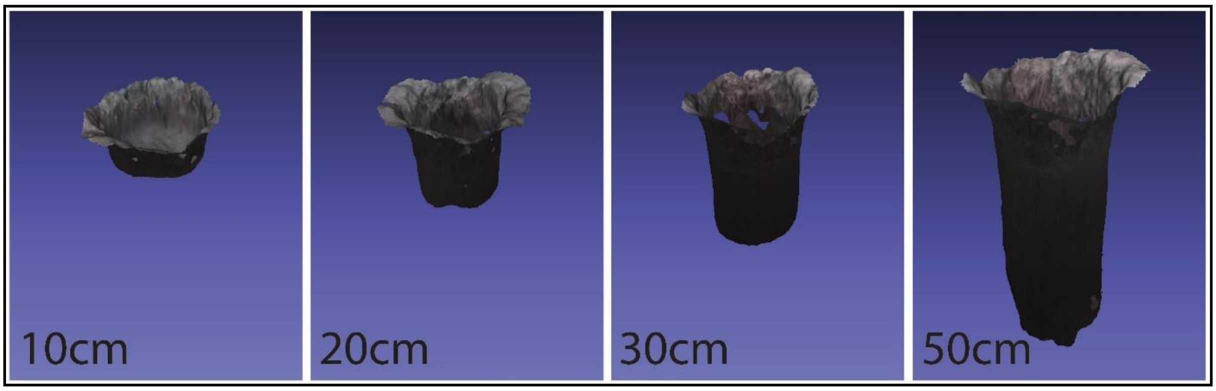
Soil penetration resistance using a digital cone penetrometer was measured twice in each plot and used to assess differences in soil compaction. The rip line was located and five insertions were recorded at each site with the average of these insertions used to characterise the soil resistance at each location.

Bulk density measurements were made using an in-situ three dimensional (3D) scanning technique developed by Scanlan *et al* (2018). This technique involves:

1. taking a 3D scan of a soil core,
2. calculating the volume of the core void,
3. measuring the weight of soil that was removed from the void and then,
4. calculating the soil bulk density.

Figure 2: 3D scanning equipment used to calculate bulk density (left) and soil strength (right).

Initially, a 10cm deep soil core was created using a posthole borer with all the soil removed from the layer kept to be dried and weighed. A 3D scanner (3D Systems, Sense 2 camera) was used to capture multiple images of the hole which the scanner software used to create a 3D model of the void (Figure 2). The process was then repeated for each 10cm layer to a depth of 50cm resulting in a void



model for each layer (Figure 3).

Figure 3: The raw 3D models of the voids captured in plot at the trial site. The soil for each 10cm layer was collected and the hole was 3D scanned to create a void model for each layer to a depth of 50cm.

The model was then processed and analysed in the MeshLab 2016.12 software (Cignoni *et al*, 2008) to remove redundant points around the surface and holes that occurred in the model. MeshLab was then used to convert the void model into a water tight manifold from which volume was calculated (Figure 4)

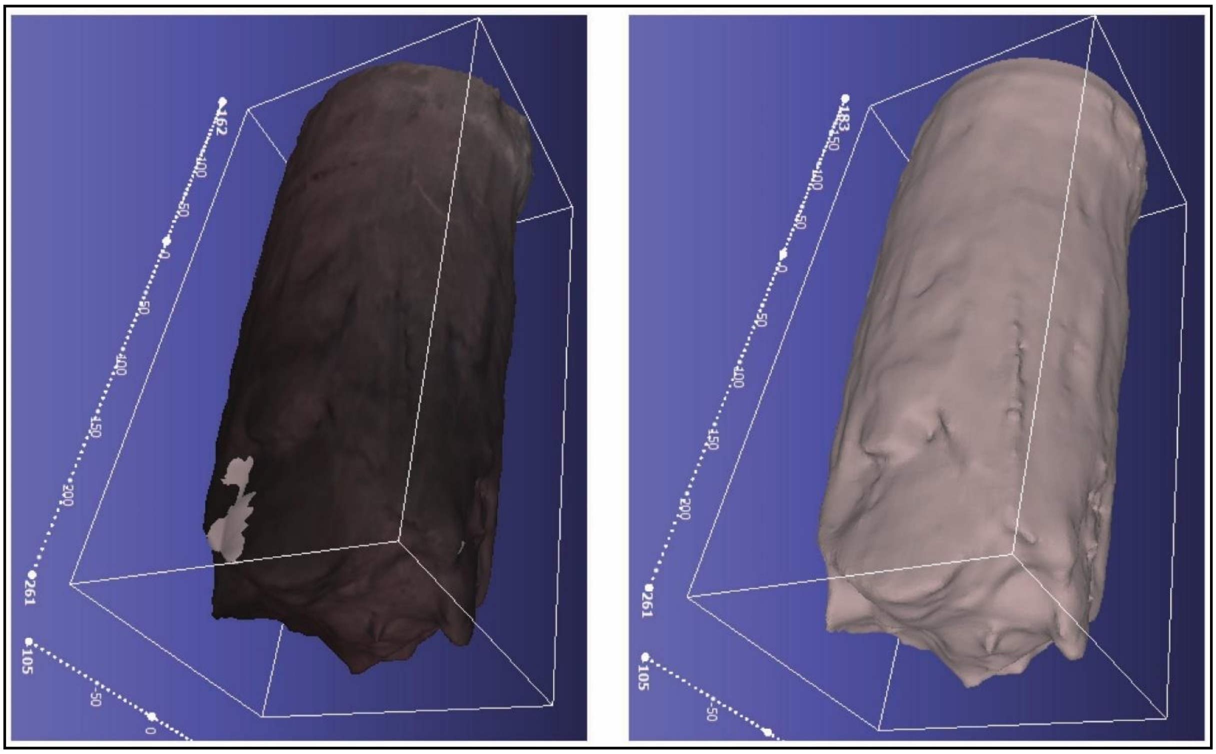


Figure 4: The raw void model (left) was processed in MeshLab to remove holes and then used to create a water tight manifold (right) from which volume was calculated

Plant density (plants/m^2) and soil pH analysis (pH analysis in 10cm intervals to 50cm) was also carried out at each soil penetrometer recording site to assess crop establishment differences and assess if subsurface acidity existed. Normalised Difference Vegetation Index (NDVI) was collected using an Un-manned Aerial Vehicle (UAV) to assess differences in above ground plant biomass and plant greenness between plots.

South Stirling site:

A deep ripping demonstration was established in 2016 near South Stirling, approximately 60km north east of Albany, WA . Two 24 metre wide demonstration strips were setup using a Heliripper, one to a depth of 350mm and the other to a depth of 700mm. Undisturbed 'Nil' plots were left around the treatment strips so yield differences could be assessed. The trial is spread across two distinct soil types; a shallow sandy gravel over laterite on the western end and a clayed deep sand to the east.

The paddock was sown to barley in 2016 and canola in 2017. A weigh trailer was used to record yield data from both gravel and sand ends of the demonstration in 2016 though yield was only available for the gravel end in 2017. Yield differences for each ripping treatment were estimated by comparing the yield from the treatment plot against the average of the two adjacent Nil plots.

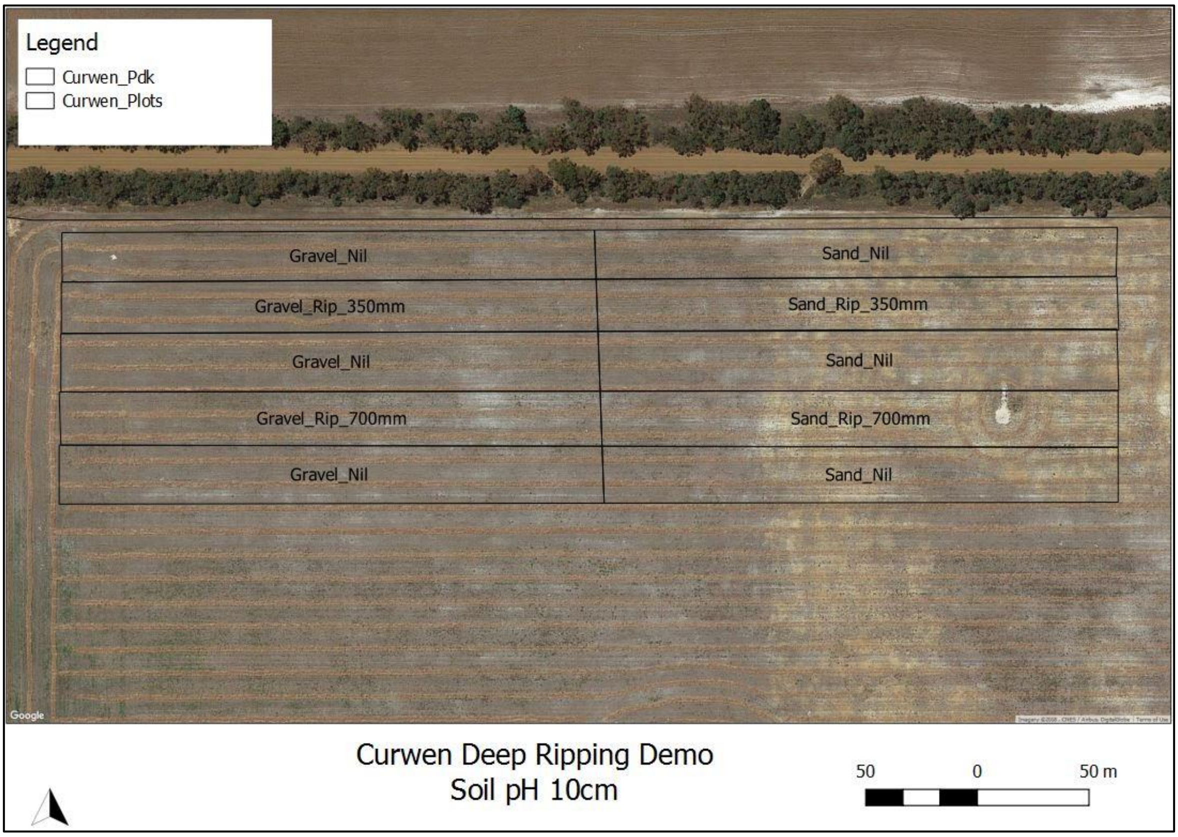


Figure 5: A deep ripping demonstration site on Reece Curwen's farm near South Stirling was established in 2016. The trial consisted of two ripping treatments at 350mm and 700mm in 24 metre wide plots. Undisturbed 'Nil' plots allowed yield comparisons to be made in barley and canola crops in 2016 and 2017.

Soil and plant measurements

A number of soil and plant measurements were collected during the 2017 season in addition to yield. Soil penetration resistance using a digital cone penetrometer was measured twice in each plot and used to assess differences in soil compaction. Where possible, the rip line was located and five insertions were recorded at each site with the average of these insertions used to characterise the soil resistance at each location. Plant density (plants/m^2) and soil pH analysis (pH analysis in 10cm intervals to 50cm) was also carried out at each soil penetrometer recording site to assess crop establishment differences and assess if subsurface acidity existed. Normalised Difference Vegetation Index (NDVI) was collected using an Un-manned Aerial Vehicle (UAV) to assess differences in above ground plant biomass and plant greenness between plots.

Broomehill site:

Three deep ripping demonstration plots were put down by Scott Thompson in late February 2015. Undisturbed 'Control' plots were left either side of the treatment strips creating a replicated trail design (Figure 1). Four passes of a 3m wide Grizzly Deep Digger with 500mm tine spacing's was used at a working depth of 450mm to create 12 metre wide plots. These plots were aligned to fit with the existing 12m Controlled Traffic Farming (CTF) system.

The demonstration plots were sown using a 12m John Deere Air Drill as part of normal seeding operations in 2015, 2016 and 2017 to Barley, Canola and Lupins respectively. The trial area was given the same nutrition, herbicide and fungicide package as the surrounding paddock.

Yield data from the 2014 - 2017 seasons was collected using the yield monitor in a Class 750 Harvester. Yield data for the 2014 season was examined to determine the yield variation at the trial site prior to deep ripping. Post ripping yield for each plot was extracted and analysed using GIS software (QGIS 3.0).

A number of soil and plant measurements were collected during the 2017 season in addition to yield. Soil penetration resistance using a digital cone recording penetrometer was measured randomly across plots and used to assess differences in soil compaction. Plant density (plants/m^2) was collected at each soil penetrometer recording site. Normalised Difference Vegetation Index (NDVI) was collected using an Un-manned Aerial Vehicle (UAV) to assess differences in above ground plant biomass and plant greenness between plots.

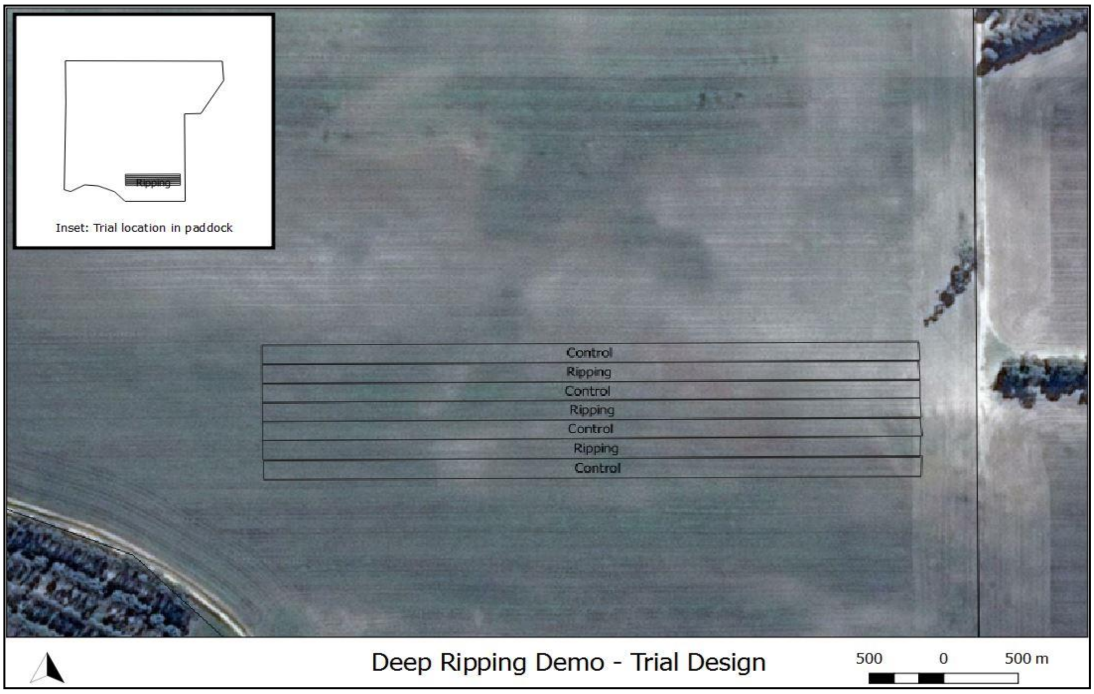


Figure 6: A deep ripping trial at Nardlah Grazing Co, Broomehill was established in 2015. The trial consisted of three, 12 metre wide ripping plots that were ripped to a depth of 450mm. Undisturbed 'Control' plots between each ripping plot allowed yield comparisons to be made in Barley, Canola and Lupin crops in 2015, 2016 and 2017.

Kojonup site:

A replicated trial was established approximately 20kms north west of Kojonup by farmer Simon Zacher, Southern DIRT and DPIRD in 2016 to assess the effect of deep ripping. Replicated plots ripped to 350mm with and without inclusion plates and at 550mm without inclusion plates were setup along with additional cultivation treatments added to the edge of the trial. These additional treatments included a scarifier working at 250mm, offset discs working at 150mm and a Heliripper working at 600mm,aimed to provide a contrast against the other treatments (Figure 1). These additional treatments were not replicated though 'Nil' strips were left to allow a comparison against the undisturbed plots (Table 1).

In total 23 plots, 12m wide and 400m long, were established which aligned with existing controlled traffic lines. Six undisturbed 'Nil' plots were distributed across the trial though not in each replication.

All sites were sown with the growers seeding machinery as part of the normal seeding operations. The paddock was sown to barley in 2016 and canola in 2017. Harvesting of the trial plots was carried out separate to the surrounding crop using the grower's harvester and recorded using a weight trailer.

Soil and plant measurements

A number of soil and plant measurements were collected during the 2017 season in addition to yield.

Soil penetration resistance using a digital cone penetrometer was measured twice in each plot and used to assess differences in soil compaction. Where possible, the rip line was located and five insertions were recorded at each site with the average of these insertions used to characterise the soil resistance at each location.

Plant density (plants/m^2) and soil pH analysis (pH analysis in 10cm intervals to 50cm) was also carried out at each soil penetrometer recording site to assess crop establishment differences and subsurface acidity.

Normalised Difference Vegetation Index (NDVI) was collected using an Un-manned Aerial Vehicle (UAV) to assess differences in above ground plant biomass and plant greenness between plots.

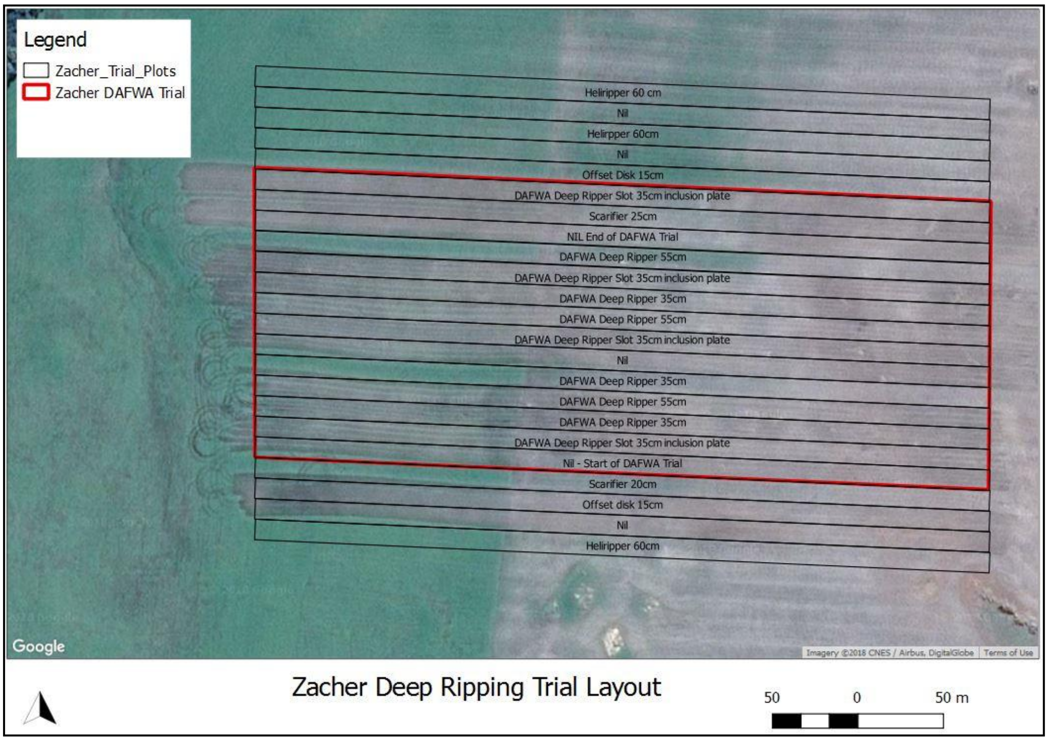


Figure 7: A replicated deep ripping trial (plots in red border) was established on the Zacher farm near Muradup in 2016. Additional cultivation treatments were added at the edge of the trial to compare the effect of scarifier, offset disc and Heliripper on crop yield.

Nyabing site:

A series of deep ripping strips were placed in six locations that covered similar soil types across the Hobley family's farm south of Nyabing, WA. Treatment strips were setup in January 2017 using a 6 metre Ausplow at a 400mm working depth. Plots created were 36 m wide and aligned with existing traffic lines which allowed three passes with the harvester. Each ripped plot had an undisturbed 'Control' plot either side (Figure 1). Plots ran the full length of the paddock and ranged from 700 to 2200 metres after the headlands were removed.

All sites were sown with the growers Equaliser Min-Till Tine Seeder in May 2017 as part of the normal seeding operations. Harvesting of the plots was carried out by the grower as part of their normal harvest operations and plots were not harvested separately. Yield data was recorded through the harvesters Topcon Yield Trak software and cleaned and calibrated in Quantum GIS (QGIS 3.0). Yield response was estimated by comparing the yield from the rip plot against the average of the two adjacent 'Control' plots.

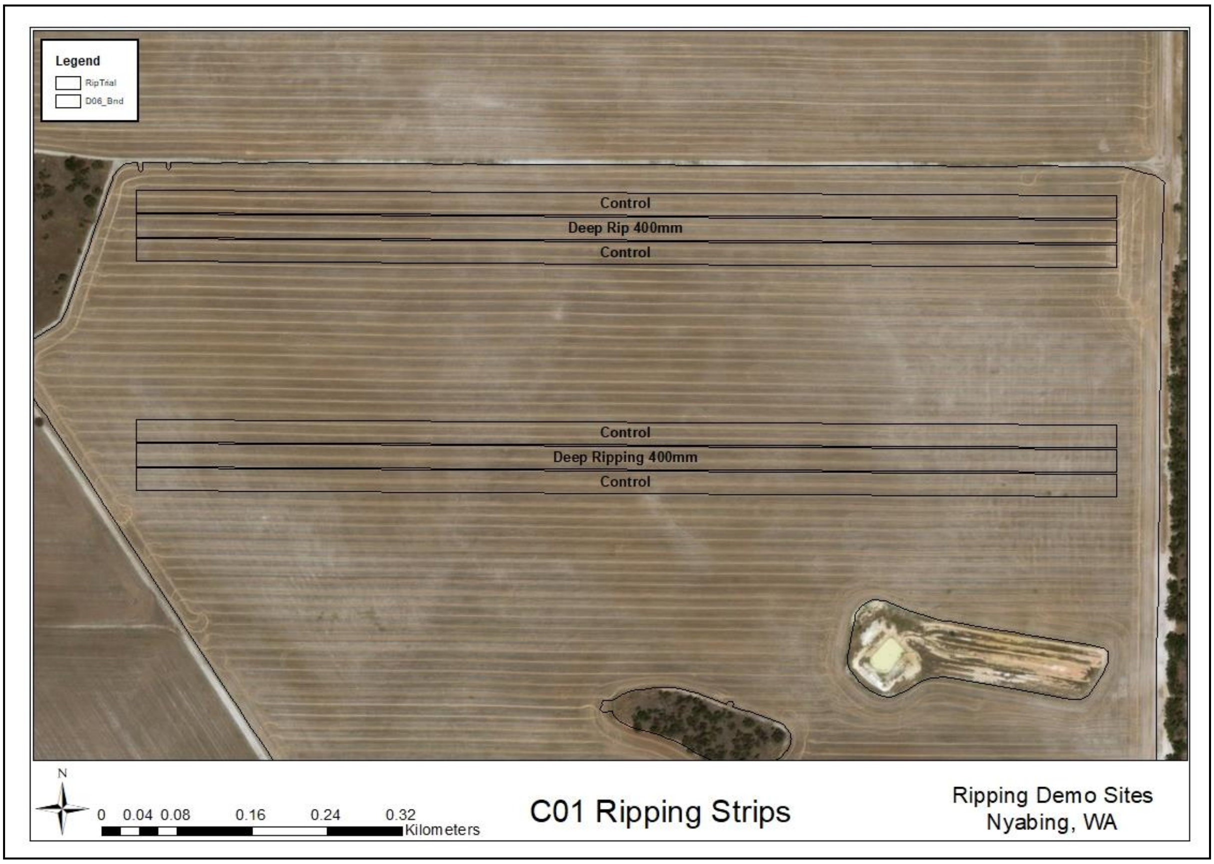


Figure 8: Six deep ripping demonstration sites were established on the Hobley's farm near Nyabing in 2017, an example of which is shown above. The sites consisted of a 36 metre wide plot ripped at 400mm. Undisturbed 'Control' plots allowed yield comparisons to be made.

Soil and plant measurements

A number of soil and plant measurements were collected during the 2017 season in addition to yield. A Rimick CP300 Cone Penetrometer was used to measure soil compaction at 180 locations across the six demonstration sites along each rip and control plot. This was made up of five insertions at 10 locations along each of the two control strips and the ripping strip at each demonstration. Insertion locations were randomly chosen in the control plots though the ripping line was found and measurements taken from within the rip line for the ripped plots and used to characterise the soil resistance at each location. Crop tiller density (tillers/m^2) was also carried out at each soil penetrometer recording site to assess crop establishment differences. Normalised Difference Vegetation Index (NDVI) was collected using an Un-manned Aerial Vehicle (UAV) to assess differences in above ground plant biomass and plant greenness between plots.

Beverley site:

An 11ha section of a 50ha paddock was ripped with a 6 metre Agrowplow at a 500mm working depth in January 2017 (Figure 1). The ripped area covers varying soil types though it is dominated by a deep coarse sand, a sand over deeper gravelly clay and a sand over shallow loamy clay. Cropping production zones are defined by these soil types with the deep coarse sand area having low production, sand over deeper gravelly clay being of medium production and the sand over shallow loamy clay a high production.

The paddock was sown to wheat in May 2017 and barley in May 2018 with the grower's machinery as part of the normal seeding operations. Harvesting of the paddock was carried out by the grower as part of their normal harvest operations. The yield data was extracted from the monitor using Agleader SMS software and statistical analysis carried out using Past3 software (Hammer et al, 2001).

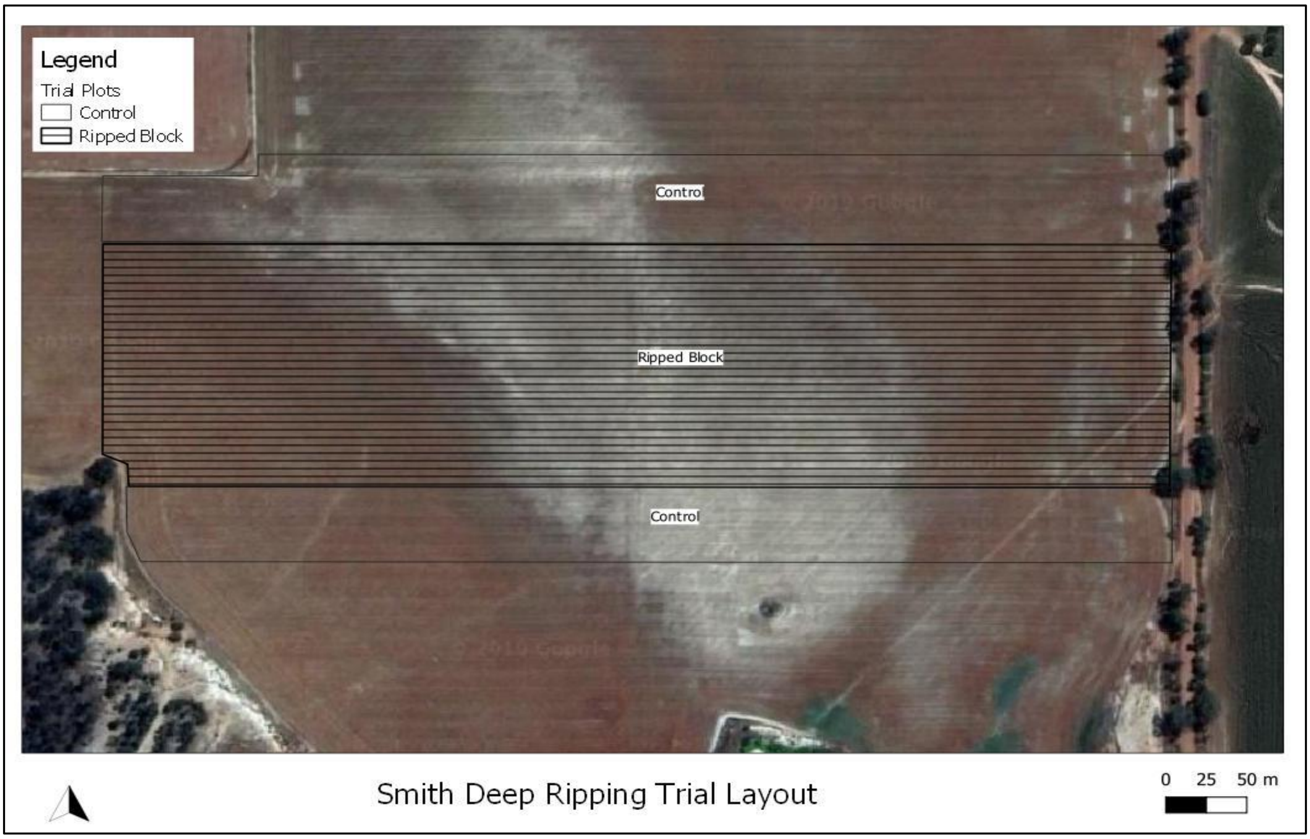


Figure 9: An 11ha area was ripped in block across a deep sand and sand over loamy clay soil types.

For both seasons, yield differences between ripping and un-ripped areas could only be made along the north and south edge of the ripped area. Yield data from the two closest header passes to the ripped area boundary, both inside and outside the ripped area, were initially compared along the entire length of the boundary (Figure 2).

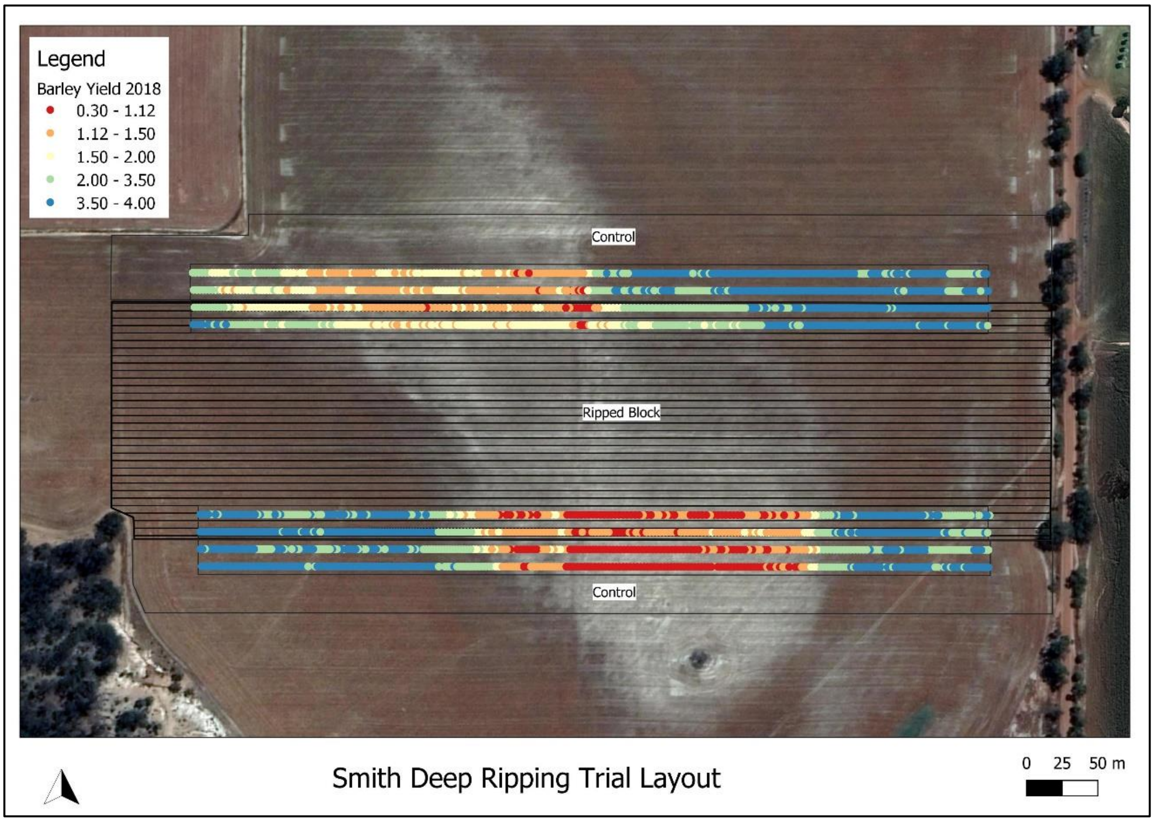


Figure 10: The two closest header passes to the treatment edge were used to compare yield differences between the ripped and un-ripped area.

The same yield data was then split into areas of Low, Medium or High production zones and yield differences re-examined within each zone (Figure 3).

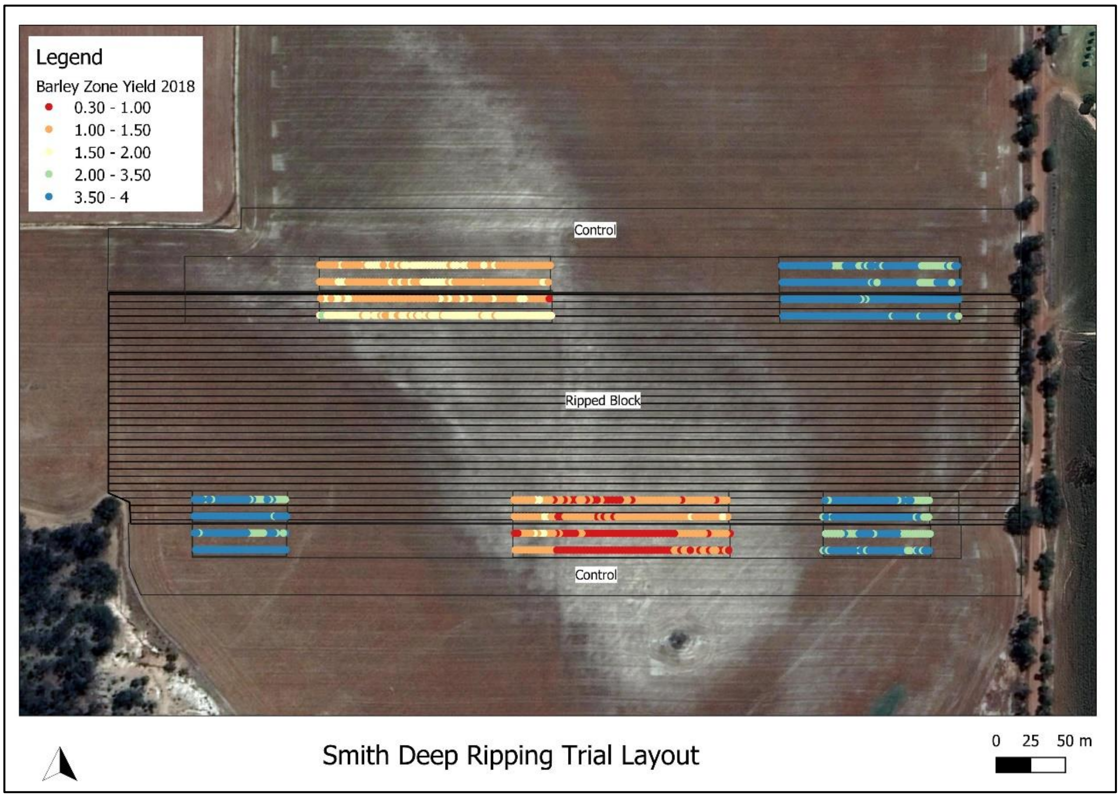


Figure 11: Yield data was split into production zones and differences compared.

Soil and plant measurements

A number of soil and plant measurements were collected during the 2017 season in addition to yield. Soil penetration resistance using a digital cone penetrometer was measured at multiple locations along each rip and control plot and used to assess differences in soil compaction. A Rimick CP300 Cone Penetrometer was used to measure soil compaction at 48 locations across the demonstration site. This was made up of five insertions at 12 locations along each of the northern and southern treatment edges. Insertions locations were randomly chosen outside the ripped area though the ripping line was found and measurements taken from within the rip line for the ripped section with the average of these insertions used to characterise the soil resistance at each location.

Normalised Difference Vegetation Index (NDVI) was collected using an Un-manned Aerial Vehicle (UAV) to assess differences in above ground plant biomass and plant greenness between plots.

Quairading site:

A 100ha paddock north east of Quairading WA was deep ripped using a 4 metre Heliripper with a maximum working depth of 700mm and spaded with a 4 metre Farmax Spader working between 250-300mm in February 2017.

The ripped and spaded area covers three distinct soil types consisting of deep white sand, deep yellow sand and sand over gravel duplex. Two 45 metre wide by 1000 metre long control strips were left untreated and allowed for the effect of treatment on yield and soil conditions to be made (Figure 1).

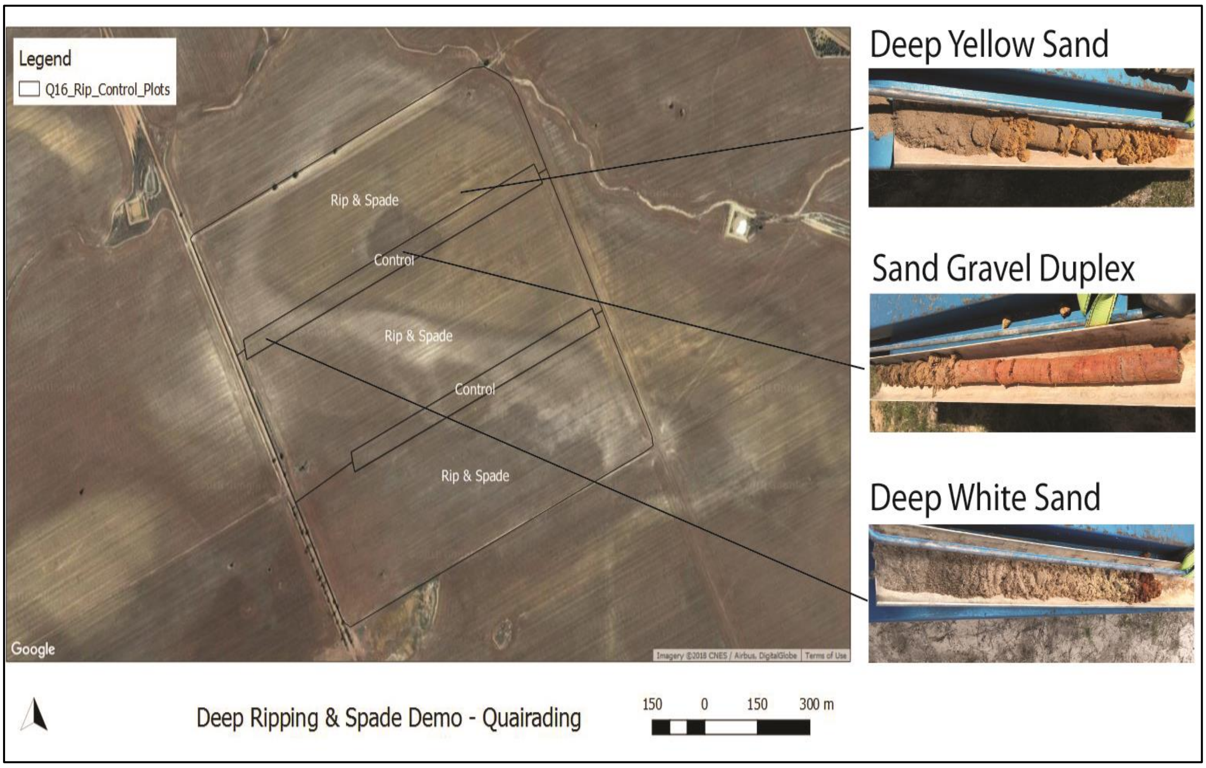


Figure 12: Deep ripping and spading was carried out in a 100ha paddock near Quairading WA. Two control strips allowed for the effect of the treatment to be measured. Soil types were assessed via coring prior to rip and spading.

The paddock was sown to wheat with the grower's machinery in May 2017 as part of the normal seeding operations. Harvest strips (100m long by 12.2m wide) along the boundary between the treated and control areas were used to collect yield data for each soil type using the farmers harvester and yield being recorded using a weigh trailer (Figure 2)

Soil and plant measurements

A number of soil and plant measurements were collected during the 2017 season in addition to yield.

Soil penetration resistance was measured at 48 locations along each rip and control plot using a Rimick CP300 digital cone penetrometer to assess differences in soil compaction. This was made up of five insertions at 12 locations along the northern edge of each control strip. Insertions locations were randomly chosen outside the ripped and spaded area though the ripping line was found and measurements taken from within the rip line for the ripped section. Measurements in the sand over gravel duplex soil type were not included in this analysis as the gravel in the soil made the data invalid.

Normalised Difference Vegetation Index (NDVI) was collected using an Un-manned Aerial Vehicle (UAV) to assess differences in above ground plant biomass and plant greenness between plots.

Soil wetting repellence was assessed via the soil Molarity Ethanol Droplet (MED) test.

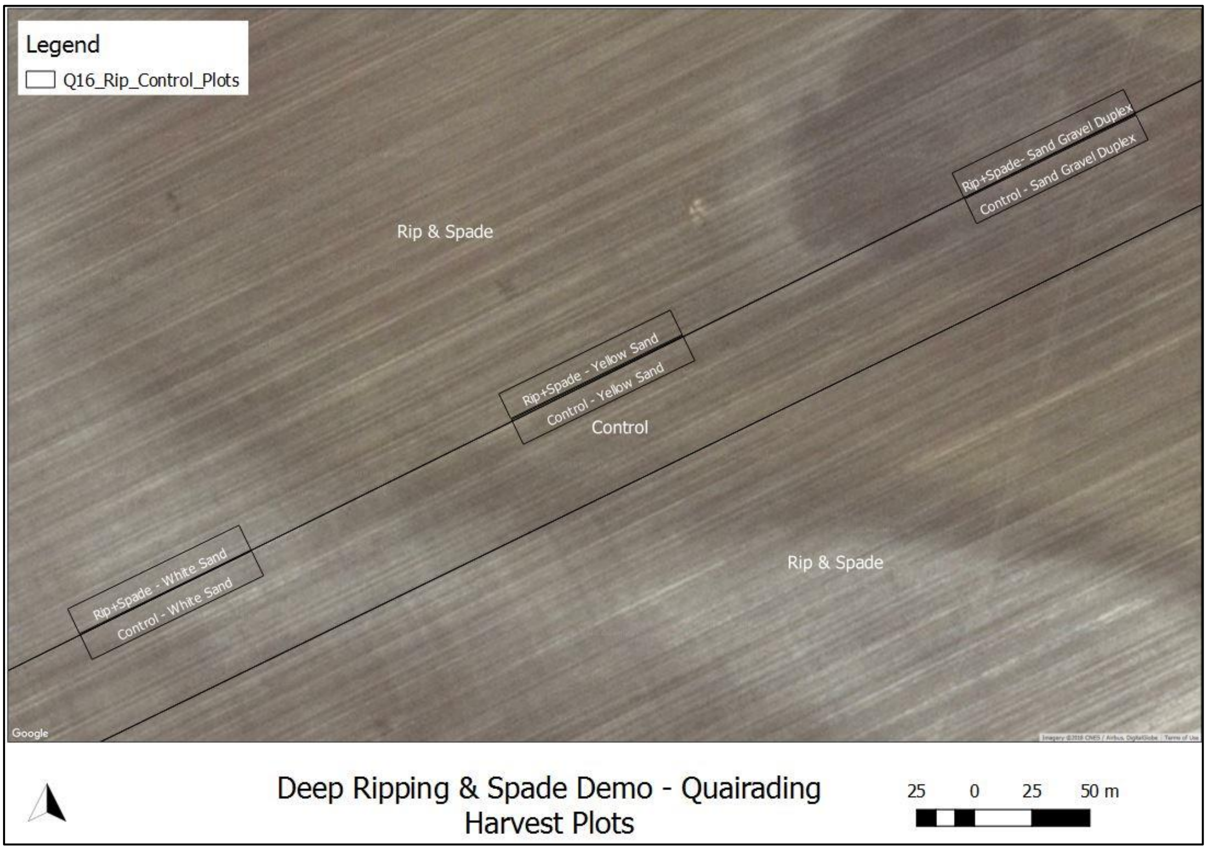


Figure 13: Yield data was collected along the boundary of the ripped + spaded and control areas in three soil types.

Northam site:

The impact of deep ripping on wheat yield was assessed in a sand over gravel soil approximately 20kms east of Northam by farmer Ty Fulwood and agronomist Tim Boyes agVivo. Treatment strips were established in early 2017 using a 3.5m wide Heliripper to a depth of 700mm and alternated between untreated control strips to create the replicated trial shown in Figure 1.

Plots were aligned to fit with the existing 12.2m control traffic system though four passes of the Heliripper was used and created 14m wide ripped plots which extended uniformly into the control plots. This is likely to have increased yield in the control plots reducing the relative difference between treatment and control.

All plots were sown with the growers seeding machinery as part of the normal seeding operations. Wheat was sown in May 2017 and barley in May 2018 with the yield data extracted from the monitor using Agleader SMS software and statistical analysis carried out using Past3 software (Hammer et al, 2001).

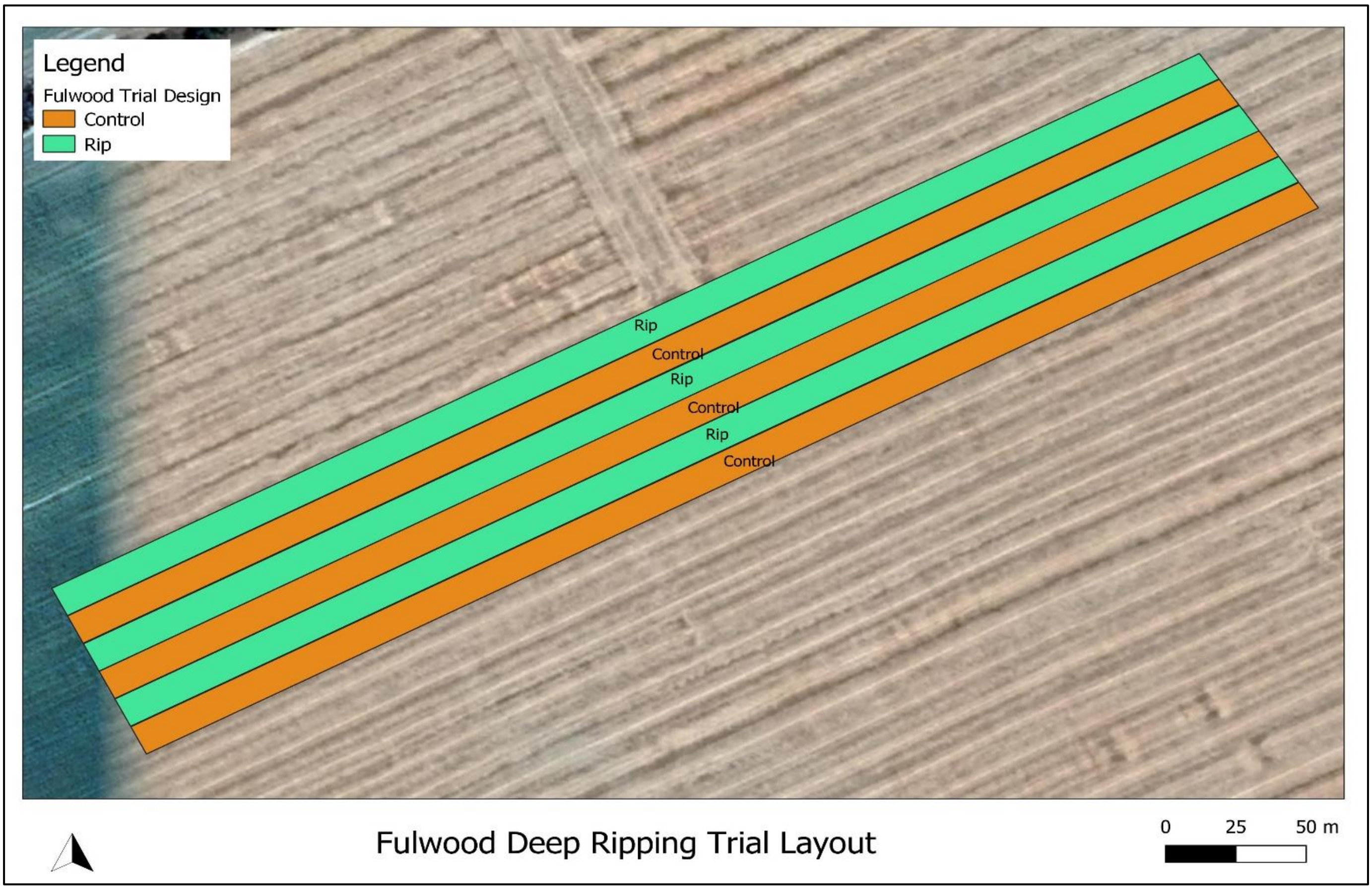


Figure 14: A deep ripping trial was established at Mount Noddy Farming near Northam in 2017.

Soil and plant measurements

Soil and plant measurements were collected during the 2017 season in addition to yield. Soil penetration resistance using a digital cone penetrometer was measured twice in each plot and used to assess differences in soil compaction. Where possible, the rip line was located and five insertions were recorded at each site with the average of these insertions used to characterise the soil resistance at each location. Normalised Difference Vegetation Index (NDVI) was collected using an Un-manned Aerial Vehicle (UAV) to assess differences in above ground plant biomass and plant greenness between plots.

Goomalling site:

The Goomalling experiment is a randomised complete block design with 4 replications that was established in 2017 on a deep yellow sand (Peartree sand) at Goomalling. The plots were established using the growers existing 12m seeding system. Plots are 4 metres wide and 22.5 metres long and are located in the wings of the seeder, either side of the wheel tracks. The area between the wheel tracks has been left as an untreated buffer. The entire site is seeded and managed by the grower throughout the season but harvesting is undertaken with a small plot harvester so yield can be assessed on individual plots.

Table 1. Soil type, physical and chemical properties and growing season rainfall.

Soil Depth	Rainfall (mm)		Repellency rating	OC	EC	pH (CACl2)	Al (CaCl2)	Clay	Silt	Sand	Compaction (Severe)
	Average Annual	Growing Season	MED Test	%	ds m-1	Ph	mk kg-1	%	%	%	
0-10cm				0.8	0.02	5.8		3	3	94	
10-20cm				0.2	0.02	4.8	1.4	3	3	94	
20-30cm	365mm	261mm (2019)	1.5-1.9	0.2	0.01	4.3	5.5	6	2	92	2.5-4.2mpA
30-40cm				0.1	0.01	4.3	8	5	5	90	
40-50cm				0.1	0.01	4.3	10				

Machines used for the tillage treatments included an Agrowplow deep ripper, Heliripper very deep ripper, Farmax rotary spader, Alpler 5-furrow reversible mouldboard plough, a modified Chamberlain Plozza system one-way plough and a custom-built clay delver. All of the tillage treatments were applied and rolled prior to seeding and implemented in the first year (2017) only.

Table 2. Experimental treatment details

No.	Treatment	Abbreviation	Effective Working Depth (cm)
1	Untreated control +/- 3t/ha Lime	CON	-
2	Deep rip +/- 3t/ha Lime	DR	32-34
3	Deep rip with topsoil inclusion +/- 3t/ha Lime	DRI	34-36
4	Deep rip + spading +/- 3t/ha Lime	DR+SP	33-35
5	Very deep rip +/- 3t/ha Lime	HR	65-68
6	Very deep rip with topsoil inclusion +/- 3t/ha Lime	HRI	62-65
7	Very deep rip + spading +/- 3t/ha Lime	HR+SP	62-65
8	Very deep rip + one-way plough +/- 3t/ha Lime	HR+OWP	62-65
9	Very deep rip with inclusion + spading +/- 3t/ha Lime	HRI+SP	62-65
10	One-way disc ploughing +/- 3t/ha Lime	OWP	30-35
11	Mouldboard plough (soil inversion) +/- 3t/ha Lime	MBP	34-36
12	Mouldboard plough + very deep ripping +/- 3t/ha Lime	MBP+HR	62-65
13	Delving + spading +/- 3t/ha Lime	DLV+SP	70+

Lime was applied at 3t/ha across the back half of each 45m plot and harvest results were taken separately from plus and minus limed plots creating 22.5m treatments.

Measurements at the site in 2019 included:

- Re-assessment of full site pH change under amelioration treatments
- Plant establishment counts
- Tiller counts
- Grain yield and quality

Narembeen site:

A lime by tillage trial was established by the Cusack family in April 2016 to assess the impact of tillage treatment and lime application on crop yield. The trial was located on a poor performing acidic deep yellow sand soil type.

The trial was designed as a fully randomised block trial with four replicates of 11 treatments plus control (Figure 1).Each plot was 18m wide and 250m long and aligned with existing guidance lines. Lime was spread using the growers Marshall Spreader at a 9m width. Deep ripping was carried out by a local contractor using a 6m Bednar Terraland at a 450mm working depth. Spading was carried out by a contractor using a 4m Farmmax spader after the plots had been deep ripped.

Figure 15: A Tillage by lime trial was were established on the Cusack family's farm north of Hyden in 2016. The trial consisted of 18 metre wide x 250m long plots.

The paddock was sown to peas in June 2016 which was spray topped in September 2016 and then brown manured with a Kelly Chain in April 2017. This was done to allow the trial 12 months to settle and provide a good seedbed for the subsequent crop. Canola was sown in May 2017 and wheat in May 2018 with the growers DBS seeder as part of the normal seeding operations.

Harvesting of the plots was carried out by the grower with a 15m header width and plots were harvested separately from the rest of the paddock. Yield data was recorded through the harvesters yield monitor and cleaned and calibrated in Quantum GIS (QGIS 3.6) and statistical analysis carried out in PAST 3 software (Hammer *et al*, 2001).

The cost of individual treatment components (lime, spreading, tillage etc.) were calculated to determine the overall cost of each treatment (Table 1). Limesand was sourced from Lancelin and costs were a combination of product ($11/t), freight ($42/t) and spreading ($4/t). Deep ripping costs of $39/ha as charged by the contactor. Spaded plots were deep ripped prior to spading and were therefore a combination of ripping and spading, which the contractor charged out at $75/ha for this job to total ($114/ha).

Table 2: The cost of each treatment as applied in this trial.

	Treatment Cost ($/ha)		
Treatment	**Lime**	**Tillage**	**Total**

Control	0	0	0
3 t/ha lime	188.6	0.0	188.6
3 t/ha lime + disc	188.6	11.0	199.6
3 t/ha lime + rip	188.6	38.5	227.1
3 t/ha lime + rip + spade	188.6	113.7	302.2
6 t/ha lime	377.1	0.0	377.1
6 t/ha lime + disc	377.1	11.0	388.1
6 t/ha lime + rip	377.1	38.5	415.6
6 t/ha lime + rip + spade	377.1	113.7	490.8
Disc only	0.0	11.0	11.0
Rip only	0.0	38.5	38.5
Rip + Spade only	0.0	113.7	113.7

Soil and plant measurements

A number of soil and plant measurements were collected during the 2017 and 2018 season in addition to yield.

Soil penetration resistance was measured at multiple locations along each plot using a Rimick CP300 Cone Penetrometer and used to assess differences in soil compaction before the trial was established in 2016 and after treatment in September 2018. This was made up of five insertions at at approximately a third of the way down each plot. The ripping line was found and measurements taken from within the rip line for the ripped plots.

Figure 16: Cone penetrometer used to measure soil strength (left) and shears used t measure plant biomass (right)

Soil testing was carried out at two locations in each plot to assess the soil pH variation and benchmark the starting soil acidity level at the site before the treatments in 2016 and then again in February 2019. Soil was collected in 10cm intervals to 50cm and soil pH carried out on each of the 480 samples at both times of sampling.

Crop plant density and plant biomass (g/m^2) was also carried out at each soil penetrometer recording site to assess crop establishment differences. Normalised Difference Vegetation Index (NDVI) was collected using an Un-manned Aerial Vehicle (UAV) to assess differences in above ground plant biomass and plant greenness between plots.

Yearlering site:

The soil type at the site is a mix of a shallow sandy loam over clay and deep white sand over clay duplex. The gravel content from the surface to 40cm steadily increases 5 to 35% the in the shallow duplex though there is less than 5% gravel in the deep duplex to 20cm though then increases to 40% gravel by 40cm.

The trial is made up of 5 treatments in a randomised and replicated strip design. All treatments were aligned with existing run lines. Trial plots were 11m wide and 180m long and separated by a 3.5m buffer on the spraying runlines (Figure 1).

Treatment summary:

The control strips were left untreated with no lime or tillage applied which therefore had no application cost. A prilled lime product (Omya Caliprill) was applied at seeding with the air seeder at 100kg/ha. Limesand was applied to the surface (top dressed) via a spreader to all other treatments plots and nothing else done to the top dressed limesand plots. A deep ripper was used to rip the deep ripping plots and ripping + spaded plots prior to the spader going over the spaded plots to loosen the soil and allow the spader to achieve a maximum working depth of 250mm (Table 1).

Table 3: Treatment description and cost of application

Treatment	Treatment Cost ($/ha)
Control	-
Prilled Lime @ 100kg/ha	$ 57
Top Dress Lime @ 2t/ha	$ 86
Deep Rip + Lime @ 2t/ha	$ 126
Deep Ripping + Spade + Lime @ 2t/ha	$ 256

All treatments were carried out a week prior to the paddock being sown to Canola in May 2015. Subsequent crops were Wheat in 2016, Oaten hay in 2017 and Canola in 2018.

Yield data was recorded with a weight trailer in the 2015 and 2016 cropping season and via the harvester yield monitor in 2018. Yield data was extracted using CLASS Agrocom software and statistical analysis carried out using Past3 software (Hammer et al, 2001). No measurements were collected in the hay crop of 2017.

Soil and plant measurements

Soil and plant measurements were collected during the 2018 season in addition to yield.

Plant density (plants/m^2), plant biomass (g/ m^2) and soil pH analysis (pH analysis in 10cm intervals to 50cm) was carried out at each soil penetrometer recording site to assess crop establishment differences and assess if subsurface acidity existed.

Normalised Difference Vegetation Index (NDVI) was measured using an Un-manned Aerial Vehicle (UAV) to assess differences in above ground plant biomass and plant greenness between plots.

Soil penetration resistance was measured using a digital cone penetrometer and used to assess differences in soil compaction. The rip line was located and five insertions were recorded at each site with the average of these insertions used to characterise the soil resistance in each plot.

Figure 17: The Facey Group Inc lime and tillage trial was finalised in 2017. The trial consisted of two lime treatments and three ripping treatments in 11 metre wide plots. Undisturbed 'Control' plots allowed yield comparisons to be made in the 2018 canola crop.

The gravel content at the site was thought to have made the digital cone penetrometer record incorrectly high values as the cone came up against gravel rocks. To overcome this, bulk density measurements were made using an in-situ three dimensional (3D) scanning technique developed by Scanlan *et al* (2018). This technique involves:

1. taking a 3D scan of a soil core,
2. calculating the volume of the core void,
3. measuring the weight of soil that was removed from the void and then,
4. calculating the soil bulk density.

Figure 18:3D scanning equipment used to calculate bulk density (left) and soil strength (right).

Initially, a 10cm deep soil core was created using a posthole borer with all the soil removed from the layer kept to be dried and weighed. A 3D scanner (3D Systems, Sense 2 camera) was used to capture multiple images of the hole which the scanner software used to create a 3D model of the void (Figure 2). The process was then repeated for each 10cm layer to a depth of 40cm resulting in a void model for each layer (Figure 3). The model was then processed and analysed in the MeshLab 2016.12 software (Cignoni *et al*, 2008) to remove redundant points around the surface and holes that occurred in the model. MeshLab was then used to convert the void model into a water tight manifold from which volume was calculated (Figure 4).

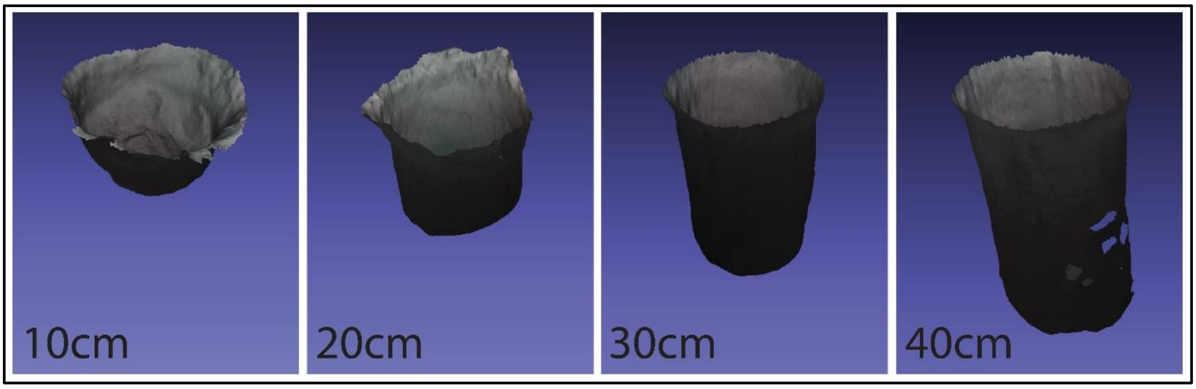


Figure 19: The raw 3D models of the voids captured in plot at the trial site. The soil for each 10cm layer was collected and the hole was 3D scanned to create a void model for each layer to a depth of 40cm.

The soil collected from each layer was dried and weighed in the laboratory to determine the mass contained in each void. Bulk density of each void layer in each plot was then calculated and reported in g/cm^3. Soil pH was also carried out on the soil collected from the hole to measure soil acidity in each plot.

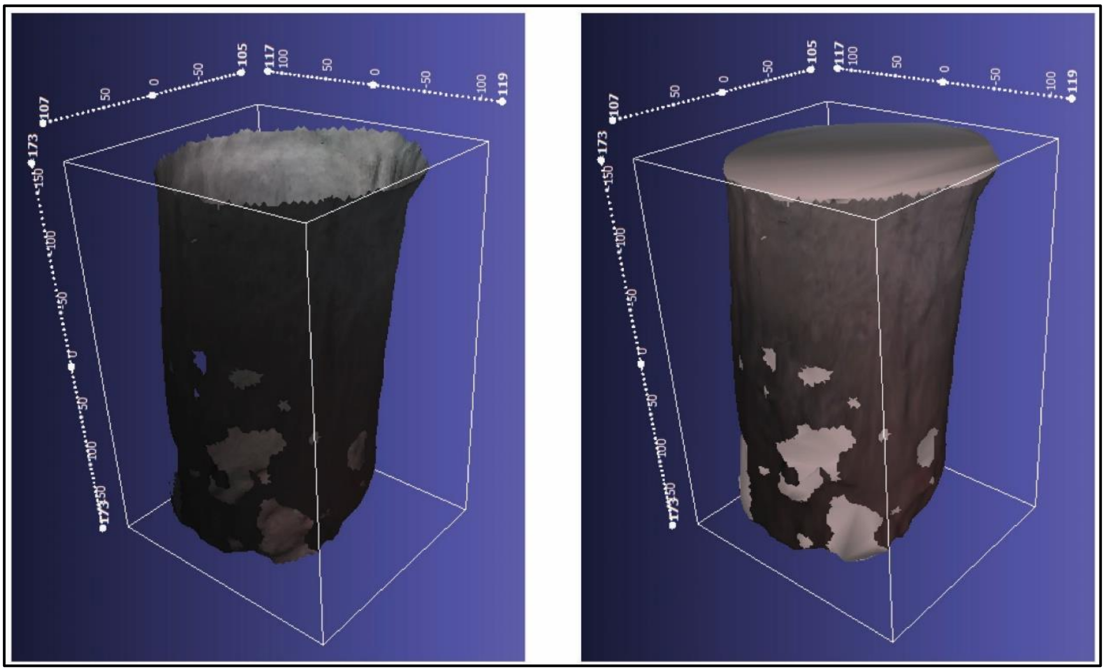


Figure 20: The raw void model (left) was processed in MeshLab to remove holes and then used to create a water tight manifold (right) from which volume was calculated.

Many additional soil and plant measurements were collected during the 2015-2017 project and can be found in the projects final report.

Location

NOTE: Where field trials have been conducted please include location details: Latitude and Longitude, or nearest town, using the table below (please add additional rows as required):

	Latitude (decimal degrees)	Longitude (decimal degrees)
Trial Site #1	-34.517549,	118.330308
Nearest Town	Kojoaneerup	
Trial Site #2	-34.637966	118.182461
Nearest Town	South Stirling	
Trial Site #3	-33.866079	117.677218
Nearest Town	Broomehill	
Trial Site #4	-33.796780	116.927073
Nearest Town	Kojonup	
Trial Site #5	-33.758761	118.155712
Nearest Town	Nyabing	
Trial Site #6	-32.110678	117.134029
Nearest Town	Beverley	
Trial Site #7	-31.943134	117.565520
Nearest Town	Quairading	
Trial Site #8	-31.630399	116.879672
Nearest Town	Northam	
Trial Site #9	-31.416670	116.892112
Nearest Town	Goomalling	
Trial Site #10	-32.106696	118.679867
Nearest Town	Narembeen	
Trial Site #11	-32.781490	117.631323
Nearest Town	Yealering	

If the research results are applicable to a specific GRDC region/s (e.g. North/South/West) or Agro - Ecological Zone/s please indicate which in the table below:

Research	Benefiting GRDC Region (can select up to three regions)	Benefiting GRDC Agro-Ecological Zone (see link: http://www.grdc.com.au/About-Us/GRDC-Agroecological-Zones) for guidance about AE-Zone locations	
Experiment Title	Choose an item. Choose an item. Choose an item.	☐ Qld Central ☐ NSW NE/Qld SE ☐ NSW Vic Slopes ☐ Tas Grain ☐ SA Midnorth-Lower Yorke Eyre ☐ WA Northern ☒ WA Eastern ☒ WA Mallee	☐ NSW Central ☐ NSW NW/Qld SW ☐ Vic High Rainfall ☐ SA Vic Mallee ☐ SA Vic Bordertown-Wimmera ☒ WA Central ☒ WA Sandplain

Results

Kojaneerup site:

Crop Yield

Yield differences due to deep ripping were observed in the 700mm and 1200mm rip treatments for barley in 2016 though only in the 1200mm ripping depth treatment for the 2017 canola. A significant positive increase in the 350mm ripping treatment and significant negative decrease from the 1200mm treatment was seen in 2018 barley yield (Figure 6)

2016 Barley Yield

The 700mm ripping treatment provided a significant average yield increase of 710kg/ha more grain than the control plots. The 1200mm rip treatment provided a significant average yield increase of 420kg/ha over the 700mm rip treatment and 1130 kg/ha over the control plots. The 350mm rip treatment provided a slight average yield increase over the control plots though this was not significant.

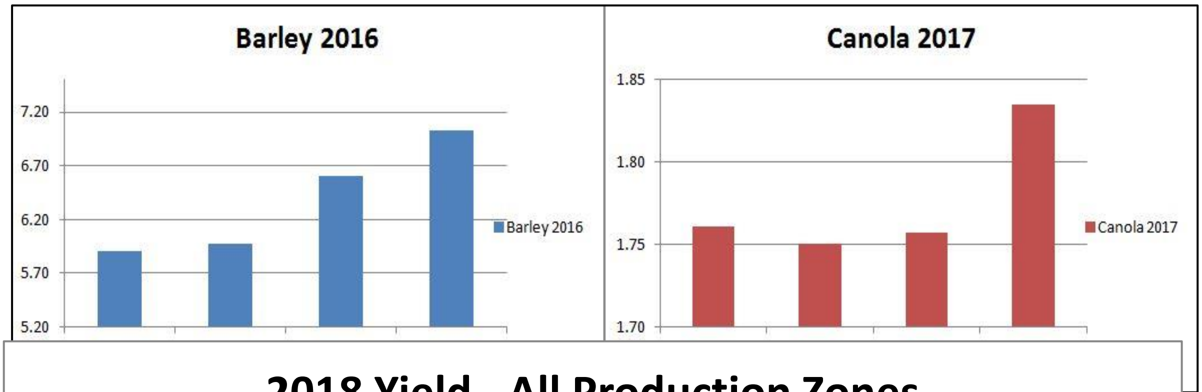
2017 Canola Yield

A marginal, though significant average yield increase of 70kg/ha was provided by the 1200mm ripping treatment in canola with all other treatments and the control showing no significant yield differences. The trial site experienced water logging and frost towards the end of the 2017 season which are thought to be contributors to this outcome.

2018 Barley Yield

The 350mm deep ripping treatment provided the only significant yield increase in 2018 which provided 100kg/ha higher than the control to record a treatment average yield of 5.26t/ha. The 700mm ripping treatment was not significantly different from the control treatment. The 1200mm ripping treatment lost an overall average of 120kg/ha when compared to the control which was significantly different to all other treatments.

The paddock was split into yield production zones by normalising the 2015 – 2018 yield layers. The yield was then divided up into these layers to see if the deep ripping effect varied across these zones. The largest relative response to ripping was in the poor production zone with all treatments giving significant yield increases over the control. There was no response to deep ripping in the high production zone (Figure 7) and could indicate that seasonal conditions allowed the crop to compensate for the constraint or other factors allow the plant to overcome the compaction in this zone.



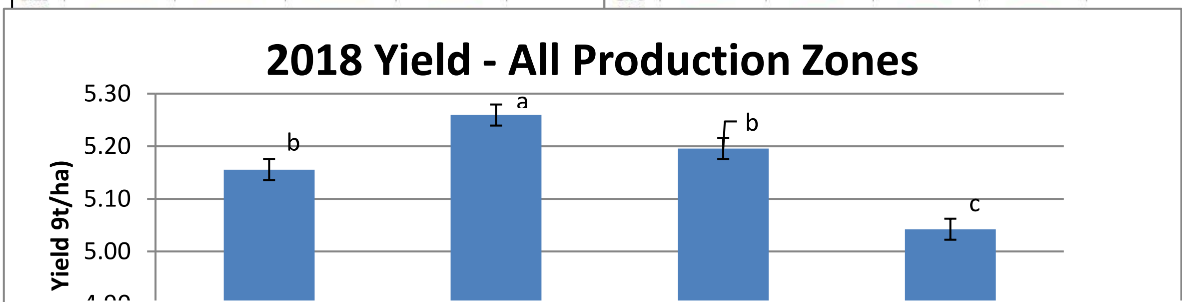


Figure 21: The average treatment yields for the trial showed that the 350mm ripping treatment was significantly different from all other treatments (denoted by letter a) and gave 100kg/ha more than the control. The 1200mm deep ripping treatment lost 120kg/ha.

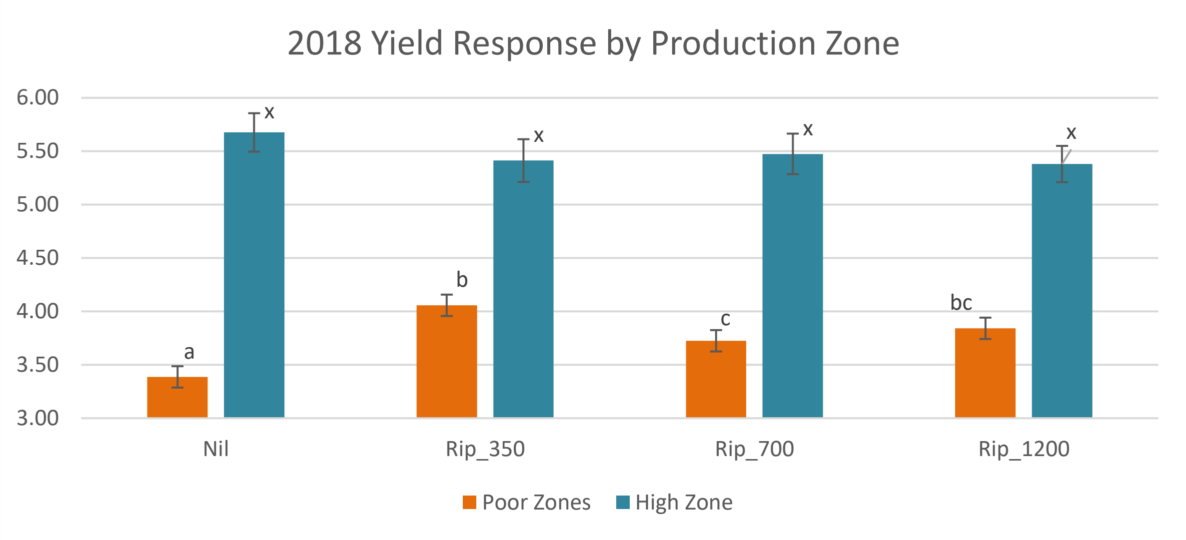


Figure 23: Average yield response by production zone showing large relative differences to the control in the poor production zones though none in the high production zones..

Soil and Plant Measurements

Soil coring across the trial found that pale sand over gravel and deep pale sand were the two soil types present at the site (Figure 8).

A Rimick CP300 Cone Penetrometer was used to measure soil compaction at 26 locations across the trial site in 2017 and found there were differences in soil strength after deep ripping. 10 of these locations were revisited in 2018 and showed that there was a slight increase in soil strength though the patterns were almost identical to that observed in 2017 (Figure 9)

Figure 24: Soil types found at the site were either pale sand over gravel (left) or deep pale sand (right).

Soil compaction in the undisturbed plots increased steadily from the surface to peak at around 3000kpa at approximately 250mm, with this value being maintained to at least 600mm. The 350mm rip treatment showed a reduction in soil compaction to approximately 300mm and then increased to peak and maintain 2600kpa to 600mm. Both the 700mm and 1200mm rip treatments were much less compact to 600mm with neither treatment having levels greater than 2000kpa in any insertion. Previous research has found 2500kpa to be the compaction level where plant root growth begins to be inhibited so it is expected that the Nil and 350mm treatments will experience compaction as a soil constraint at this site and may help explain yield differences observed.

Soil pH analysis found 0-10cm pH levels were below targets of pH 5.5 though the pH generally increased to be above pH 5.0 from 10 - 50cm (Figure 9b). There was a small amount of soil pH spatial variation across the site with four sites being below pH targets in the 0-30cm layers though this is not thought to pose a major factor in yield difference at this site. There was no pH difference between 2017 and 2018.

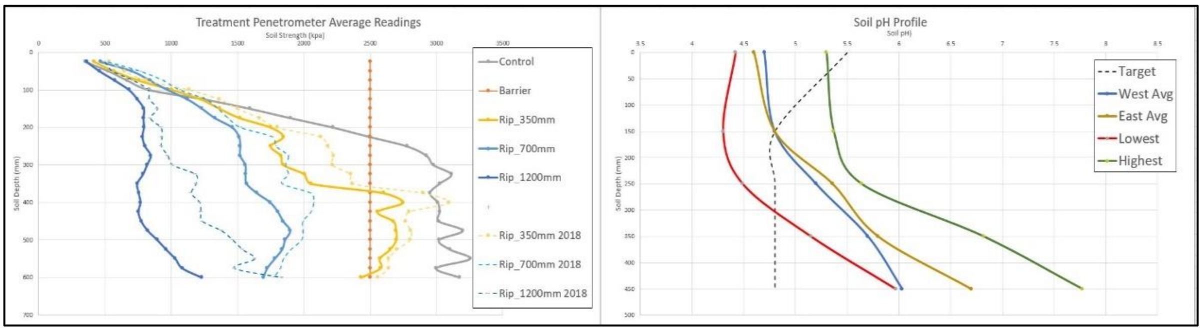


Figure 25a and 9b: Average soil resistance measurements from ripped and control plots as recorded by a cone penetrometer in august 2017 and soil pH values collected in February 2018.

The 3D scanning bulk density cores were collected 50 metre in from the western edge of plots in replicate two and were all within the deep white sand soil type. Bulk density only slightly increased with depth across all treatments and followed a similar pattern to that of the penetrometer readings (Table 1).

Table 4: Bulk density of soil of each plot in replicate two was calculated.

Treatment	Dry Soil Weight (g)				Void Volume (cm^3)				Bulk Density			
	10 cm	20 cm	30 cm	5 0cm	10cm	20cm	30cm	50cm	10cm	20cm	30cm	50cm
Control	5,236	8,657	15,567	24,566	4,201	7,458	8,684	16,325	1.01	1.53	1.43	1.63
Rip 350mm	5,325	9,236	14,569	25,652	4,536	7,658	8,753	16,587	0.96	1.37	1.32	1.55
Rip 700mm	5,197	7,869	12,892	21,588	4,521	7,522	8,432	15,896	0.92	1.38	1.42	1.55
Rip 1200mm	5,254	8,243	13,988	22,248	4,438	7,501	8,653	16,425	0.95	1.28	1.29	1.26

The bulk density values found at the site are not thought to be high enough to impede plant root growth although the bulk density measurements stop at 50cm and penetrometer readings indicate compaction is likely to increase deeper than this level. Also, effort was taken to find the middle of the rip lines for all cores so this may represent the loosest, least compact parts of the soil profile. It was noted that the core for the 1200mm ripping treatment was especially soft when sampled and quite different to the area immediately adjacent that had not been ripped.

Plant counts showed no overall difference between the treatments with a very small range and variance seen in the 2018 barley. The imagery captured by the UAV shows variation in NDVI across the trial site (Figure 10) and is due to plant biomass rather than plants/m2.

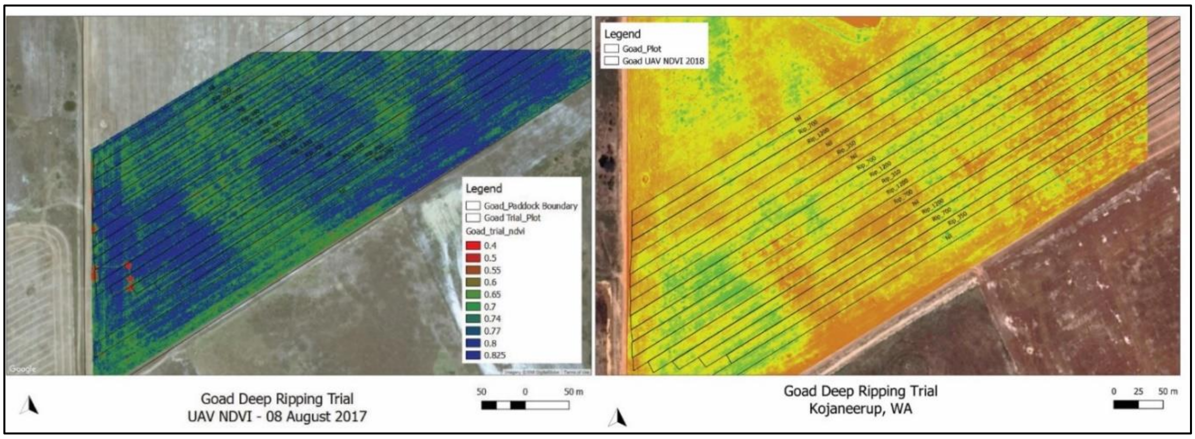


Figure 26: NDVI imagery shows biomass variation across the trial

Returns of Deep Ripping

The net benefit of all ripping was positive, or neutral, for all treatments with all the major benefits coming after the first year and then falling quickly away. It is thought that only the 700mm ripping depth provided an acceptable return on investment over this time period.

The 350mm ripping treatment only just broken even between 2016 and 2018 giving back a total of $1/ha. The 700mm ripping treatment returned $128/ha and was likely to be economically viable. Though the 1200mm treatment gave the largest yield increase and released a $283/ha benefit in 2016, the results were not continued and the high cost of treatment reduced the economic outcome achieved.

Table 5: Economic return of each treatment show varied results across the ripping depths and seasons.

Treatment	Treat. Cost ($/ha)	Amortised Treat. Cost over three years ($/ha/yr)	Net Benefit from Ripping 2016 ($/ha) Barley @ $250/t	Net Benefit from Ripping 2017 ($/ha) Canola @ $500/t	Net Benefit from Ripping 2018 ($/ha) Barley @ $250/t	Accumulated Return - Costs over three years ($/ha)
Control	-	-	0		0	0
Rip 350mm	40	13	25	-10	26	1
Rip 700mm	60	20	178	0	10	128
Rip 1200mm	200	67	283	35	-28	89

The 1200mm ripping treatment has provided the greatest yield advantage at this site though as it was carried out using a bulldozer it is unlikely to be practical to implement on a larger scale. It does encourage further work to see how ripping deeper than 700mm can be achieved in a cost effective manner.

South Stirling site:

Crop Yield

The impact that deep ripping has had on yield cannot be definitely quantified as this is an un-replicated demonstration and the results should only be used as a guide to likely outcomes. Yield increases were recorded in both ripping treatments and across soil types in barley (2016) and canola (2017) (Figure 2). Unfortunately the yield data on the deep sand soil type of the demonstration could not be collected for canola in 2017.

2016 Barley Yield

The 350mm ripping treatment in the gravel soil type provided the largest apparent yield increase of 750kg/ha when compared with the adjacent Nil strips. The 700mm ripping treatment in the gravel recorded a 370 kg/ha yield increase over the adjacent Nil strips. Yield increases were smaller in the deep sand soil type with the 700mm ripping treatment showing a 220 kg/ha yield increase and the 350mm ripping treatment showing a 220 kg/ha yield increase.

2017 Canola Yield

The 350mm ripping treatment in the gravel soil type recorded the largest yield increase again in 2017 of 280 kg/ha more canola than the adjacent nil plots. The 700mm plot in the gravel soil type showed a 110kg/ha yield increase when compared to the Nil plots.

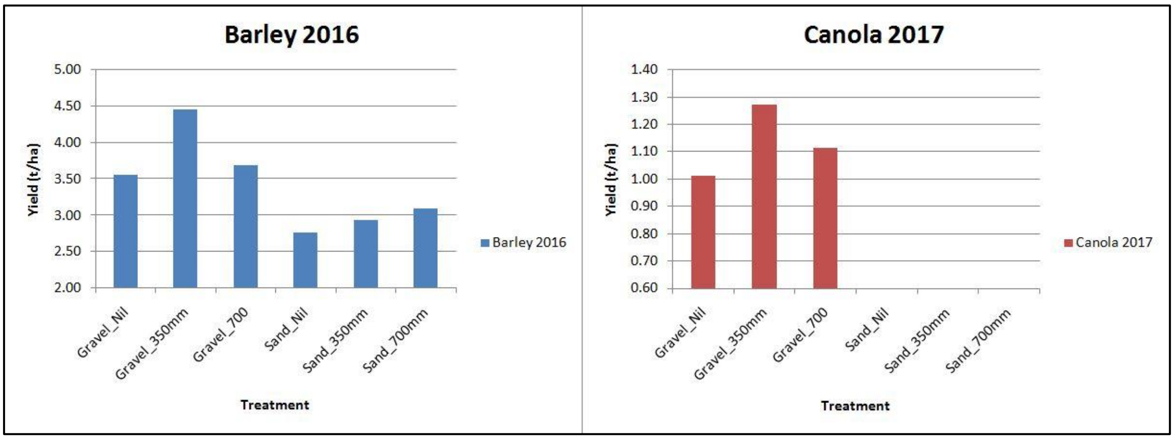


Figure 27: Average crop yield for the deep ripping and control plots showed that deep ripping provided an apparent yield benefits in barley (2016) and in canola (2017).

Soil and Plant Measurements

2018 Pasture Greenness and Cover

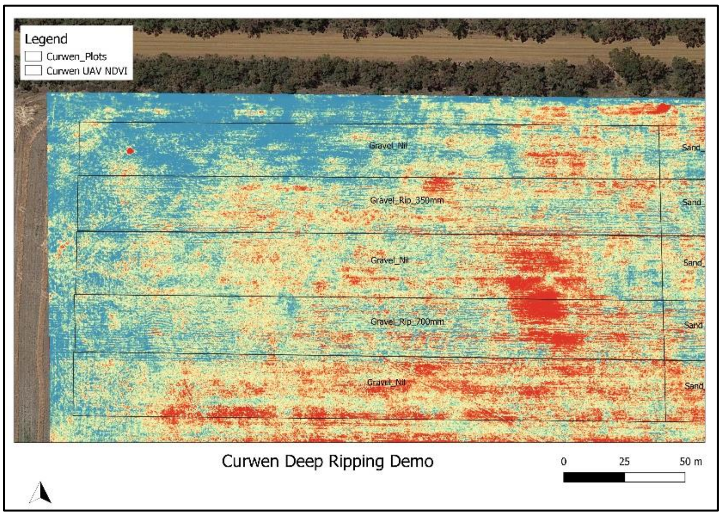


Figure 28: UAV NDVI imagery of the gravel soil plots captured in August 2018 showing significantly more green plant cover in the 700mm treatment than the adjacent Nil treatments.

Analysis of UAV NDVI imagery showed there was a significant difference in the area covered by green plant material when the 700mm deep ripped plot in the gravel soil type was compared to the adjacent Nil plots (Figure 6). There were no other significant differences in plant cover between plots even though visual assessment suggested that there may have been small areas of difference.

There was no difference in the greenness values between treatments in either the gravel or sand soil types. This may have been due to the pasture being very short and close to the ground from grazing livestock.

Soil Measurements

Soil coring across the trial site confirmed that shallow sandy gravel over literate and clayed deep sand were the two soil types present (Figure 7). All soil penetrometer insertions in the pale sand over gravel soil type were discarded due to the gravel interfering with the readings though all other insertions were kept.

Figure 29: Soil types found at the site were either pale sand over gravel (left) or deep pale sand (right).

A Rimick CP300 Cone Penetrometer was used to measure soil compaction at 16 locations across the trial site and found there were differences in soil strength after deep ripping (Figure 8a).

Soil compaction in the undisturbed plots increased steadily from the surface to peak at around 5000kpa at approximately 600mm.

The 350mm rip treatment showed a reduction in soil compaction to approximately 300mm and then increased to peak and maintain 5000kpa at 600mm.

The 700mm rip treatment was less compact to 600mm though soil strength levels greater than 2500kpa were still observed.

Previous research has found 2500kpa to be the compaction level where plant root growth begins to be inhibited so it is expected that the demonstration site will experience compaction as a soil constraint and may help explain yield differences observed.

Soil pH analysis showed large variations in soil pH across the site with almost a whole pH unit range being observed in each 10cm soil layer. Soil pH variation still existed within the soil type groups highlighting the natural variation in soils and impact of claying the soil surface (Figure 8b). Overall, soil pH fell well below pH targets of 5.5 in the topsoil and 4.8 in the subsurface. It is expected that subsurface soil acidity will be restricting root growth at the site and will be a severe soil constraint to the barley and canola crops which were planted.

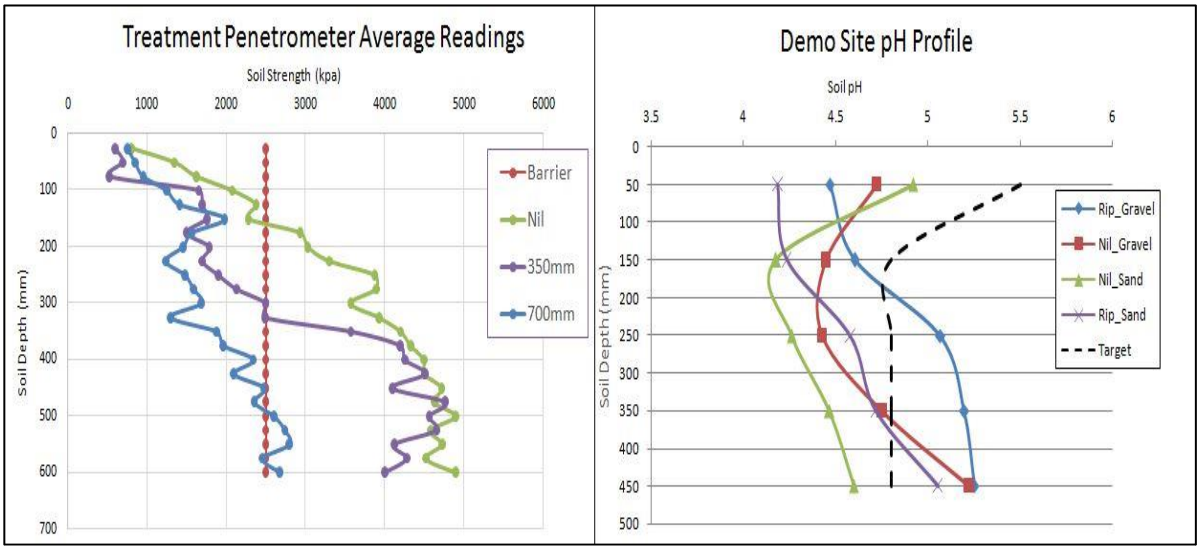


Figure 30: Average soil strength measurements from ripped and control plots as recorded by a cone penetrometer in August 2017 and soil pH values collected in February 2018

The 3D scanning bulk density cores were collected in the centre of each plot and were either in the gravel or deep sand soil type. The core could not be dug deeper than 30cm in the gravel soil type as the gravel was too hard. Bulk density increased with depth across all treatments and followed a similar pattern to that of the penetrometer readings (Table 1). There was a decrease in bulk density in the 40cm layer of the ripped plots in sand and a possible reduction in the gravel soil.

Table 6: The bulk density of soil collected at the centre of each plot was calculated by determining the weight of soil from a core of known volume.

	Dry Soil Weight (g)				Void Volume (cm^3)				Bulk Density			
Treatment	10cm	20cm	30cm	40cm	10cm	20cm	30cm	40cm	10cm	20cm	30cm	40cm
Sand Control	4,635	11,580	17,025	26,998	3,987	7,663	10,985	15,748	1.16	1.51	1.55	1.71
Sand 350mm	5,212	13,627	16,425	24,255	4,451	8,425	11,568	16,852	1.17	1.62	1.42	1.44
Sand 700mm	4,698	10,566	16,558	22,352	4,021	7,856	11,053	15,896	1.17	1.34	1.50	1.41
Gravel Control	7,489	13,566	30,665	N/A	6,203	9,254	15,668	N/A	1.21	1.47	1.96	N/A
Gravel 350mm	7,523	14,255	25,845	N/A	7,524	10,235	16,255	N/A	1.00	1.39	1.59	N/A
Gravel 700mm	6,237	12,555	28,356	N/A	5,896	8,547	14,993	N/A	1.06	1.47	1.89	N/A

Returns of Deep Ripping

The net benefit of both ripping depths was positive for the sand and gravel soil types and look to be sustained over the two years of data available. The 350mm ripping depth gave the greatest average benefit of $164/ha in the gravel soil and the highest overall return of $278/ha after costs had been removed (Table 2)

The higher cost of the 700mm ripping depth was not balanced by increased yield gains and was therefore not as profitable as the less costly 350mm treatment.

Table 7: Economic return of each treatment.

Treatment	Treat. Cost ($/ha)	Amortised Treat. Cost over three years ($/ha/yr)	Benefit from Ripping 2016 ($/ha) Barley @ $250/t	Benefit from Ripping 2017 ($/ha) Canola @ $500/t	Accumulated Return - Costs over three years ($/ha)
Control Gravel	-	-	0		0
Rip 350mm Gravel	50	17	188	140	278
Rip 700mm Gravel	80	27	93	55	68
Control Sand					
Rip 350mm Sand	40	13	55	-	47
Rip 700mm Sand	60	20	80	-	68

The longevity of the treatment effect will determine how cost effective deep ripping is in this environment and on these soil types. The yield results from the 2019 season will be important to quantify how long the ripping effect seen here will last.

Broomehill site:

Crop Yield

ANOVA analysis of crop yields for the trial showed a significant increase in yield between the ripped and control plots in each subsequent crop after deep ripping and that no significant difference existed in the season immediately prior to ripping treatments being established (Figure 5).

The largest yield increase was seen in the 2016 Canola crop where an average 310 kg/ha yield increase was recorded in the ripped plots over the control. Lower yield increases were seen in the 2015 Barley and the 2017 Lupin crops where 157 kg/ha and 90kg/ha yield increases respectively were recorded in ripped plots over the control plots.

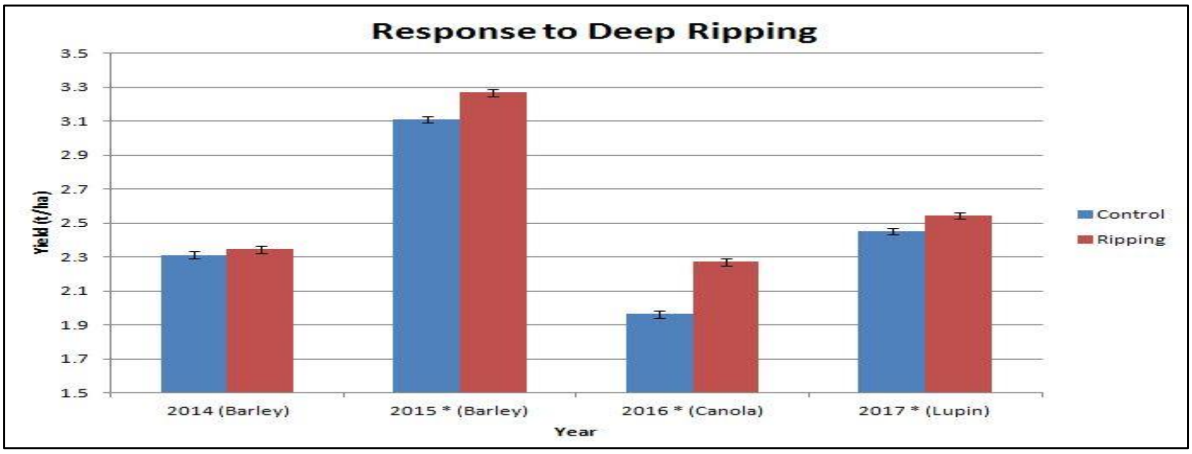


Figure 31: Average crop yield for the ripping and control plots showed there was no significant difference observed pre-treatment (2014) though significant differences (denoted by *) were present in each season and crop type after ripping (2015 - 2017).

Soil and Plant Measurements

A Rimick CP300 Cone Penetrometer was initially used to measure soil compaction at 27 locations across the trial site (Figure 6).

Five insertions were recorded at each site and the average of these used to characterise the soil resistance at each location.

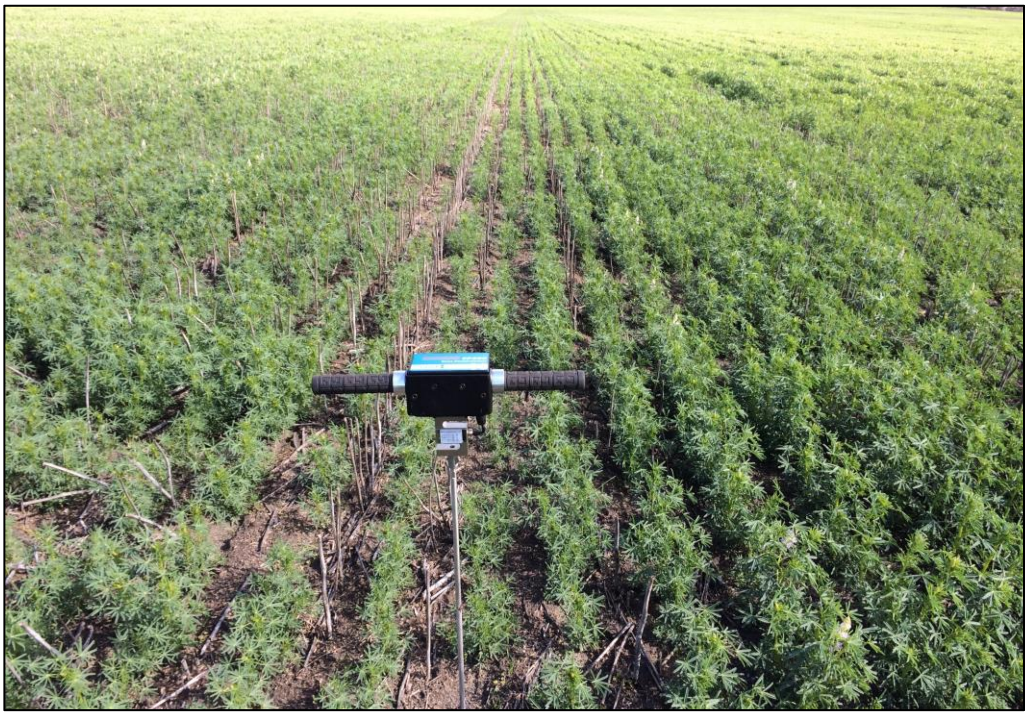
Gravel in the soil interferes with the ability to obtain an accurate measurement and limited the number of recordings that could be used to 5 from ripped plots and 5 from the control plots. These sites were all within a sand over clay duplex soil type rather than the sandy gravel soil type which dominated the trial area.

For this reason it was suggested that the data presented be viewed as only a guide to soil compaction at the site.

In the soil type where soil penetrometer recordings could be made it was found that there was a reduction in soil resistance within the ripped plots when compared to the control plots, particularly in the soil layers between 100 – 300mm (Figure 7). It was also found that the reduction in soil resistance in the ripped plots gave an overall average reading that was less than 2500 kpa which previous research has found to be the value where plant root growth begins to be inhibited.

In comparison, the average measurements in the control plots peaked at above 3000 kpa which indicate that there may be a soil constraint at this site caused by compaction. The severity of the constraint may not be all that large as the soil strength drops below 2500 kpa after 250mm soil depth.

Figure 32: Rimick CP300 Cone Penetrometer used to record soil resistance across the trial site.



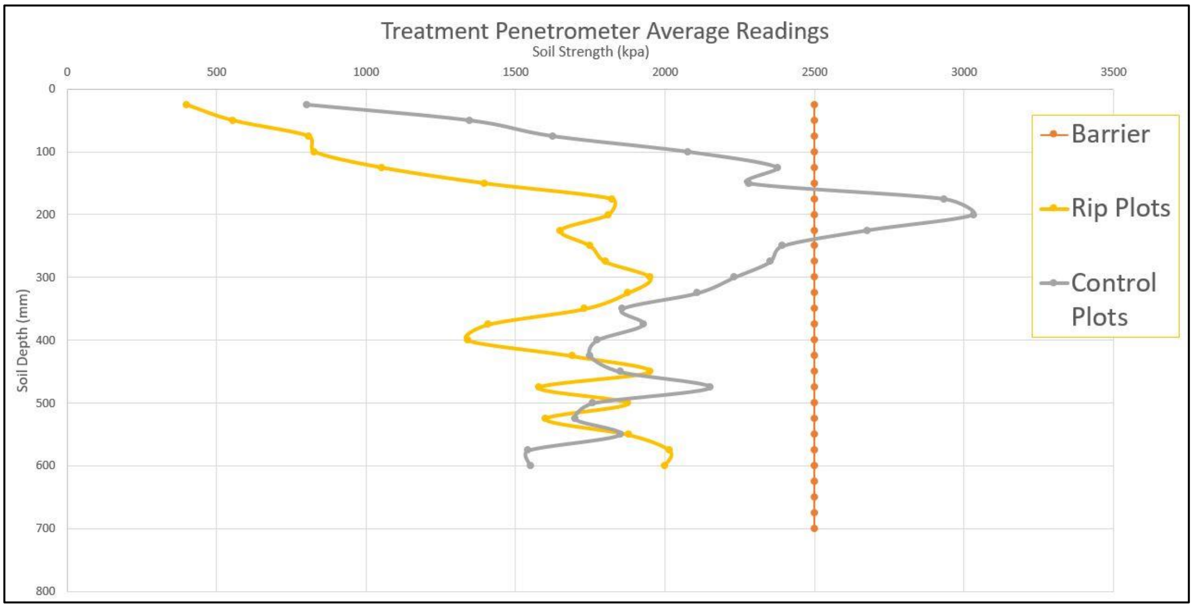


Figure 33: Average soil resistance measurements from ripped and control plots as recorded by a cone penetrometer.

The 3D scanning bulk density cores were collected 150 metre in from the eastern edge of the plots. Soil type varied from sand over gravel in the northern plots to shallow sandy gravel in the south.

Bulk density only slightly increased with depth in the control plots and the maximum values at 50cm are not thought to result in compaction being a major constraint. The bulk density of the southern ripped plot shows a reduction in bulk density when compared to the adjacent control plots thought this seen in the northern ripped plots (Table 1).

Table 8: Bulk density of soil from each plot was calculated across the trial area.

	Dry Soil Weight (g)				Void Volume (cm^3)				Bulk Density			
Treatment	10cm	20cm	30cm	50cm	10cm	20cm	30cm	50cm	10cm	20cm	30cm	50cm
Control	4,167	11,584	16,504	26,491	4,140	7,584	11,504	16,212	1.01	1.53	1.43	1.63
Rip	4,103	10,806	16,820	24,491	4,452	7,806	11,820	15,822	0.92	1.38	1.42	1.55
Control	4,256	11,134	16,507	25,555	4,450	8,134	12,507	16,471	0.96	1.37	1.32	1.55
Rip	4,158	9,137	17,917	20,560	4,360	7,137	13,917	16,344	0.95	1.28	1.29	1.26
Control	4,328	12,012	15,852	24,523	4,394	7,966	11,563	15,478	0.98	1.51	1.37	1.58

The bulk density values found at the site are not thought to be high enough to impede plant root growth. Though the bulk density measurements stop at 50cm, penetrometer readings indicate compaction is unlikely to increase deeper than this level.

Also, effort was taken to find the middle of the rip lines for all cores so this may represent the loosest, least compact parts of the soil profile. It was noted that the 3D scan and bulk density measurement for the southern rip plot was taken from a rip line that remained very loose and had left gravelly clay remaining on the soil surface (see Figure 2).

Plant counts showed no overall difference between the treatments in both 2017 and 2018 though a large range and variance was recorded in the plots of each treatment. This is best shown in the imagery captured by the UAV which shows large variation in NDVI across the trial site (Figure 8a).

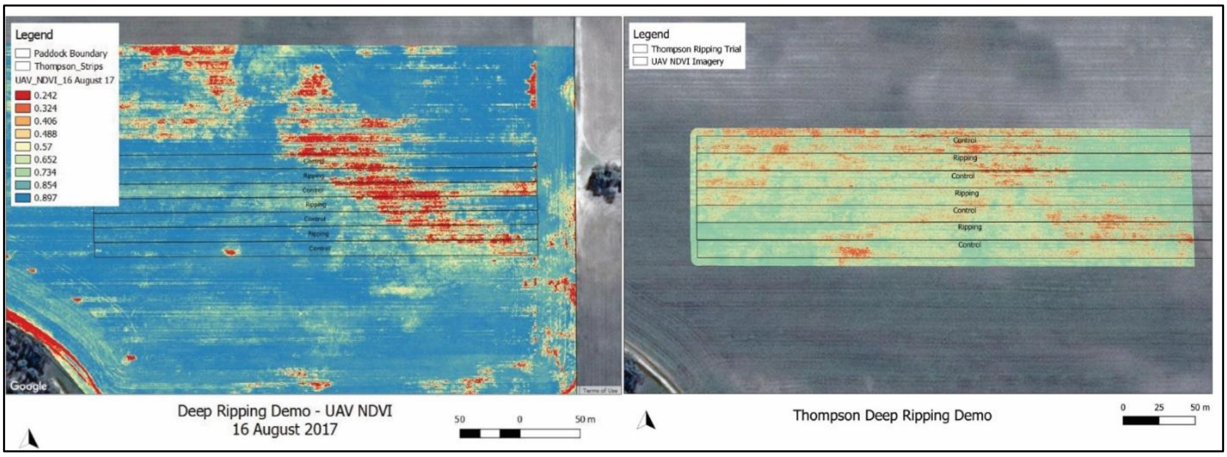


Figure 34a and 8b: NDVI imagery from 2017 (8a, left) and 2018 (8b, right) shows biomass variation across the trial though no difference between treatments

The 2018 NDVI imagery (Figure 8b) does not show any statistical difference in greenness between the treatments though an overall better ground cover percentage than the 2017 crop. A significant increase in plant biomass was recorded between the ripped and control plots in the 2018 wheat crop (Figure 9). It again should be noted that the biomass cuts were taken directly over the ripped strips.

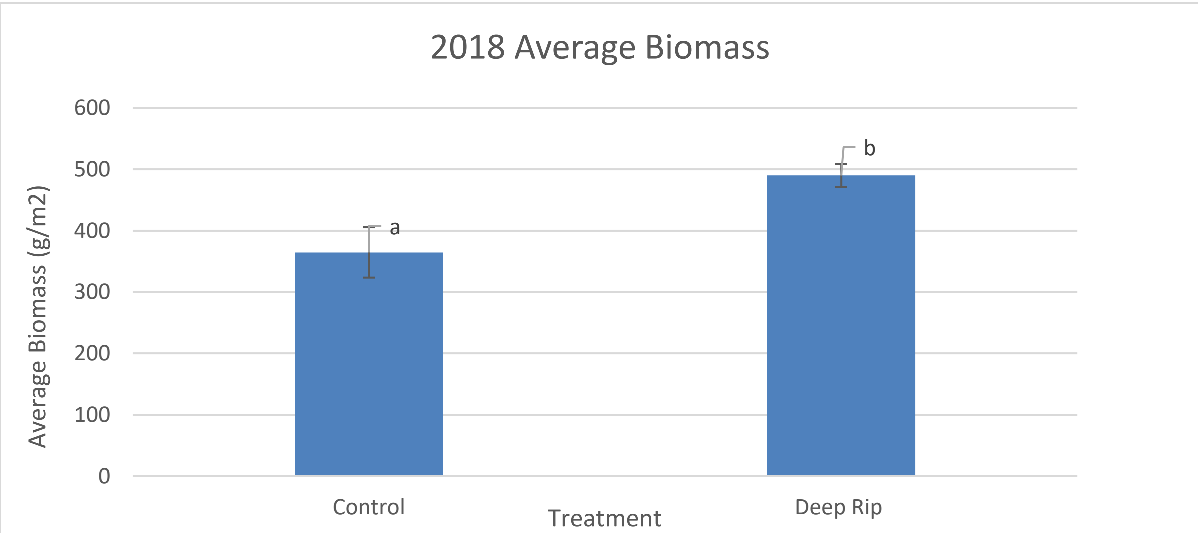


Figure 35: Biomass cuts showed a significant increase in plant weights between ripped and control plots.

Returns of Deep Ripping

The net benefit of all ripping was positive for deep ripping at this location and provided an average annual return of $72/ha over the 2015 – 2017 period (Table 2). The plant biomass difference in 2018 would also likely have resulted in a yield and economic benefit though this cannot be measured.

Table 9: Economic benefit for deep ripping was positive and sustained over the three year period.

Treatment	Treat. Cost ($/ha)	Amortised Treat. Cost over three years ($/ha/yr)	Net Benefit from Ripping 2015 ($/ha) Barley @ $250/t	Net Benefit from Ripping 2016 ($/ha) Canola @ $500/t	Net Benefit from Ripping 2017 ($/ha) Lupin @ $250/t	Accumulated Return - Costs over three years ($/ha)
Control	-	-	0		0	0

Deep Rip	40	13	39	155	23	177

The 2017 season saw the smallest yield difference between treatment and control plots which may be due to a lupin crop being less responsive to deep ripping than barley or canola or may be a result of the deep ripping effect being reduced with time.

The yield responses to deep ripping may continue to be monitored over the 2019 season to see if the treatment effects continue. The longevity of the treatment effect will determine how cost effective deep ripping is in this environment and on these soil types.

Kojonup site:

Crop Yield

Comparison of the annual yield response has been split into two groups to reflect the treatments that are replicated and those that are not for both the 2016 and 2017 seasons.

A significant yield difference was observed only in the 350mm rip treatment in 2016 which gave a 260kg/ha increase (lsd = 204kg/ha) over the Nil plots. There was a non-significant yield difference of approximately 200kg/ha for the other ripping treatments in 2016. The offset disc and scarifier treatments indicated a yield increase over the Nil plots and the Heliripper suggested a yield decrease, though the significance of these trends cannot be verified and are likely misleading.

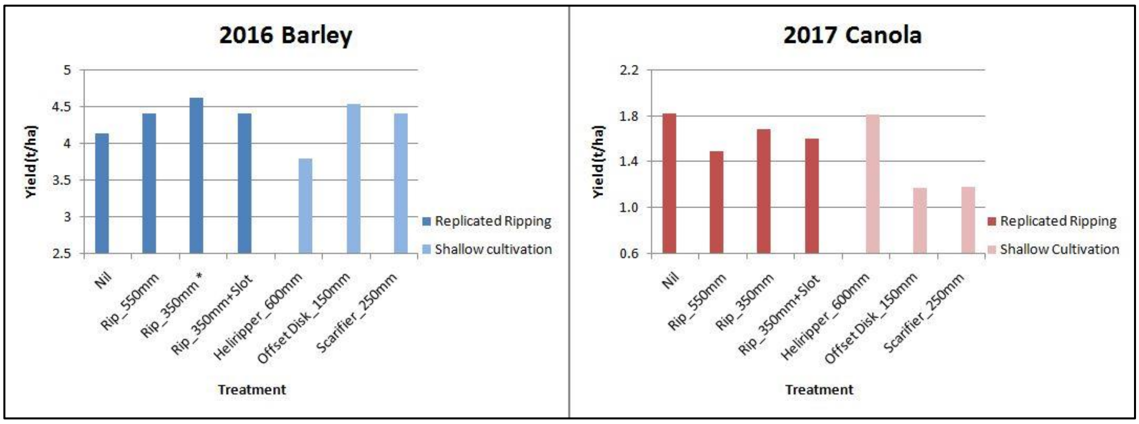


Figure 36: Average crop yield for the deep ripping and control plots showed that deep ripping to 350mm povided a yield benefit in 2016. Significance is represented by the "x" in the treatment label on the x axis.

Yield data in 2017 showed an overall decrease in yield in all ripping treatments when compared to the Nil treatment except in the un-replicated Heliripper treatment which had a similar yield to the nil treatments.

Windy conditions prior to harvesting the trial resulted in pod shatter and an estimated 50% loss of grain. An un-even application of in season nitrogen was found using the UAV NDVI imagery (Figure 7) and unfortunately both of these issues raise concerns about the validity of the 2017 yield results.

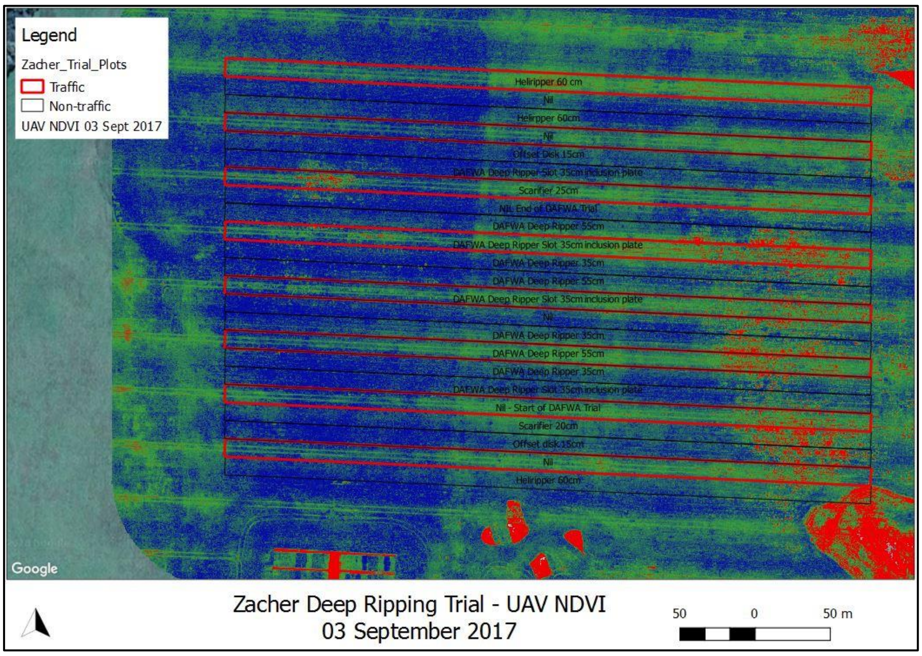


Figure 37: UAV NDVI imagery captured on 03 September 2017 shows variations in biomass across the trial. The influence of gravel soiltype on biomass can be seen on the eastern end and the influence of past merged paddock can be seen on the western end.

Soil and Plant Measurements

Soil coring across the trial site confirmed that loamy sand over gravelly clay and sandy gravel loam over gravel were the two soil types present (Figure 8). The sandy gravel was located in the eastern end of the trial and this area was excluded from all analysis.

A Rimick CP300 Cone Penetrometer was used to measure soil compaction at 46 locations across the trial. This was made up of five insertions at 2 locations along each plot. Insertions locations were randomly chosen in the control plots though the ripping line was found and measurements taken from within the rip line for the ripped plots.

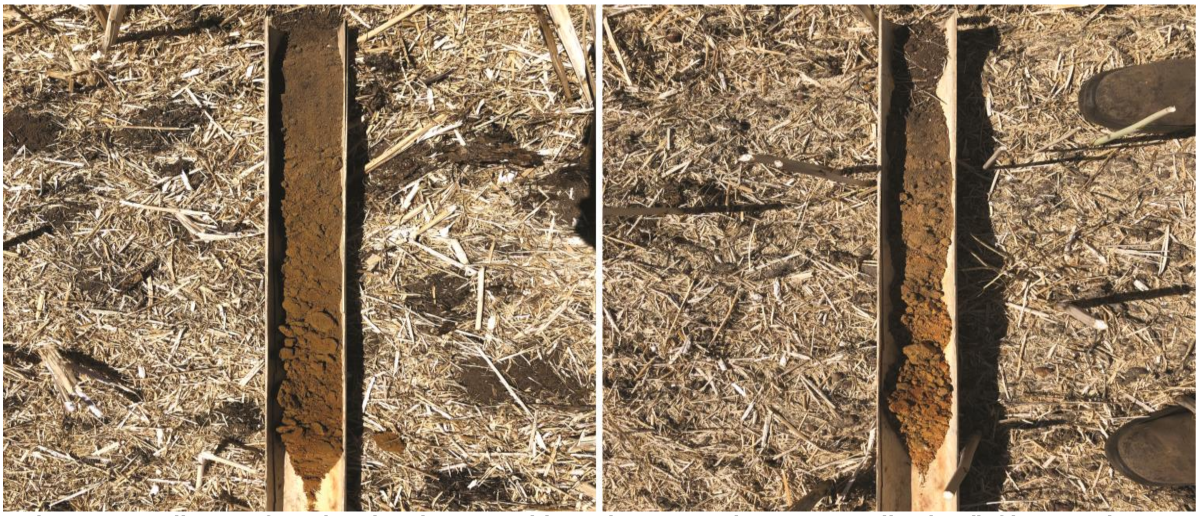


Figure 38: Soil types found at the site were either a loamy sandy over gravelly clay (left) or sandy gravel loam over gravel (right).

No measurements were collected from the shallow cultivation treatments or below 600mm in the other treatments. Many locations had too much gravel to measure compaction accurately and were discarded from the data set.

The average soil strength was found to be reduced in the deep ripping plots to the depth of working then increased (Figure 9). The control plots consistently reached 2500kpa between 150 – 200mm soil depth and increased to peak at 4500-5000kpa at 400mm depth. Deep ripping plots generally maintained compaction levels below 2500kpa to 400mm depth then increased to levels similar to the control plots.

Previous research has found 2500kpa to be the compaction level where plant root growth begins to be inhibited. This indicates that the deep ripping did not remove compaction as a constraint below 400mm across the trial site.

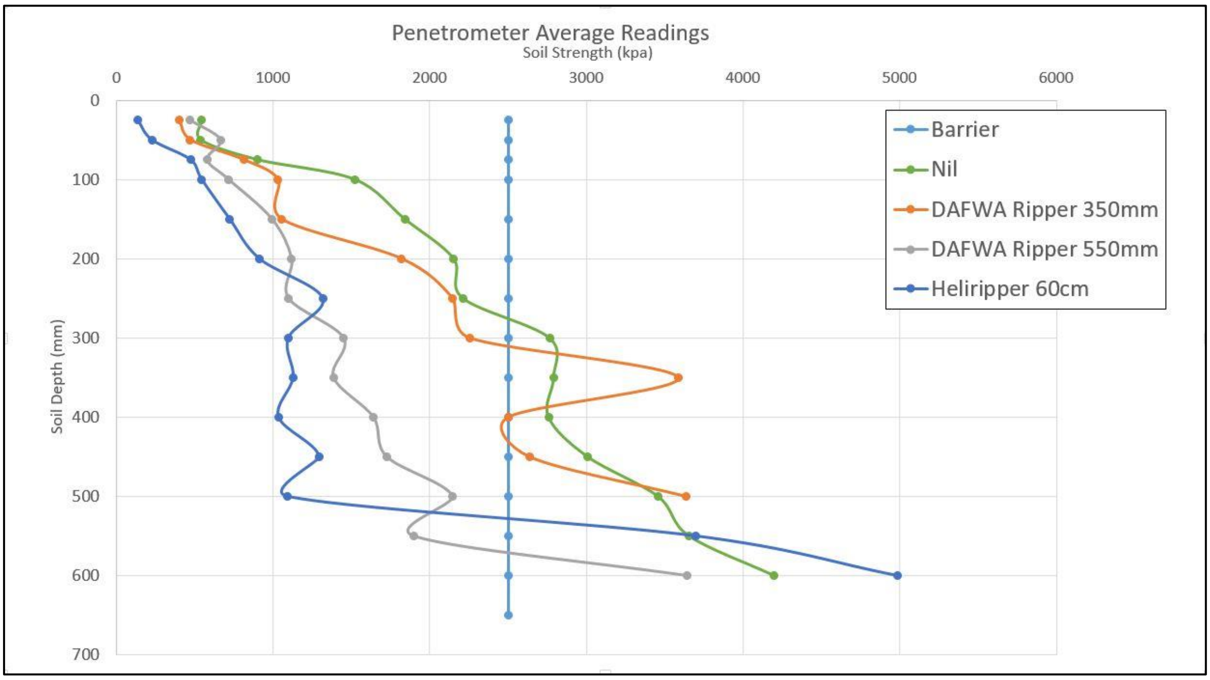


Figure 39: Average soil strength measurements from ripped and control plots as recorded by a cone penetrometer in August 2017.

The 3D scanning bulk density cores were collected 150 metre in from the eastern edge of DAFWA replicate two trial plots with the exception of one of the 350mm + Slotting plots which were not sampled. Soil type was a consistent loam sand over gravel sand over gravel.

Bulk density increased with depth in the control plots though the maximum values at 50cm are not thought to result in compaction being a major constraint. The bulk density of the ripped plots varied and showed an increase in bulk density with depth in the 350mm + slotting and 550mm ripping plots when compared to the adjacent control plots (Table 1).

Table 2: Bulk density of soil from each plot was calculated across the trial area.

	Dry Soil Weight (g)				Void Volume (cm^3)				Bulk Density			
Treatment	10cm	20cm	30cm	50cm	10cm	20cm	30cm	50cm	10cm	20cm	30cm	50cm
Control	5,500	10,587	15,574	21,074	4,258	7,489	10,365	15,078	1.29	1.41	1.50	1.40
DAFWA 350mm	6,589	9,986	15,426	22,015	4,436	7,368	11,235	14,535	1.49	1.36	1.37	1.51
DAFWA 350mm + Slotting	4,532	10,697	20,956	25,488	4,125	8,215	10,569	14,835	1.10	1.30	1.98	1.72
DAFWA 550mm	5,245	10,365	18,414	23,659	4,625	6,987	10,365	14,525	1.13	1.48	1.78	1.63

Though the bulk density values found at the site are not thought to be high enough to impede plant root growth, the measurements stop at 50cm. Penetrometer readings indicate compaction is likely to increase deeper than this level and may increase further than was able to be measured. Effort was made to find the middle of the rip lines for all cores so this may represent the loosest, least compact parts of the soil profile.

Plant biomass in 2018 showed no significant increase in biomass for the ripping treatments though did measure a significant reduction in biomass for the 350mm + Slotting plots (Figure 9). This is thought to be caused by two sampling sites having much lower plant counts were the samples were collected.

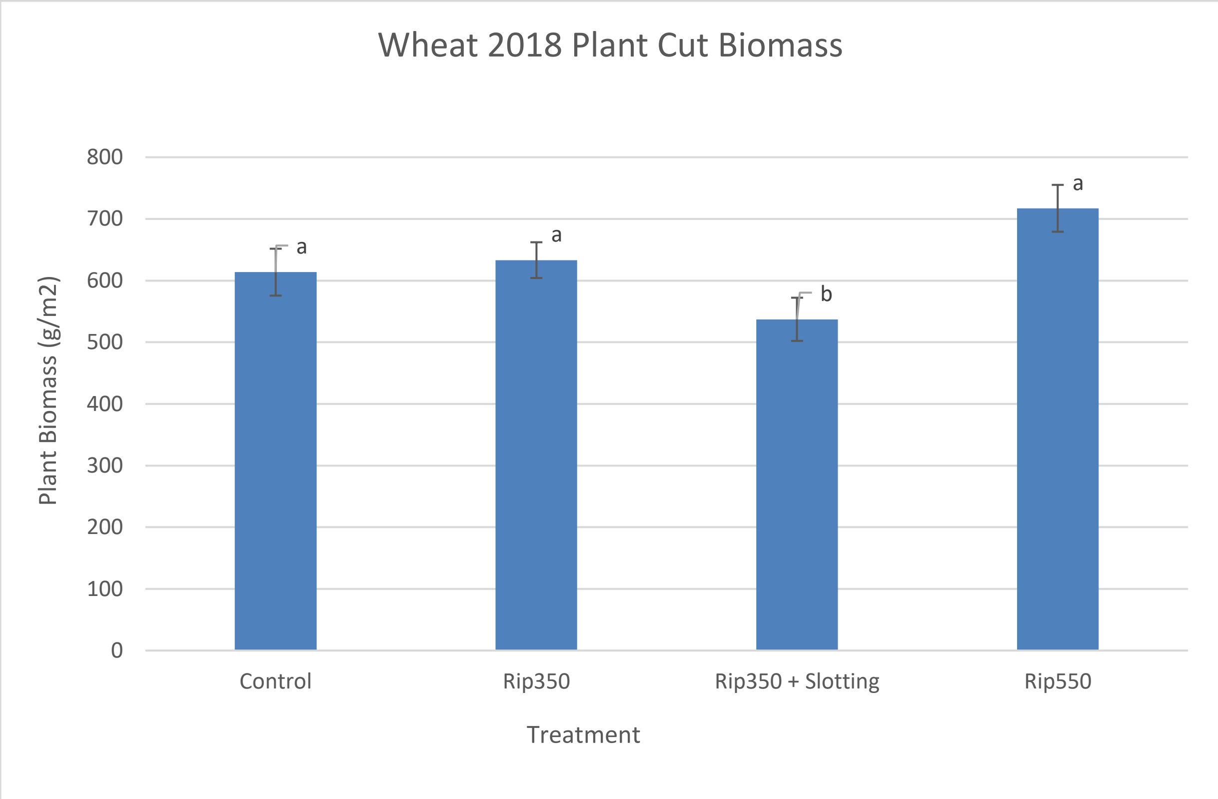


Figure 40: Plant biomass as measured by plant cuts from the 2018 wheat crop.

Returns of Deep Ripping

An economic analysis of the advantage of deep ripping at this site can only be carried out for the 2016 cropping season due to the 2017 yield being compromised and the 2018 data not being available.

All deep ripping treatments returned a positive yield and economic benefit, with the exception of the Helripper 600mm treatment which ended giving $108/ha less than the control (Table 2). The ripping 350mm and 550mm provided similar benefits of $54/ha and 50/ha respectively. The ripping 350mm + Slotting treatment returned $108/ha and the indicating that the use of slotting plates doubled the effectiveness of the deep ripping at this depth.

Table 10: Economic return of the treatments for the 2016 season.

Treatment	Treat. Cost ($/ha)	Amortised Treat. Cost over three years ($/ha/yr)	Benefit from Ripping 2016 ($/ha) Barley @ $250/t	Accumulated Return - Costs over three years ($/ha)
Control	-	-	0	0
Rip 350mm	40	13	68	54
Rip 350mm + Slotting	45	15	123	108
Rip 550mm	55	18	68	50
Helipipper_600mm	70	23	-85	-108

Offset Disk_150mm	15	5	98	93
Scarifier_250mm	15	5	69	64

The yield responses from shallower ripping treatments provided an average economic increase of $79/ha suggesting that the yield response may being caused by something other than subsoil compaction.

The longevity of the treatment effect will determine how cost effective deep ripping is in this environment and on these soil types. Analysis of the yield data from the 2018 season will be important to quantify how long the ripping effect seen here will last and will be carried out if the data is made available.

Nyabing site:

Crop Yield

Significant yield increases were recorded in the ripped strips in both the 2017 and 2018 seasons when compared to the adjacent control plots (Figure 3). Yield increases ranged from 179 to 469 kg/ha (Table 1).

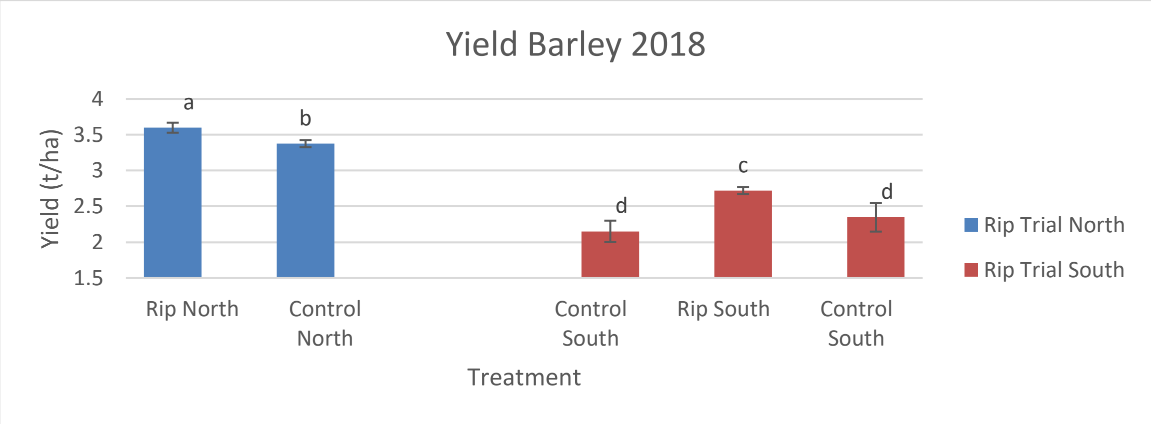


Figure 41: Average crop yield for the deep ripping and control plots showed that deep ripping provided a significant yield increase in both trial strips. It also showed that Planet barley had a significantly higher yield than Spartacus in this location.

Table 11: Estimated increase in yield as a result of deep ripping at six demonstration sites near Nyabing.

Ripping Trial	2017 Yield Benefit (kg/ha)	2018 Yield Benefit (kg/ha)
C01 North	179	223
C01 South	218	469
Average Benefit	199	346

Yield differences were measured between the barley varieties with the ripped and un-ripped Planet barley out yielding the ripped and un-ripped Spartacus barley though there was approximately 170 metres between the two trials.

Soil and Plant Measurements

Soil strength was reduced in the deep ripping plots when compared to the adjacent control plots in 2017 and was maintained into the 2018 season (Figure 4). 2018 measurements in the southern rip trial had increased and had more variation when compared to 2017. It is unclear if this represents a return to pre-ripping soil strength levels or if seasonal conditions (i.e. drier soil profile) are the cause of this change. No differences in the northern rip strip were observed.

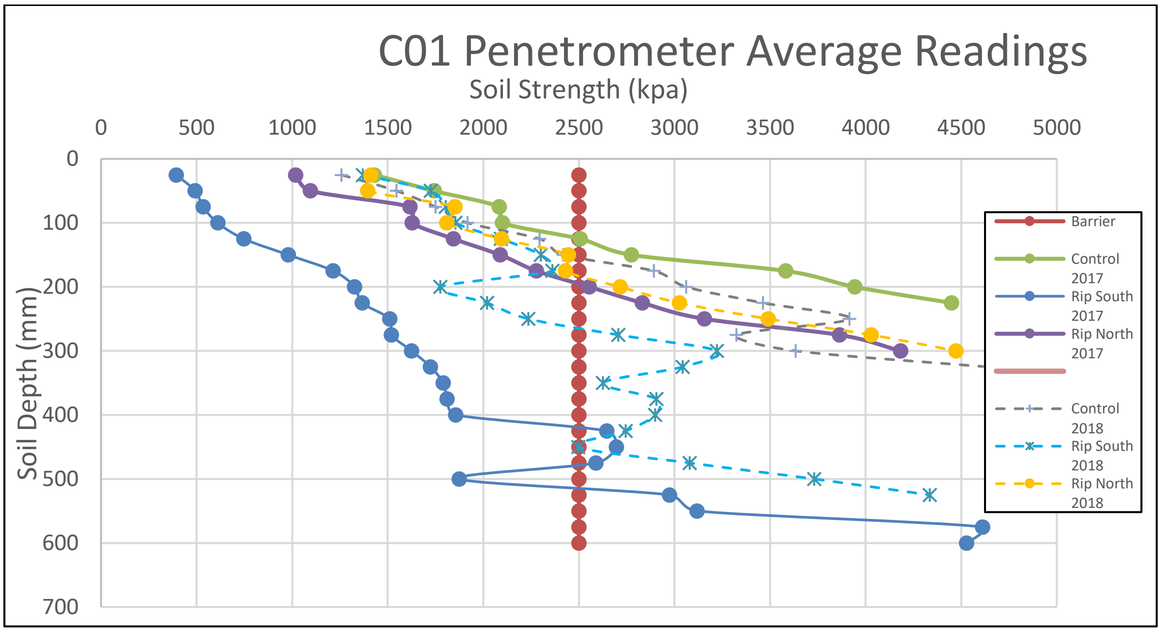


Figure 42: Comparison of soil strength measurements from ripped and control plots measured in 2017 (solid lines) and 2018 (dashed lines).

The control plots consistently reached 2500kpa between 150 – 300mm soil depth and increased to peak at 4500-5000kpa at 400 – 500mm depth. Deep ripping plots generally maintained compaction levels below 2500kpa to 400mm depth then increased to levels similar to the control plots. The ripped plots in the northern trial maintained higher levels of compaction than at the southern trial in both years.

Previous research has found 2500kpa to be the compaction level where plant root growth begins to be inhibited and indicates that the deep ripping did not remove fully remove compaction as a constraint in these areas.

Plant tiller density was measured by counting tillers along a 0.3m section of crop row at each penetrometer recording site (Table 2). This showed very even plant establishment and tiller density between the ripped plots and though there was a slight overall increase in the ripped plots there was no overall difference between the treatments.

Table 12: Crop tiller counts recorded at multiple locations in each plot showed no overall difference between treatments

	Avg. Tiller Density (tiller/m2)			
Ripping Demo ID	Ripped Plot		Control Plot	
	2017	2018	2017	2018
C01 North	402	356	396	350
C01 South	445	388	437	380
Average	398		391	

There were small visual differences in plant greenness in the ripped strips throughout the season though it was not consistent along the length of the plots. The imagery captured by the UAV shows only small differences in NDVI across the sites though ripped plots have small areas that have higher biomass than the adjacent control plots (Figure 4). The imagery also shows the difference in greenness of the Planet and Spartacus varieties and the need to drop one control plot from the northern trial.

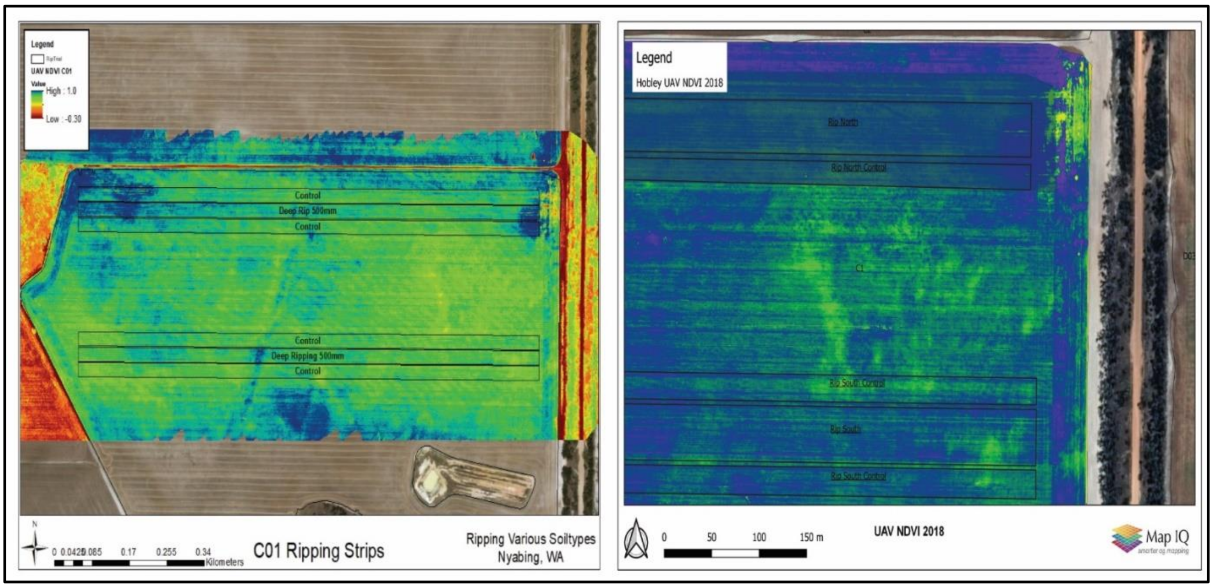


Figure 4: NDVI imagery shows biomass variation across the trial though no measurable difference between treatments

Returns of Deep Ripping

There was an average net benefit of $106/ha from deep ripping in this paddock over the control. The southern trial strip provided higher returns in both years of the trail with an average benefit of $91/ha over the two seasons. The northern trial had similar returns each season and averaged $55/ha.

These results are economically significant and make the deep ripping practice worth the effort, especially if the yield benefits continue over time. The longevity of the treatment effect will determine just how cost effective deep ripping is in this environment and on these soil types.

Table 13: The annual gross margin for each treatment and cumulated return over the two years examined.

Treatment	Treatment Cost ($/ha)	Amortised Treatment Cost over two years ($/ha)	Benefit from Ripping 2017 ($/ha) Wheat @ $300/t	Benefit from Ripping 2018 ($/ha) Barley @ $250/t	Return on Investment over two years ($/ha)
Control	-	-	0	0	0
Deep Rip North	40	20	54	56	69
Deep Rip South	40	20	65	117	143
Average	-	-	60	87	106

Beverley site:

Crop Yield

Yield differences in 2017 and 2018 were initially examined along the entire length of the ripped boundary. A negative yield response was observed on the northern boundary and a positive response on the southern boundary in both seasons. In 2017, a yield loss of 140kg/ha was recorded along the northern edge of the ripped area while a 70kg/ha yield gain was seen along the southern edge (Figure 4). A very similar pattern was seen in 2018 with a 300kg loss recorded along the northern boundary and a 60kg increase on the southern boundary (Figure 4).

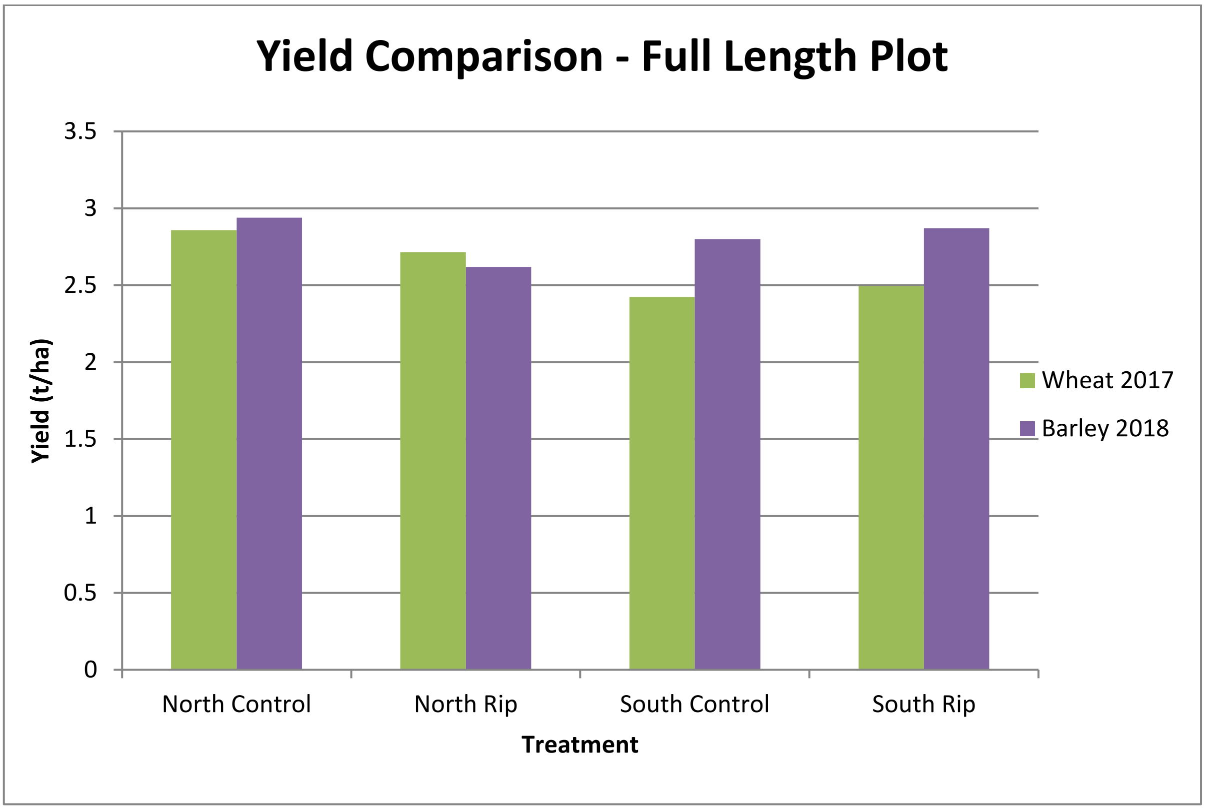


Figure 43: Yield comparison between the ripped and un-ripped area shown mixed results when examining the entire plot length.

Yield differences between production zones along the ripped area boundary were then examined (Figure 5). Zones were correlated soil type where the deep coarse sand area having low production, sand over deeper gravelly clay being of medium production and the sand over shallow loamy clay a high production

High production zone

Deep ripping increased yield in the high production zones with a 270kg/ha and 400 kg/ha benefit recorded in the ripped plots in 2017 and a 101kg/ha and 443kg/ha yield increase in 2018.

Low and medium production zone

Deep ripping resulted in a 40kg/ha decrease in yield in the medium production zone in 2017 and 38kg/ha yield reduction in 2018.

A 140kg/ha yield decrease in the northern low production zone was recorded in 2017 although a 121 kg/ha increase was recorded in 2018. The low production zone on the southern edge saw a 340kg/ha yield benefit in 2017 and 219 kg/ha increase in 2018 (Figure 5).

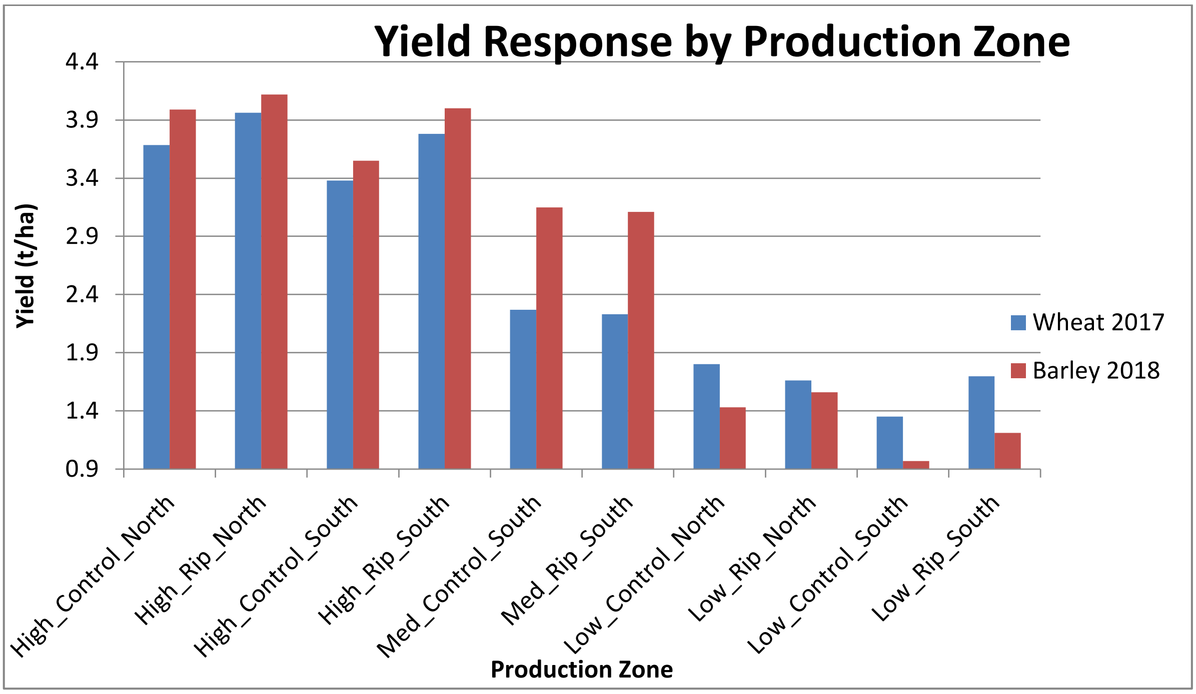


Figure 44: Yield differences in varying production zones where observed at the site.

Soil and Plant Measurements

Soil strength was found to be reduced in the deep ripping when compared to the soil in the adjacent un-ripped area with a natural reduction in compaction in soil deeper than 400mm where soil strength reduces to just above 2500kpa between 400-600mm in all treatments (Figure 6).

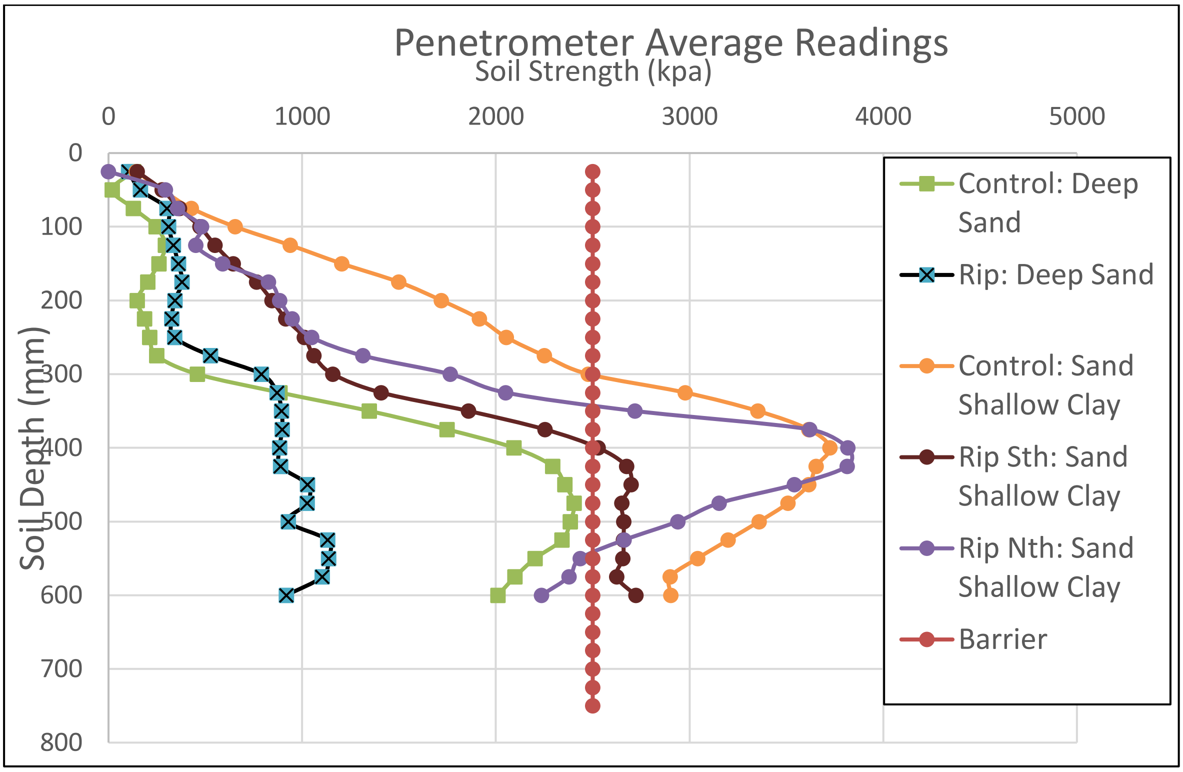


Figure 45: Average soil strength measurements from ripped and control plots as recorded by a cone penetrometer in August 2017.

The control plots reached 2500kpa between 300 – 400mm soil depth and increased to peak at 3500-4000kpa at 400 - 500mm with the exception of the un-ripped deep sand which had the highest reading of just below 2500 kpa.

Deep ripping plots generally maintained compaction levels below 2500kpa to 400mm depth then increased to levels between2500-300kpa to 600mm. The northern sand over shallow clay plot reached the same soil strength of as the adjacent control plot at 400mm soil depth.

Previous research has found 2500kpa to be the compaction level where plant root growth begins to be inhibited and indicates that the deep ripping did not fully remove compaction as a constraint in these areas.

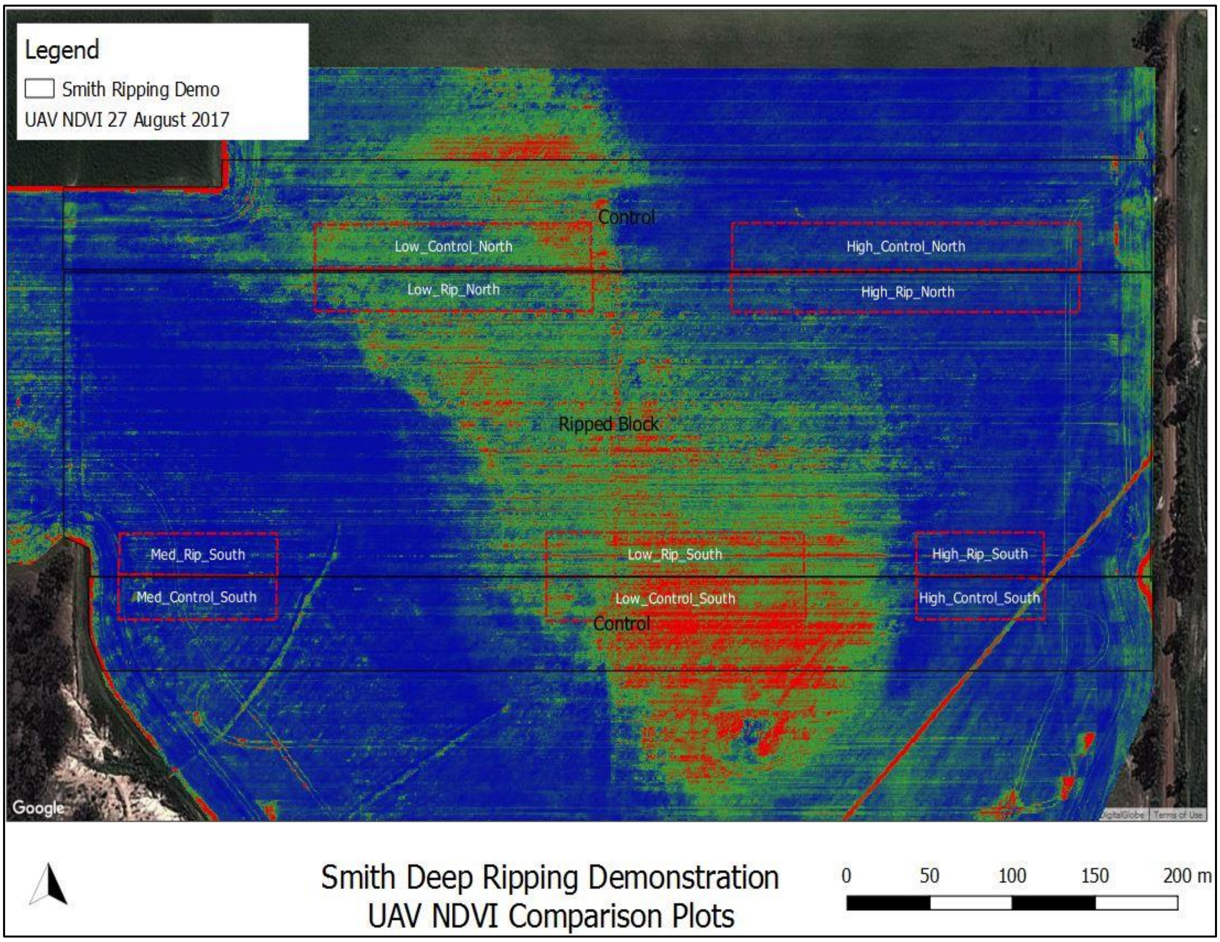


Figure 46: UAV NDVI captured 27 August 2017 shows large variation in crop biomass. Soil type is thought to be the main driver of production at this site

Small visual differences in plant greenness in the boundary of ripped and control areas throughout each season though it was not consistent along the length of the plots. The imagery captured by the UAV in 2017 shows a large variation in biomass across the site though only small differences in NDVI between the treatment areas (Figure 7).

Returns of Deep Ripping

There was an average net benefit of $51/ha from deep ripping in this paddock over the 2017 and 2018 cropping seasons (Table One).

The sand over shallow clay soil type, that was associated with the high production zone, provided the highest returns in both years of the trial with an average benefit of $87/ha. The deeper sands of the medium and northern low productions zones had a negative result with a cumulative loss of $55/ha and $67/ha respectively. The southern low production zone provided positive returns in both years and averaged $82/ha benefit from ripping.

These results are economically significant and make the deep ripping practice worth the effort in the sand over shallow clay and deep sand soil types. The longevity of the treatment effect will determine just how cost effective deep ripping is in this environment and on these soil types.

Table 14: The annual benefit for each treatment and cumulated return over the two years examined.

Treatment	Treatment Cost ($/ha)	Amortised Treatment Cost over two years ($/ha)	Benefit from Ripping 2017 ($/ha) Wheat @ $300/t	Benefit from Ripping 2018 ($/ha) Barley @ $250/t	Return on Investment over two years ($/ha)
Control North	-	-	-	-	-
High Rip North	45	22.5	83.3	32.5	70.8
High Control South	-	-	-	-	-
High Rip South	45	22.5	120.5	112.5	188.0
Med Control South	-	-	-	-	-
Med Rip South	45	22.5	-12.0	-10.0	-67.0
Low Control North	-	-	-	-	-
Low Rip North	45	22.5	-42.1	32.5	-54.6
Low Control South	-	-	-	-	-
Low Rip South	45	22.5	103.4	60.0	118.4
Average	-	-	50.6	45.5	51.1

Quairading site:

Crop Yield

The impact that deep ripping has had on yield cannot be definitely quantified as this is an un-replicated demonstration and the results should only be used as a guide to likely outcomes, though the size of the yield differences provides confidence that the effects are likely to be seen in other areas that have similar soil constraints.

Large yield differences between ripped and spaded and control areas were seen across all soil types (Figure 3). The largest difference was recorded in the deep yellow sand where yield increased by 1,148kg/ha, an almost 108% benefit to deep ripping and spading. A similar yield increase of 1,107kg/ha, a 68% benefit, was recorded in the sand over gravel duplex soil type and in deep white sand were 451kg/ha, or 68% increase was observed.

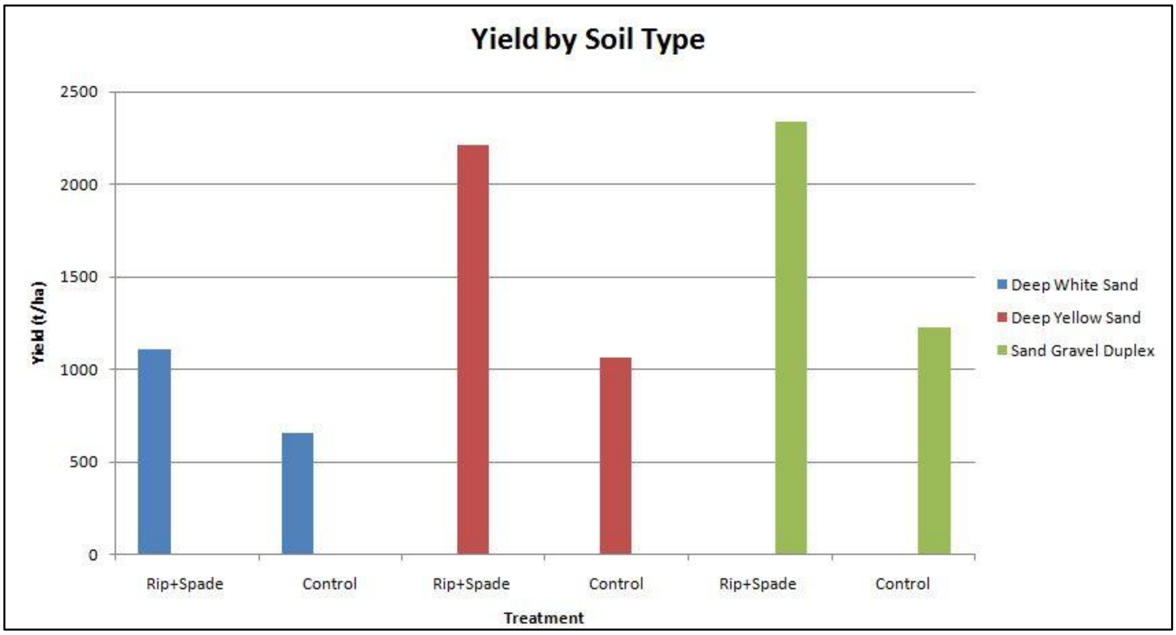


Figure 47: Large yield differences due to deep ripping were recorded across all soil types.

Soil and Plant Measurements

The average soil strength was found to be reduced in the deep ripping and spaded area when compared to the adjacent un-ripped soil (Figure 4). The control strips consistently reached 2500kpa between 200 – 250mm soil depth and increased to peak at over 4000kpa at 400mm. The data indicates that there is a natural reduction in compaction in soil deeper than 400mm as the soil strength reduces to just above 2000kpa at 750mm.

Deep ripping plots generally maintained compaction levels below 2500kpa to 750mm depth. Previous research has found 2500kpa to be the compaction level where plant root growth begins to be inhibited and indicates that the deep ripping fully remove compaction as a constraint in the sandy soil types.

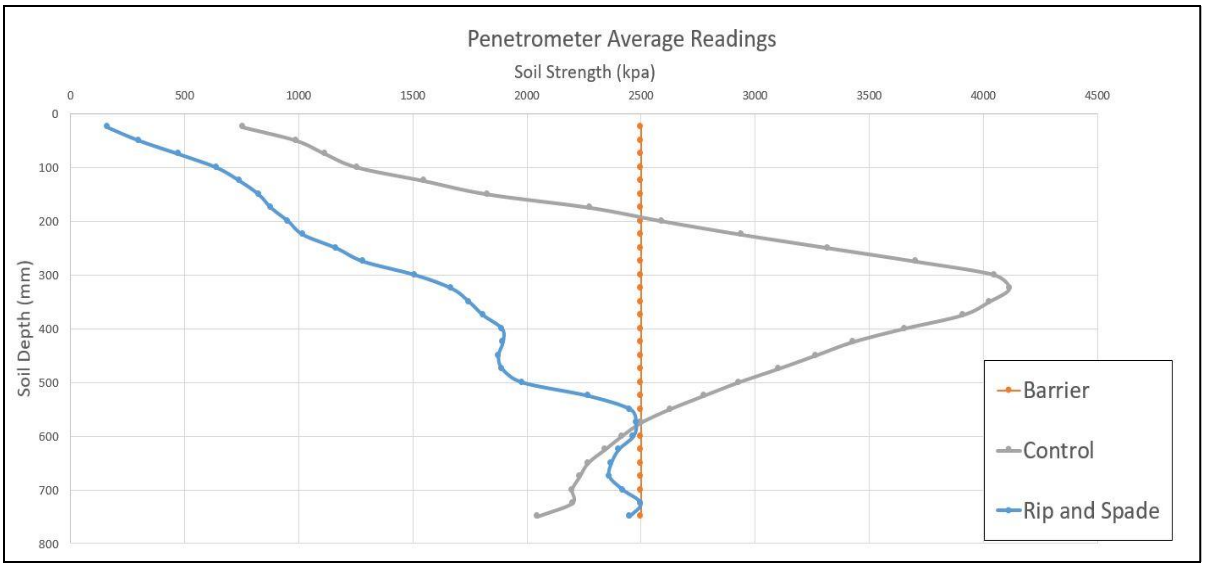


Figure 48: Average soil strength measurements from ripped and control plots as recorded by a cone penetrometer in August 2017.

A large difference in plant biomass was observed between ripped and spaded and control areas when the site was visited throughout the season. This is highlighted in the NDVI imagery captured by the UAV that shows a much more even plant density and biomass exists in the treated areas (Figure 5).

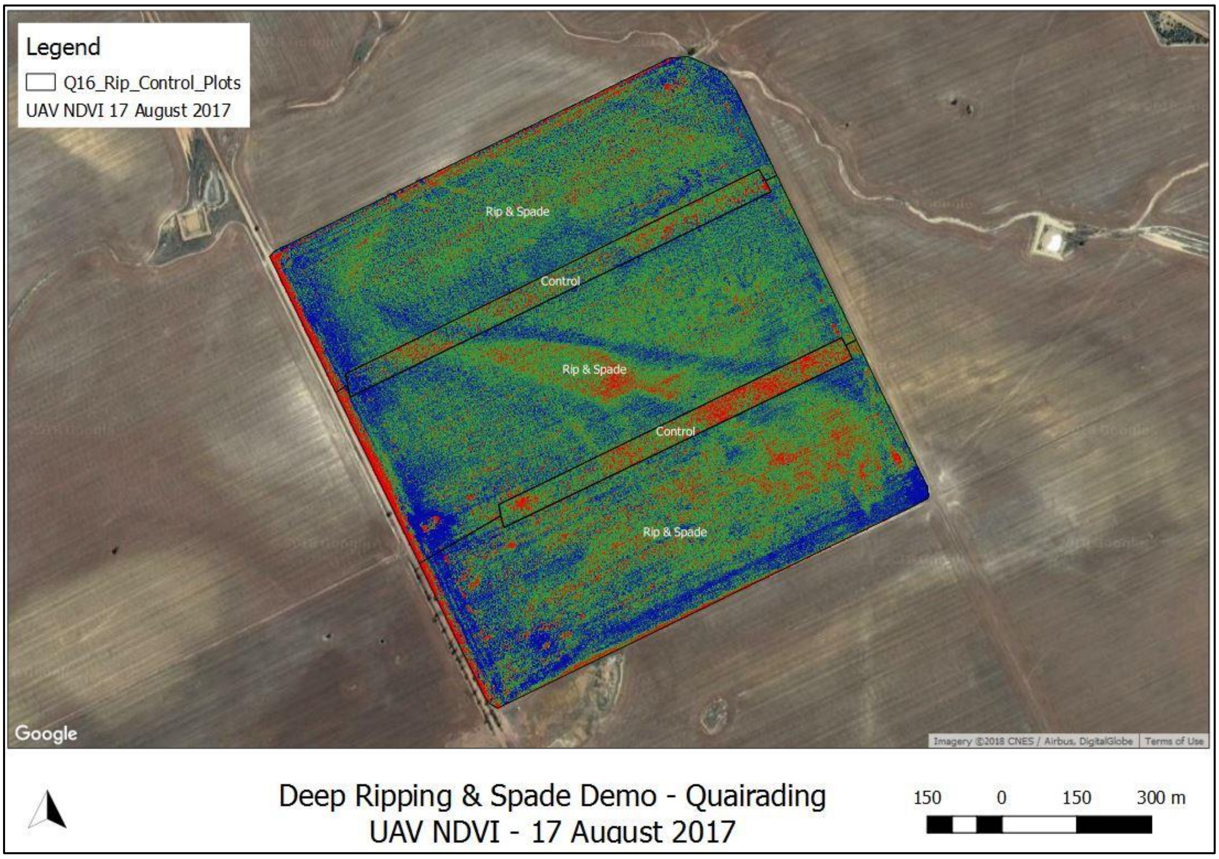


Figure 49: A large difference in plant biomass was observed between ripped and spaded and control areas when visiting the paddock throughout the season. This is highlighted in the NDVI imagery captured by the UAV that shows a much more even plant density and biomass exists in the treated areas.

The UAV NDVI also captured localised areas within the control strips that showed very poor growth that was thought to be due to severe, localised non wetting not picked up in the MED test or soil disease. This effect was not seen in the treated areas and indicates that yield increases seen in this site may be due to more than just the removal of compaction as a soil constraint. More investigation into the cause of these areas will be carried out during the 2018 season.

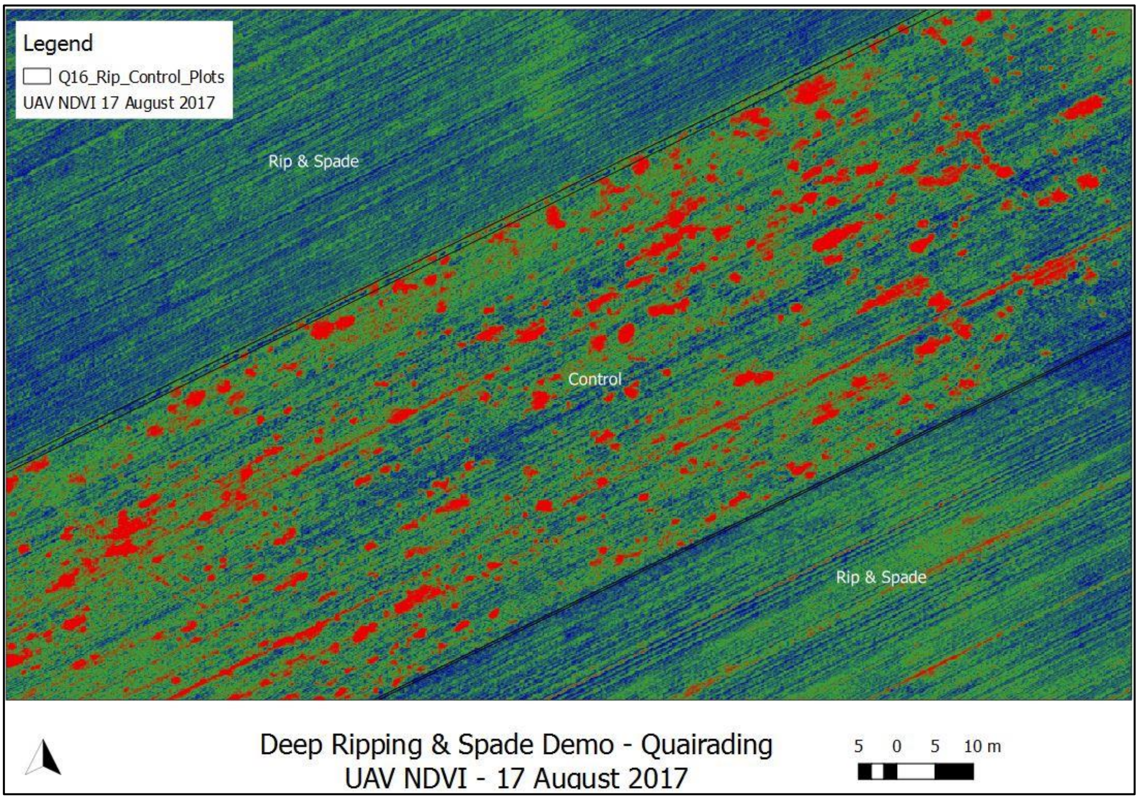


Figure 50: Paddock scale UAV NDVI captured 27 August 2017 shows large variation in crop biomass.

Returns of Deep Ripping

A detailed economic analysis of the advantage of deep ripping has not yet been carried out at this site though the results of the demonstration encourage further replicated trials to accurately quantify the benefits of deep ripping in the area. Due to the very large yield increase seen in the treated areas it is thought that there has been a positive return on investment though actual costs of the treatment and prices of crops would need to be examined.

The yield responses to deep ripping and spading will continue to be monitored over the 2018 season to see if the treatment effects continue. The longevity of the treatment effect will determine how cost effective deep ripping and spading is in this environment and on these soil types.

The yield results from the 2018 season will be important to quantify how long the ripping effect seen here will last.

Northam site:

Crop Yield

Deep ripping provided a 446kg wheat yield increase in 2017 and 340kg/ha barley increase in 2018 when compared to the control plots. Paired sample t test analysis shows both yield increases are significantly different ($p < 0.001$) to the control (Figure 2).

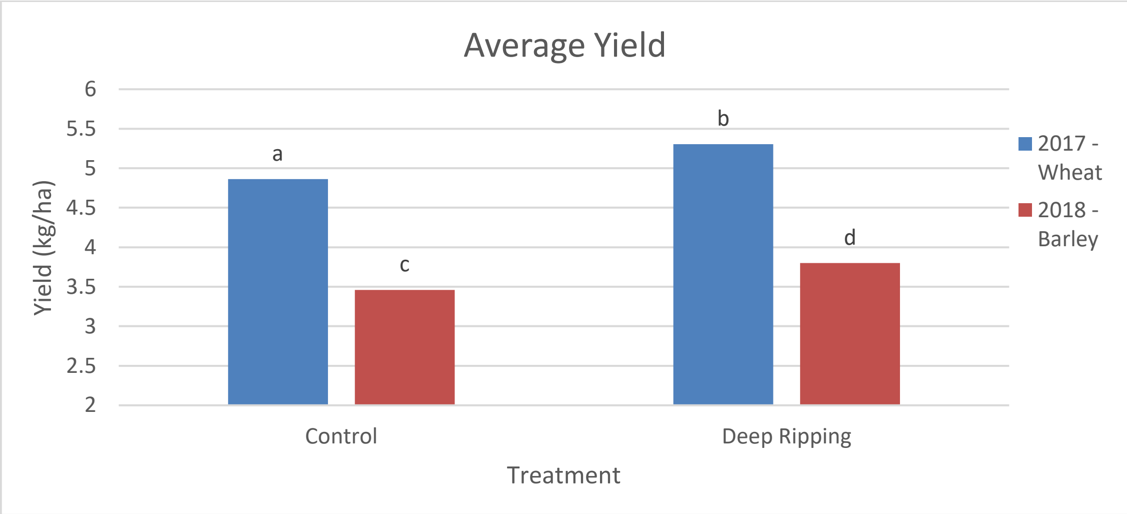


Figure 51: Average crop yield for the deep ripping and control plots showed that deep ripping to 700mm provided a yield benefit in 2017 and 2018.

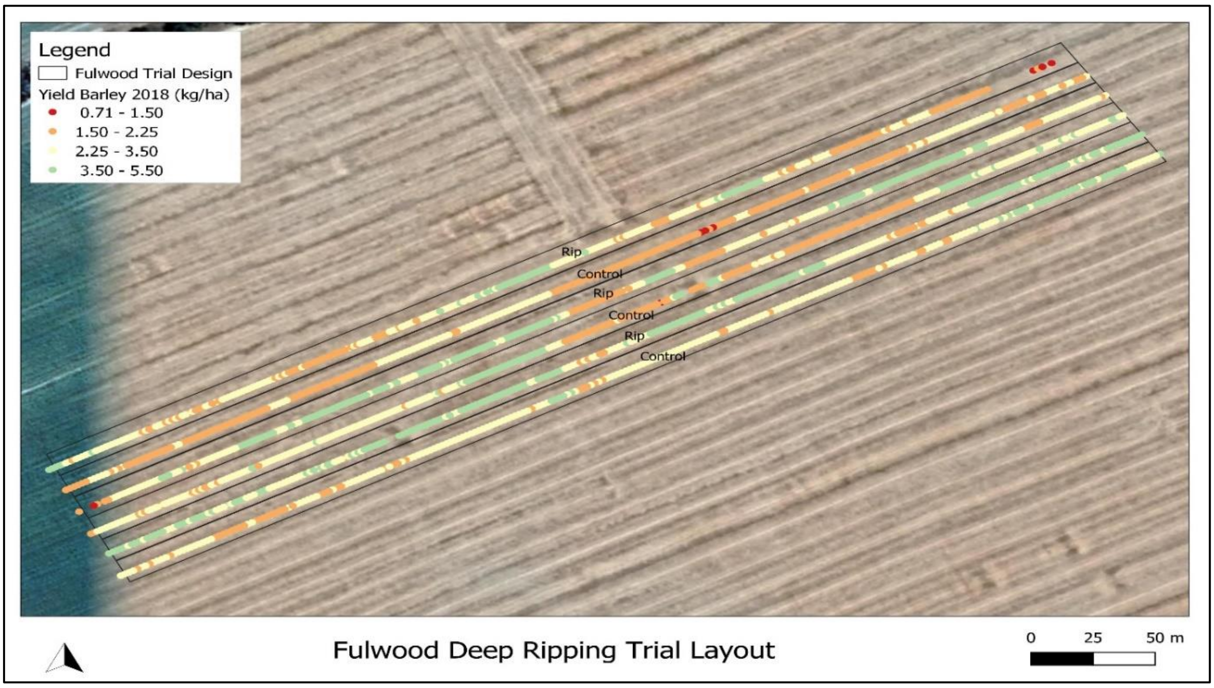


Figure 52: Yield data for each plot showed an overall yield increase in the ripped plots in both the 2017 and 2018 seasons.

Analysis of harvest data showed large variation in yield mass existed in 2017 along each plot and also within and between the treatments (Figure 3). The 2018 barley yield was more even and did not show such

large variance in yield. Yield differences were assessed with a paired t test to account for these variations and showed the yield differences were significantly different in both seasons.

NDVI imagery was captured across the trial in September 2017 using an UAV and multispectral camera. This imagery showed some variation in plant biomass existed between the treatments as well as along each plot

(Figure 4). Biomass differences were observed in specific areas of the trial with the eastern end of the trial appearing to be more responsive to deep ripping than the western end.

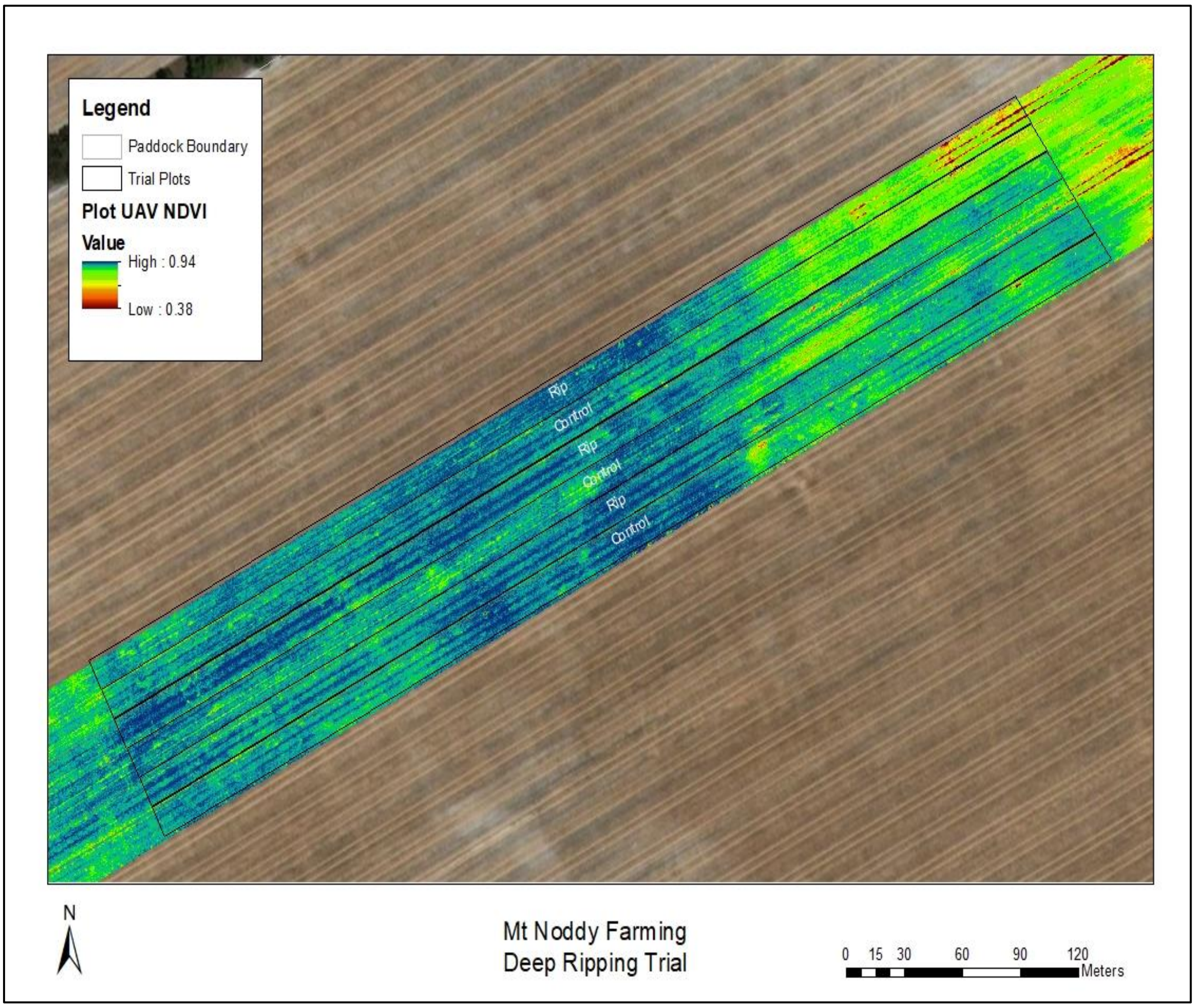


Figure 53: UAV NDVI imagery captured during September 2017 shows variations in biomass across the trial.

Soil and Plant Measurements

A Rimick CP300 Cone Penetrometer was used to measure soil compaction at 30 locations across the trial. This was made up of five insertions at 5 locations along each plot. Insertions locations were randomly chosen in the control plots though the ripping line was found and measurements taken from within the rip line for the ripped plots.

The average soil strength was found to be reduced in the deep ripping plots and did not exceed severe levels of compaction (i.e. 2500kpa) to the depth of 750mm (Figure 5). The control plots were found to be more compact than the deep ripped plots with severe soil compaction being measured between 500mm and 750mm soil depth.

Previous research has found 2500kpa to be the compaction level where plant root growth begins to be inhibited. This indicates that the deep ripping created a less compact soil profile when compared to the control and removed compaction as a constraint below 500mm across the trial site.

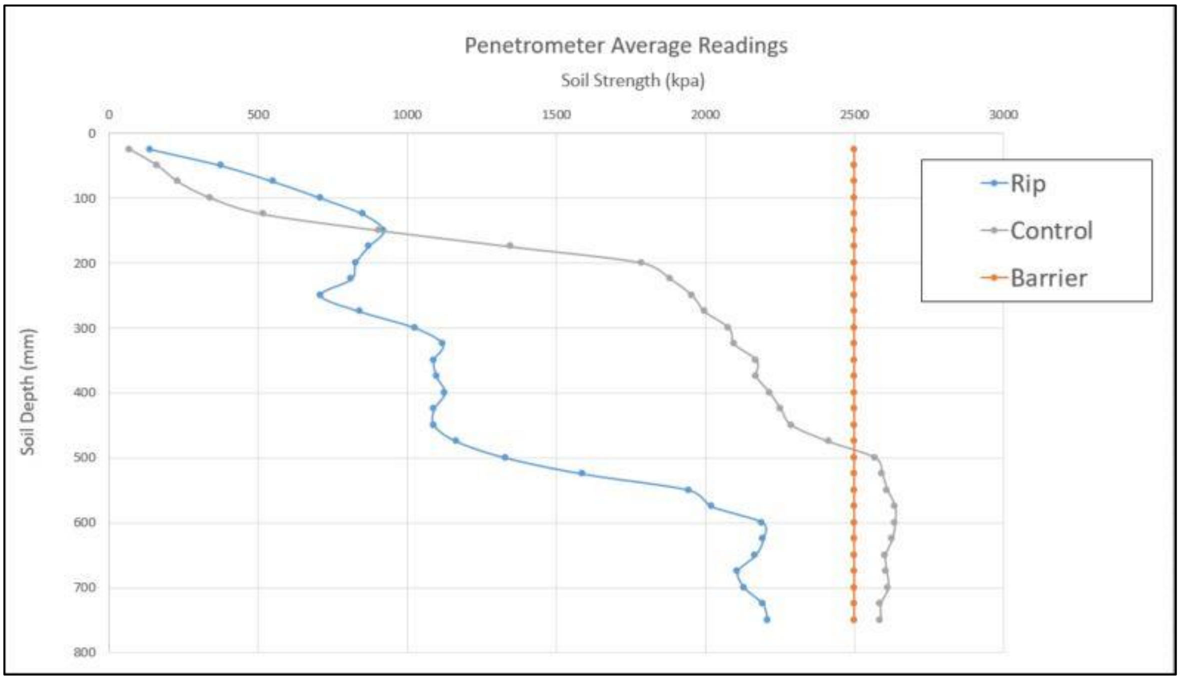


Figure 5: Average soil strength measurements from ripped and control plots as recorded by a cone penetrometer in August 2017.

Returns of Deep Ripping

This trial showed an average annual net benefit of $99/ha from deep ripping over the control. The larger yield increase and higher prices of the 2017 wheat crop provided the largest economic benefit of $156/ha. The additional $102/ha increase from the 2018 barley crop brings the two season cumulative benefit of deep ripping to $198/ha after the $60/ha treatment cost has been deducted.

These results are economically significant and make the deep ripping practice worth the effort, especially if the yield benefits continue over time. The longevity of the treatment effect will determine just how cost effective deep ripping is in this environment and on these soil types.

Table 15: The annual benefit for each treatment and cumulated return over the two years examined.

Treatment	Treatment Cost ($/ha)	Amortised Treatment Cost over two years ($/ha)	Benefit from Ripping 2017 ($/ha) Wheat @ $350/t	Benefit from Ripping 2018 ($/ha) Barley @ $300/t	Return on Investment over two years ($/ha)
Control	-	-	0	0	0
Deep Ripping	60	30	156	102	198

Goomalling site:

Crop establishment

In 2020 significant wind events in late May and early June negatively impacted the trial Lupin crop establishment across multiple treatments. The trial was discontinued mid season due to poor recovery of the crop post establishment.

Soil Constraints

Subsoil Compaction

Revisiting the soil tillage treatments in the year of trial establishment in 2017 the effective working depth of the tillage treatments varied from 30cm to more than 70cm (Table 2). All of the treatments reduced the soil strength of the top 30cm of soil to a penetration resistance less than 2000kPa (Figure 1). All of the very deep ripping (including Ripping via Delver) treatments removed severe compaction to their working depth of below 60cm with a soil penetration resistance of less than 2500 kPa throughout the profile.

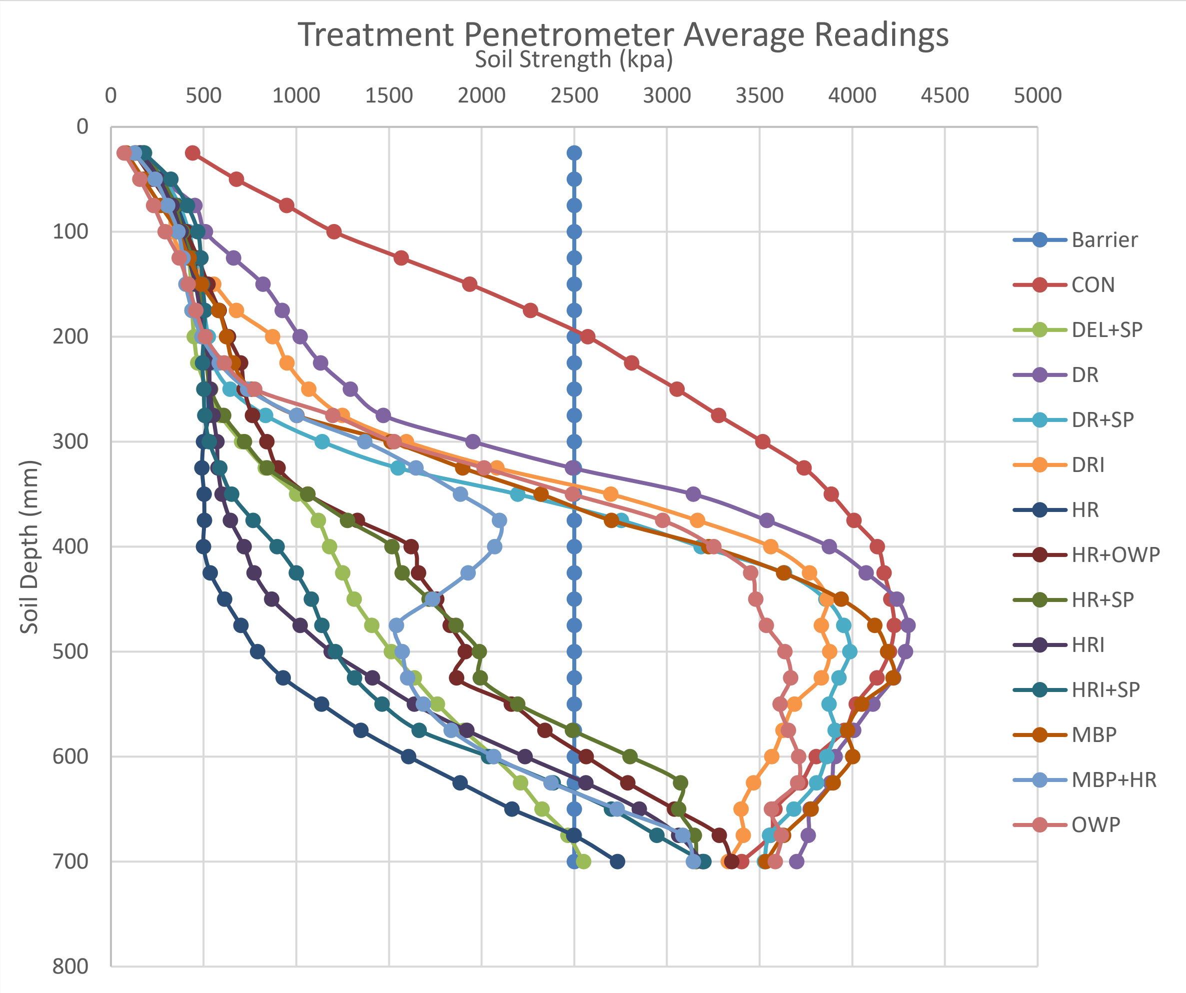


Figure 1. Soil strength measured in kPa comparing tillage treatments as measured by a RIMIK data logging Penetrometer in August of 2017 when soils reached moisture field capacity.

Re-evaluation of soil strength and subsoil compaction was completed in August 2020, 3 ½ years after initial strategic tillage implementation. The trial treatments were not trafficked during the life of the trial, except with a light-weight trial harvester for each year's crop harvest completion.

Figure 1a. shows that under controlled traffic situations the benefits of very deep ripping (HR) to remedy sub soil compaction have been sustained over the period of the trial, with soil strength remaining at or below 2500kPa to a depth of around 400mm in the very deep ripping treatments.

In all other treatments re-compaction to a limiting strength above 2500kPa was evident below a depth of 250mm.

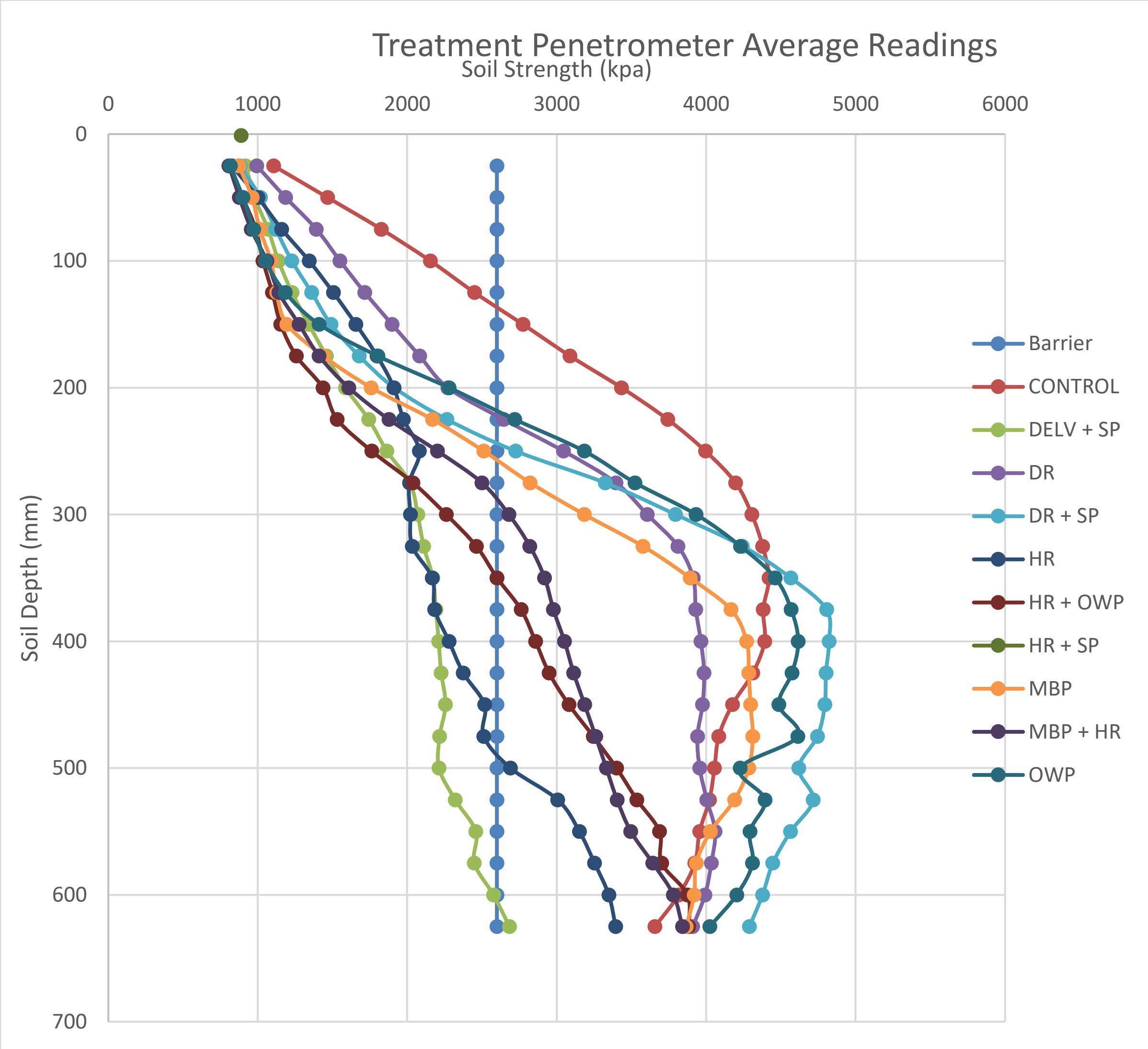


Figure 1a. Soil strength measured in kPa comparing tillage treatments as measured by a RIMIK data logging Penetrometer in August of 2020 (3½ years after initial tillage implementation) when soils reached moisture field capacity.

Acidity

Subsoil acidity was an issue for the Goomalling site with an average pH_{Ca} of 4.5 or lower in the 20-30cm, 30-40cm and 40-50cm depth increments when initially tested in 2017.

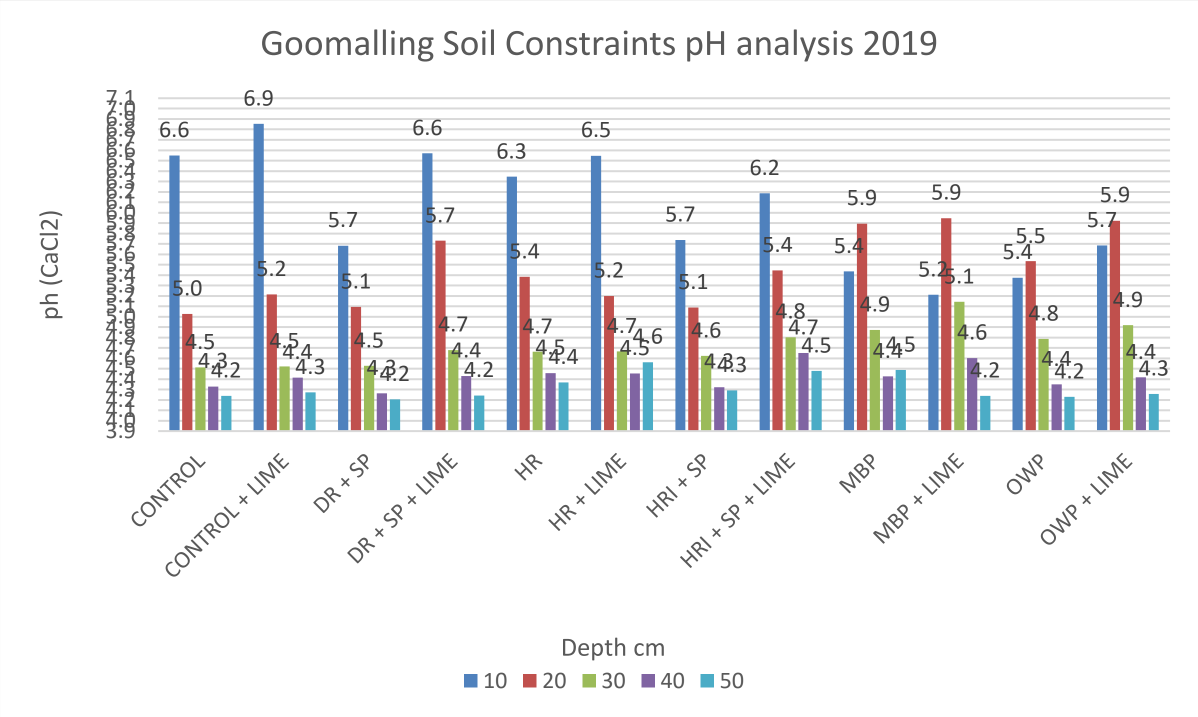


Figure 2. pH analysis in 10cm increments from 0-50cm, 2 years post lime application and tillage intervention (Measured March 2019)

The spading, one-way plough and mouldboard plough treatments can mix and bury the lime and less acid topsoil to the working depth. Follow up soil testing was completed in 2019, 2 years following the lime application and tillage interventions, to re-assess lime movement to depth under the different treatments. Margin of error of testing and laboratory analysis of pH is estimated at 0.2units. pH increase in the control plots (no tillage) plus lime was measured at an increase of 0.3 at 0-10cm with no improvement in pH below 10cm (Figure 2.). Deep ripping plus spading plus lime measured no change in pH at 0-10cm, an increase of 0.7 units at 10-20cm and increase of 0.2 units at 20-30cm. No improvement was measure below 30cm.

Very deep ripping with inclusion plates plus spading plus lime measured a reduction in pH of 0.4 units at 0-10cm, an increase of 0.4 units at 10-20cm, an increase of 0.3 units at 20-30cm and an increase of 0.2 units at 30-40cm.

One way ploughing plus lime measured a reduction of pH of 0.9 units at 0-10cm, an increase of 0.9 units at 10-20cm, and an increase of 0.4 units at 20-30cm.

Mouldboard ploughing plus lime measured a reduction of pH of 1.4 units at 0-10cm, an increase of 0.9 units at 10-20cm, and an increase of 0.6 units at 20-30cm and an increase of 0.3 units at 30-40cm.

The reduction of pH at the soil surface and its general improvement at depth in both the spading and inversion tillage techniques is consistent with our understanding of the physical burial and inversion of topsoil under these tillage interventions.

Water Repellence

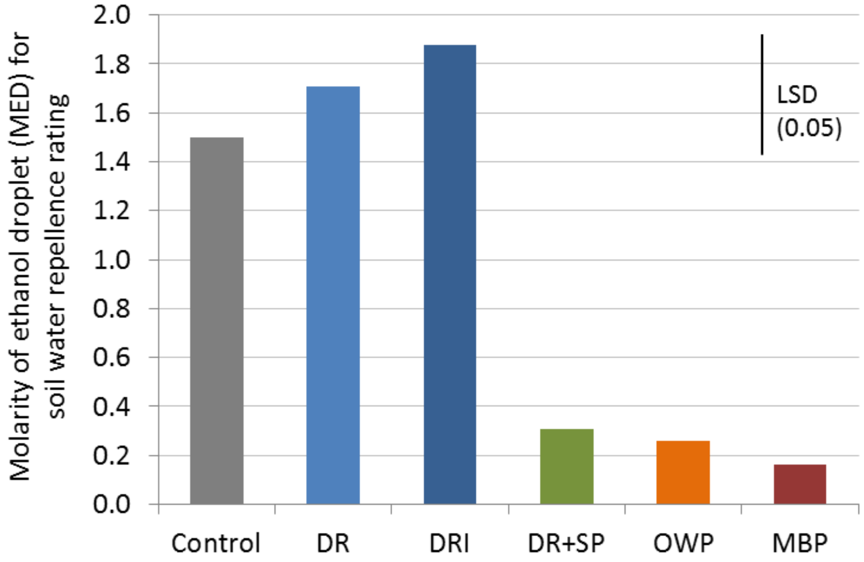


Figure 3. Molarity of ethanol droplet (MED) for soil water repellence rating. (Measured 2017)

Water repellence in the control plots was moderate based on the laboratory MED test result. Deep ripping exacerbated the expression of water repellence whereas spading, one way ploughing and mouldboard ploughing decreased the repellence of the topsoils (Figure 3).

Goomalling - Crop Growth and Grain Yield

Wheat yield potential for this site for 2017 and 2018, with a dry finish, was estimated to be 1.93t/ha and 1.8t/ha respectively and in 2019 at 1.07t/ha (see modified French-Schultz calculator at www.soilquality.org.au/calculators/yield_potential). The untreated control only achieved 41% (2017), 49% (2018) and 35% (2019) of yield potential, while very deep ripping achieved 93% (2017),89% (2018) and 54% (2019) and very deep ripping with spading 72% (2017),91% (2018) and 61% (2019) of wheat yield potential.

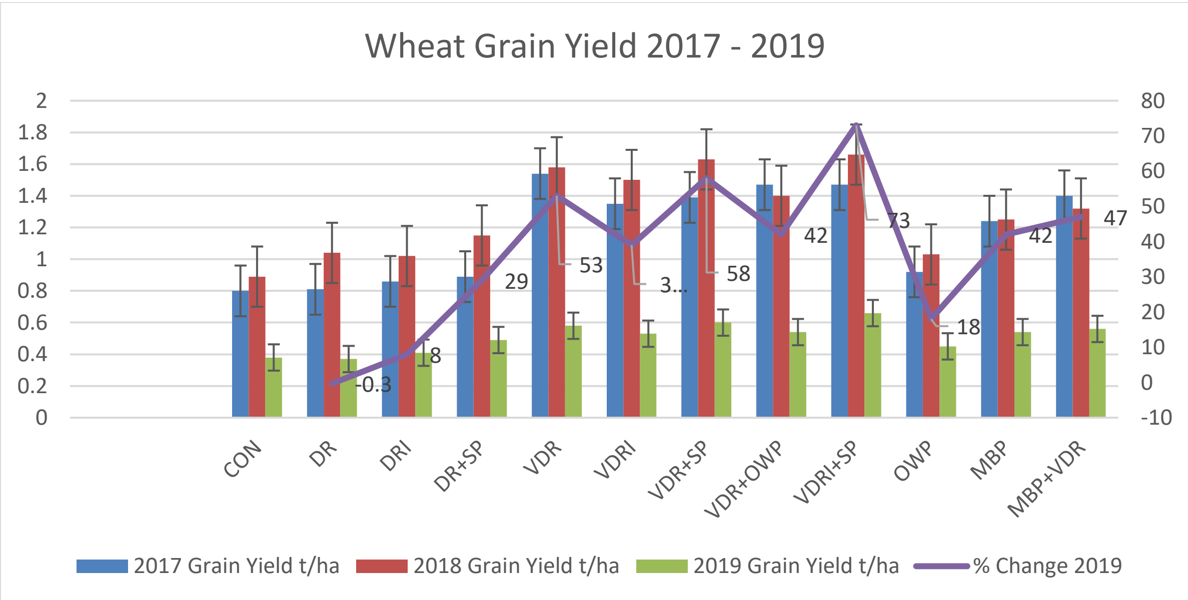


Figure 5. Wheat grain yields in 2017, 2018 and 2019 in response to strategic deep tillage treatments applied in 2017 on deep yellow sand at Goomalling, Western Australia. LSD (0.05) of 0.16t/ha 2017 and 0.19t/ha 2018 and 0.083t/ha 2019

Narembeen site:

Soil and Plant Measurements

Soil strength was reduced in the deep ripping and spaded plots when compared to the plots that did not receive deep ripping and was maintained into the 2018 season (Figure 7). The control plots consistently reached 2500kpa between 100 – 150mm soil depth and increased to peak at 4000-5500kpa at 200mm depth. Deep ripping plots maintained compaction levels below 2500kpa to 700mm depth were measurements stopped.

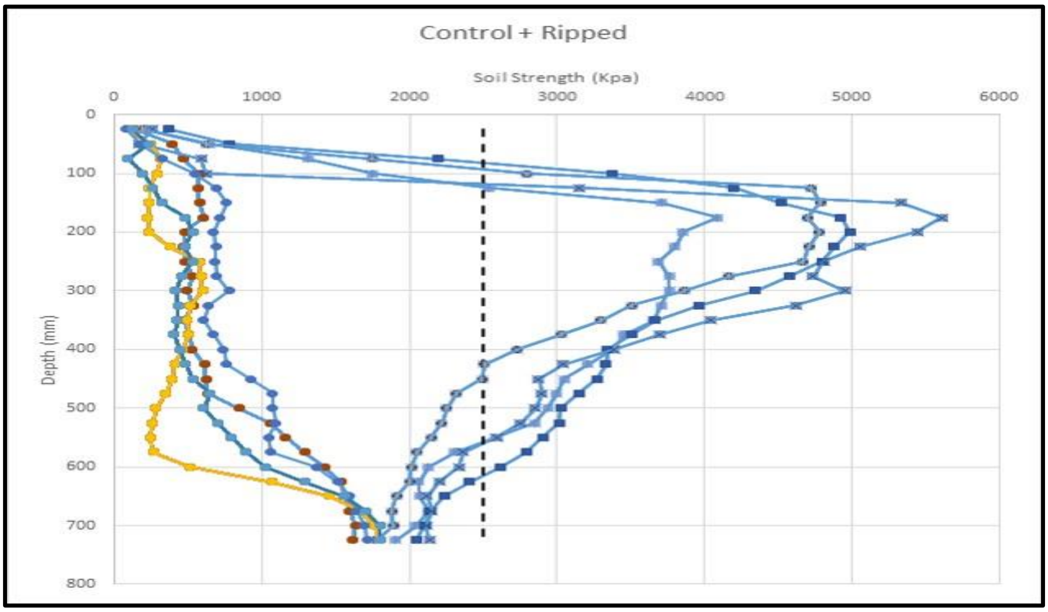


Figure 54: Comparison of soil strength measurements from ripped and control plots measured in 2017 (solid lines) and 2018 (dashed lines).

Previous research has found 2500kpa to be the compaction level where plant root growth begins to be inhibited and indicates that the deep ripping fully removed compaction as a constraint in these areas. The compaction in the un-ripped plots is very likely to cause a severe constraint to root growth.

The trial plots were soil tested in February 2019 in the same locations as sampled pre-treatment to examine soil pH changes against the benchmark values.

Soil pH had changed in the lime treatments proportional to rates of lime applied. The high rates of lime had an interaction with tillage treatments with ripping and ripping + spading treatments showing increases in soil pH below the top 20cm of soil (Figure 4). All samples 0-10cm soil pH above pH5.5 though all remain severely acidic (pH <4.5) below 30cm.

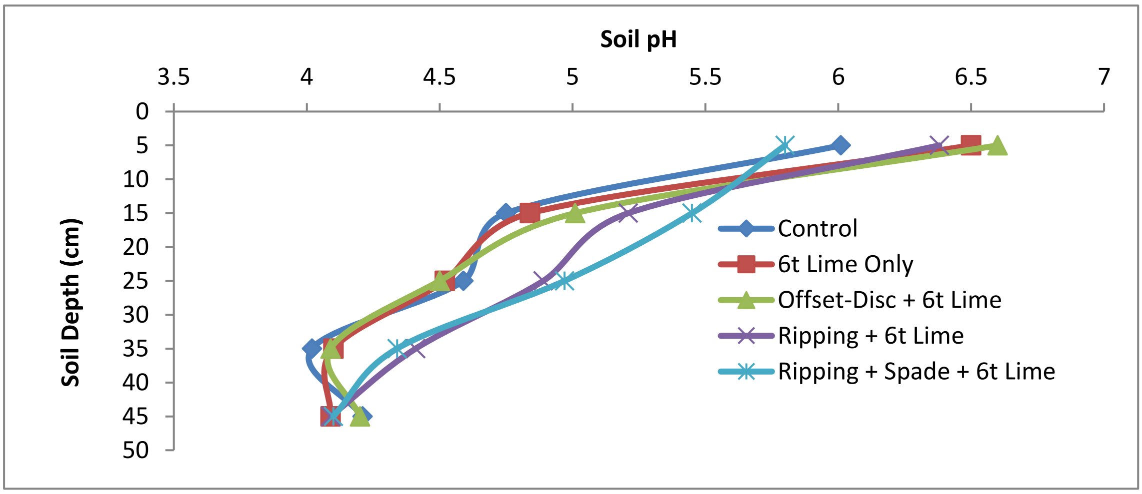


Figure 55: Soil pH average for each treatment after amelioration in 2019.

Crop Establishment and Yield

The 2017 canola crop was negatively impacted by the dry start to the 2017 season which resulted in very different crop establishment across the trial (Figure 3). The biggest differences were seen in the spaded plots which had significantly less canola plant density than all other plots, having an average of 3 plants/m^2. Some ripped plots also had a reduced number of plants than the control though density was still high enough to achieve a reasonable yield. Site inspection in June 2017 showed that the canola in the spaded plots was planted deeper than the other plots in a layer of dry soil. No difference in plant density was seen in the 2018 wheat crop.

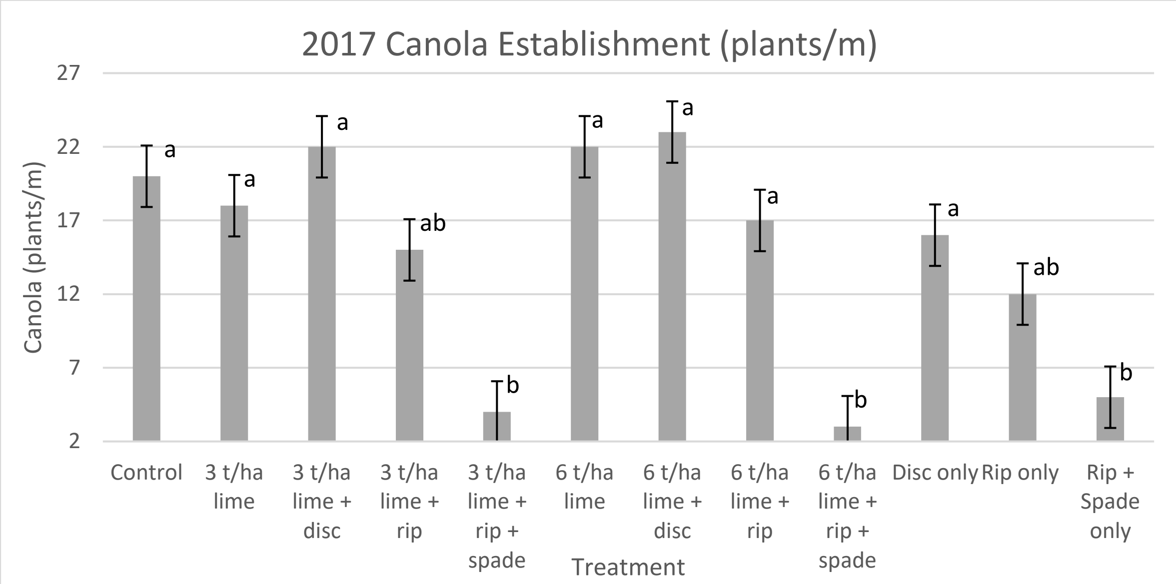


Figure 56: Differences in plant density in the 2017 canola crop showed a large reduction in the spaded plots.

There were large differences in plant greenness in the spaded treatments throughout the 2017 season caused by the variation in plant density which the UAV NDVI imagery shows very clearly (Figure 6).

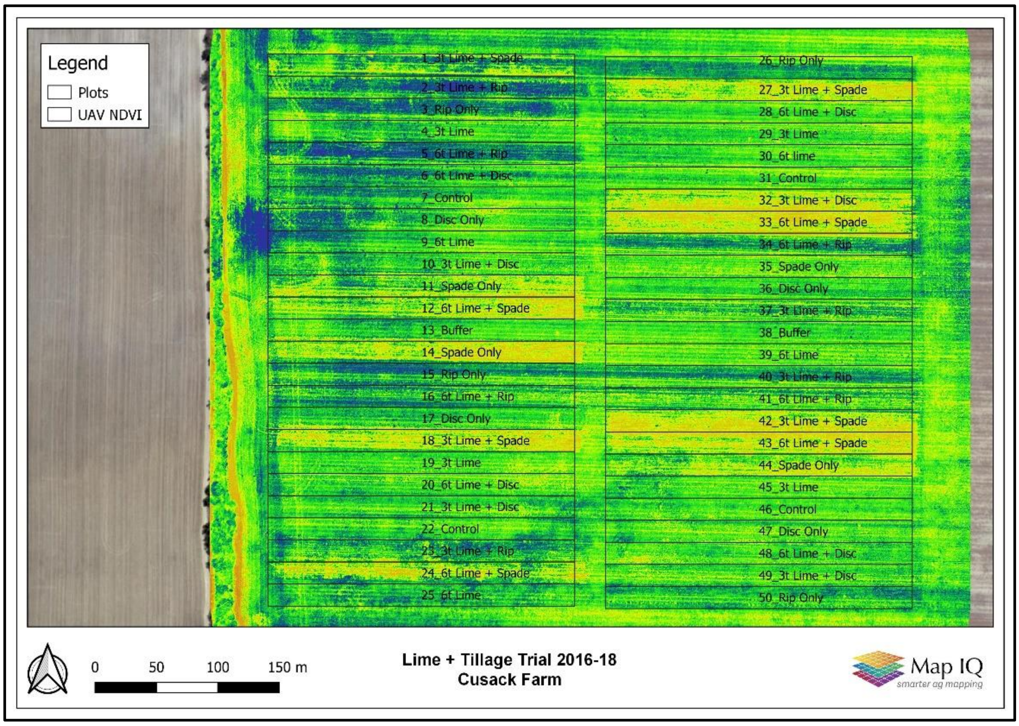


Figure 6; UAV NDVI imagery showing very poor establishment and subsequent low plant density in the spaded treatments.

Significant yield differences were seen in the 2017 yield data (Figure 4) with all the ripping and ripping plus lime treatments returning the highest yield increases when compared to the control. Any of the spaded treatments, with or without lime, gave the lowest yields averaging 350kg/ha less than the Control treatment. The largest yield increase was provided by the Ripping + 6t/ha lime treatments and gave an average 800kg/ha increase in yield.

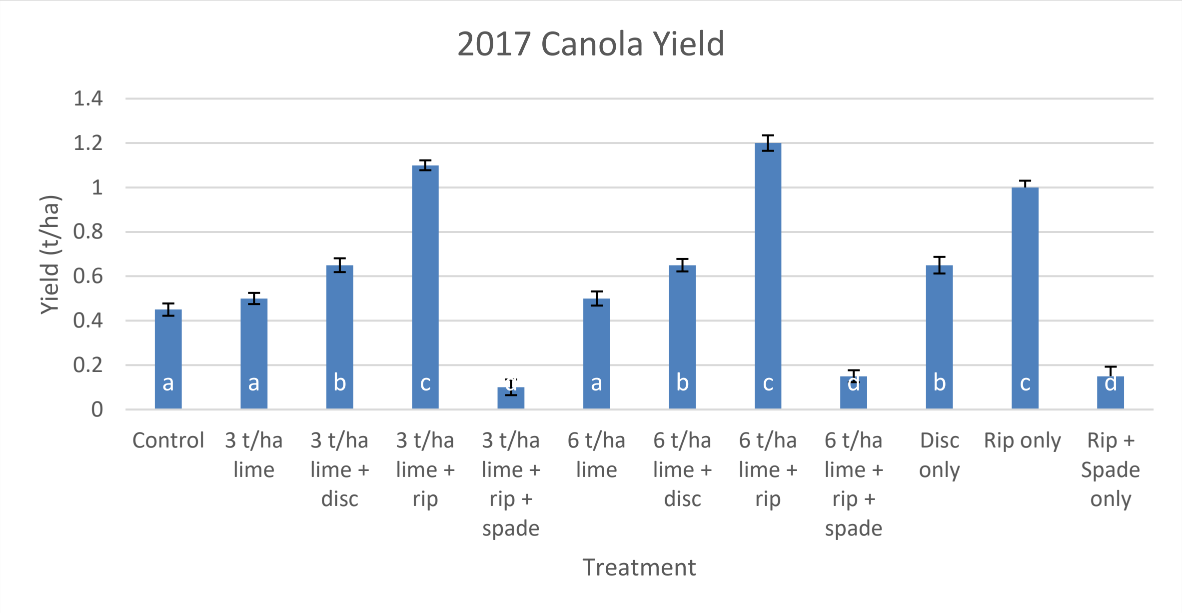


Figure 7: Average yield of treatments form the canola crop in 2017

In 2018, the highest yielding treatment was again the Ripping + 6t/ha lime which had similar average yields to the Rip only and Rip + Spade only treatments and provided 970kg/ha more wheat than the Control (Figure 5). There was no difference in yield between the Control and any of the non-tillage or disc tillage treatments, regardless of lime application though. In contrast to this, any of the ripped or ripped + spaded treatments performed significantly better than the non-tillage or disced treatments, regardless of lime application.

This indicates that soil compaction is likely to be the main constraint at this site and not soil acidity as first thought.

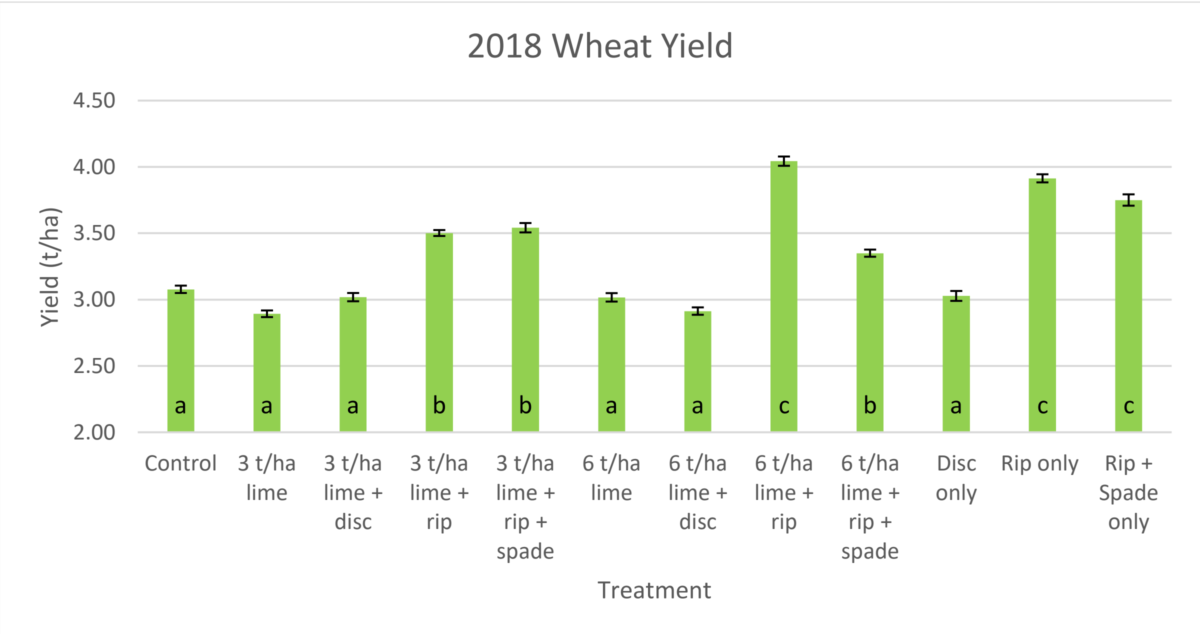


Figure 57: Average yield of treatments form the wheat crop in 2018

Returns of Deep Ripping

There was a very large range in overall economic returns from the treatments with the largest benefit being $655/ha for the Rip Only treatment and the greatest loss of -$505/ha coming from the Rip + Spade + 6t/ha lime treatment (Table 2). The surface applied lime treatments and lime with discing or spading treatments made an average loss of approximately -$300/ha. The only limed treatments to have a positive return were combined with ripping which gave an average $376/ha benefit.

Table 16: Economic return of the treatments for the 2017 and 2018 season.

Treatment	Treatment Cost ($/ha)	Amortised Treatment Cost over two years ($/ha/yr)	Benefit from Ripping 2017 ($/ha) Canola @ $500/	Benefit from Ripping 2018 ($/ha) Barley @ $350/t	Net Return minus Costs of Investment over two years ($/ha)
Control	0	0	0	0	0
3 t/ha lime	189	94	25	-92	-256
3 t/ha lime + disc	200	100	100	-29	-129
3 t/ha lime + rip	227	114	325	212	310
3 t/ha lime + rip + spade	302	151	-175	232	-245
6 t/ha lime	377	189	25	-30	-382
6 t/ha lime + disc	388	194	100	-82	-370
6 t/ha lime + rip	416	208	375	483	442
6 t/ha lime + rip + spade	491	245	-150	136	-505
Disc only	11	6	100	-25	64
Rip only	39	19	275	418	655
Rip + Spade only	114	57	-150	337	73

The very high cost of the treatments meant the yield benefits needed to be high in both years of the trial for there to be a profit returned in the two years of the trial. The failure to get the 2017 canola crop established resulted in some very large losses (average loss of $-162/ha) in addition to already high cost of treatments.

This may be a good example of the risk that is taken when carrying out amelioration practices such as ripping or spading. Not only is there a large investment being made in terms of lime and tillage costs, but the practices themselves may actually cause a negative impact on yield which can cost just as much as the activity itself, effectively doubling the economic impact of the activity.

Yearlering site:

Crop Yield

Canola germinate was delayed at the trial site in 2018 due to the dry start to the season and resulted in a much lower yield in this section of the paddock of 443 kg/ha across the trial.

The Control and Deep Ripping plots recorded the lowest average yield of 407 & 408 kg/ha respectively. The Calipril and Topdressed Lime plots measured slightly higher though the Rip and Spaded Plots was found to be significantly different from all other treatments with an average of 530 kg/ha which provide an additional 123 kg/ha of canola over the control (Figure 5).

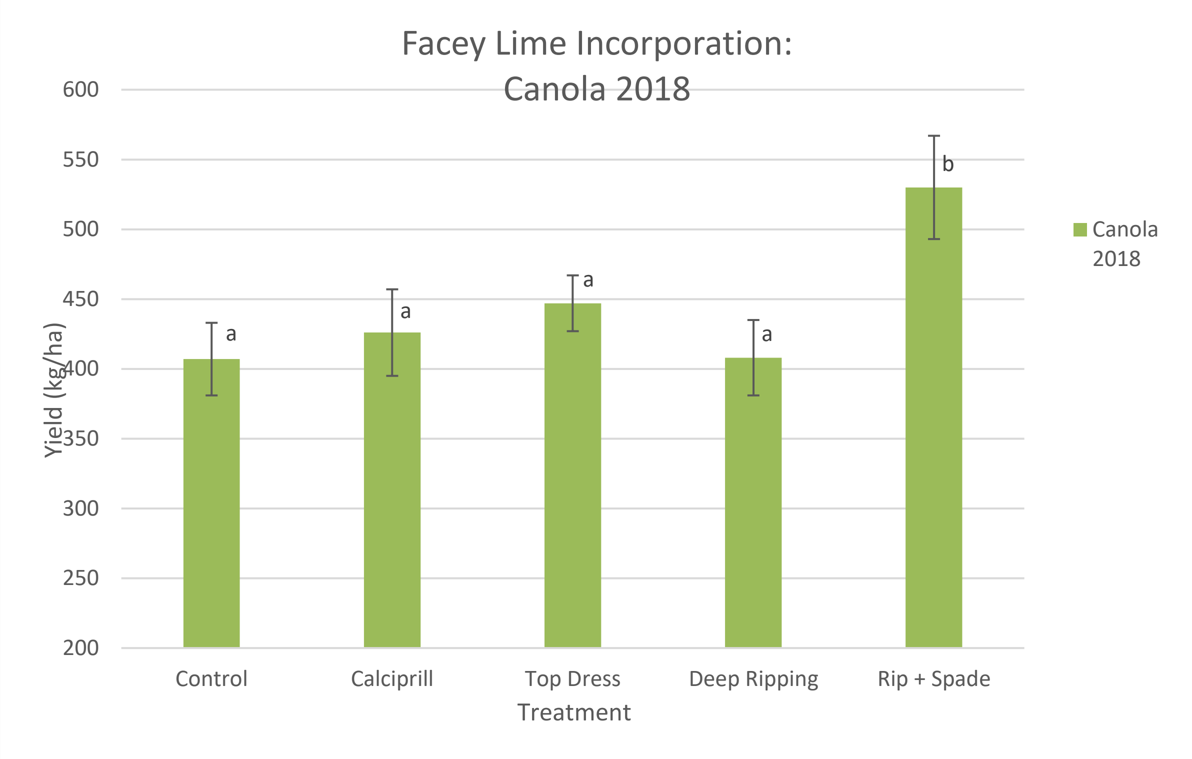


Figure 58: The average treatment yields for the trial showed that the Rip and Spade treatment was significantly different from all other treatments (denoted by letter b) and gave 123kg/ha more canola than the control.

Yield differences were not significant in any treatment in the 2015 and 2016 canola and wheat crops (Figure 6).

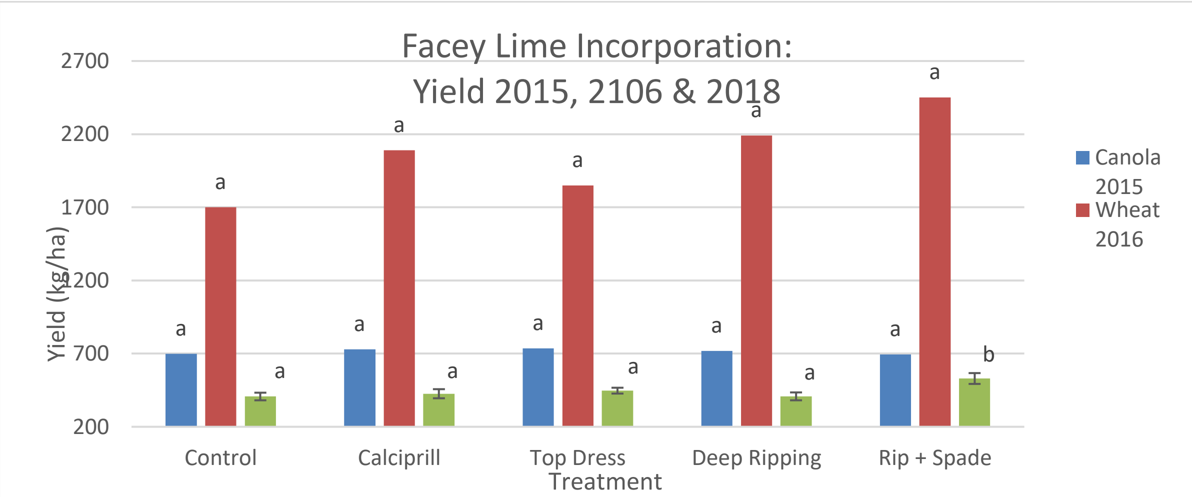


Figure 59: No significant difference in average yield between treatments was observed until the 2018 canola crop.

Soil and Plant Measurements

A Rimick CP300 Cone Penetrometer was used to measure soil strength at 45 locations across the trial site (3 in each plot) and found there were differences in soil strength across soil types though not between the treatments (Figure 7).

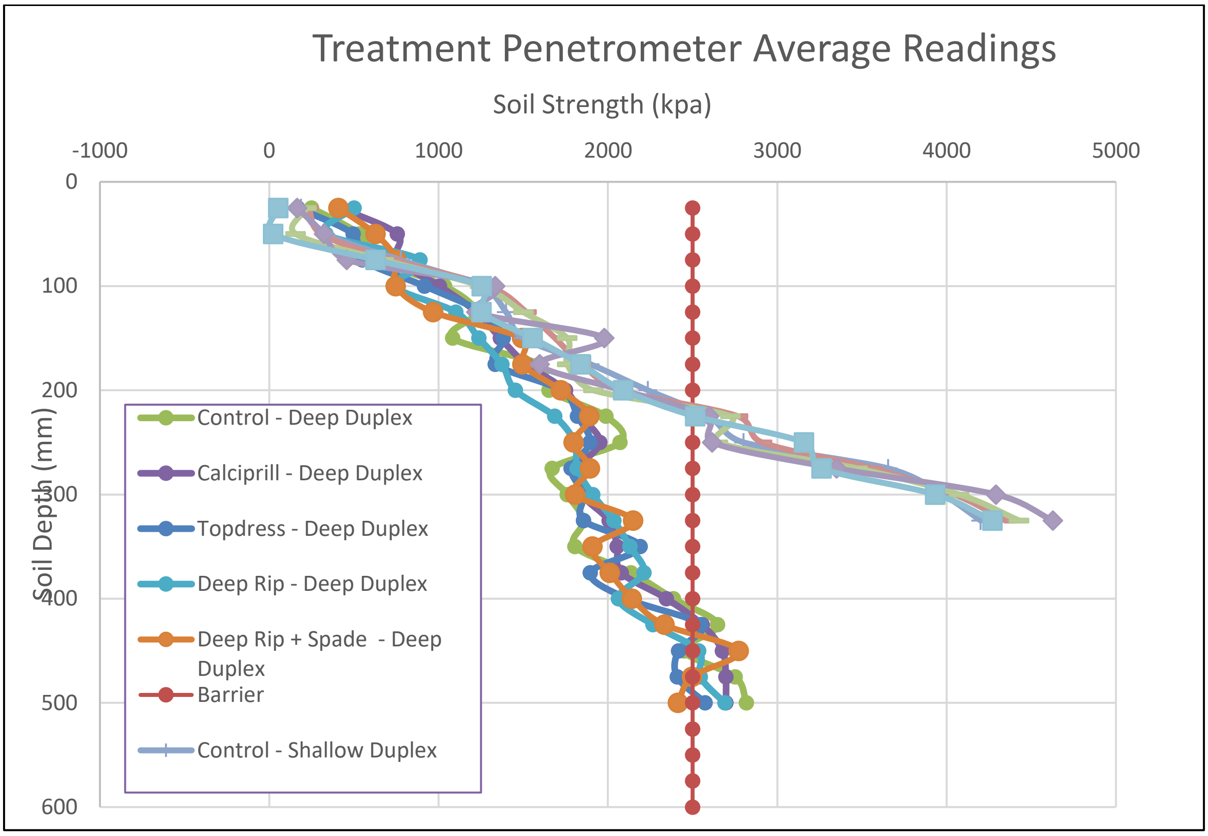


Figure 60: Soil strength differences were found between the deep duplex and shallow duplex though not between treatments.

Soil strength in the shallow duplex increased steadily from the surface and peaked at around 5000kpa at approximately 300mm, at which point it could not be pushed further into the soil. The deep duplex measured a reduced soil strength with the penetrometer recording maximum average values of 2500kpa -3000kpa at 500mm depth. Previous research has found 2500kpa to be the compaction level where plant root growth begins to be inhibited so it is expected that the shallow duplex will experience a greater production penalty due to compaction relative to the shallow duplex.

The 3D scanning bulk density cores were collected 50 metre in from the western edge of replicate one plots and were all within the deep duplex soil type. Although statistical differences cannot be determined as only one replicate was sampled, bulk density increased with depth across all treatments and followed a similar pattern to that of the penetrometer readings (Table 2). There was a decrease in bulk density in the 40cm layer of the Deep Rip+ Spaded plot though no other observations indicated a reduction in bulk density across the other treatments.

Table 17: The bulk density of soil at the west end of each plot was calculated by determining the weight of soil collected from a core of known volume.

	Dry Soil Weight (g)				Void Volume (cm^3)				Bulk Density			
Treatment	10cm	20cm	30cm	40cm	10cm	20cm	30cm	40cm	10cm	20cm	30cm	40cm
Control	4,173	11,514	19,542	26,492	4,025	7,676	11,507	14,016	1.04	1.50	1.70	1.89
Calciprill	4,213	9,893	19,354	24,869	3,997	7,721	12,187	13,985	1.05	1.28	1.59	1.78
Top Dressed	4,039	9,937	18,697	23,589	4,123	7,924	10,983	13,587	0.98	1.25	1.70	1.74
Deep Rip	4,200	11,061	21,476	25,429	4,547	7,993	12,578	13,588	0.92	1.38	1.71	1.87
Deep Rip + Spade	3,912	10,612	19,882	24,559	4,272	7,924	11,723	14,845	0.92	1.34	1.70	1.65

Soil pH analysis found 0-10cm pH levels were below targets of pH 5.5 though the Top Dressed Lime treatments had the greatest pH and almost at the target (Figure 8). Soil pH decreased for all the treatments that did not have tillage applied and were below the subsurface soil pH target of 4.8 until a soil depth of 40cm was reached. The tillage treatments showed varied sub surface soil pH and measured above and below the target in the 10 to 30cm layers and may be due to the mixing nature of the tillage treatments.

It is not expected that the soil pH in the surface or the sub surface is low enough to cause a significant reduction in production at this site.

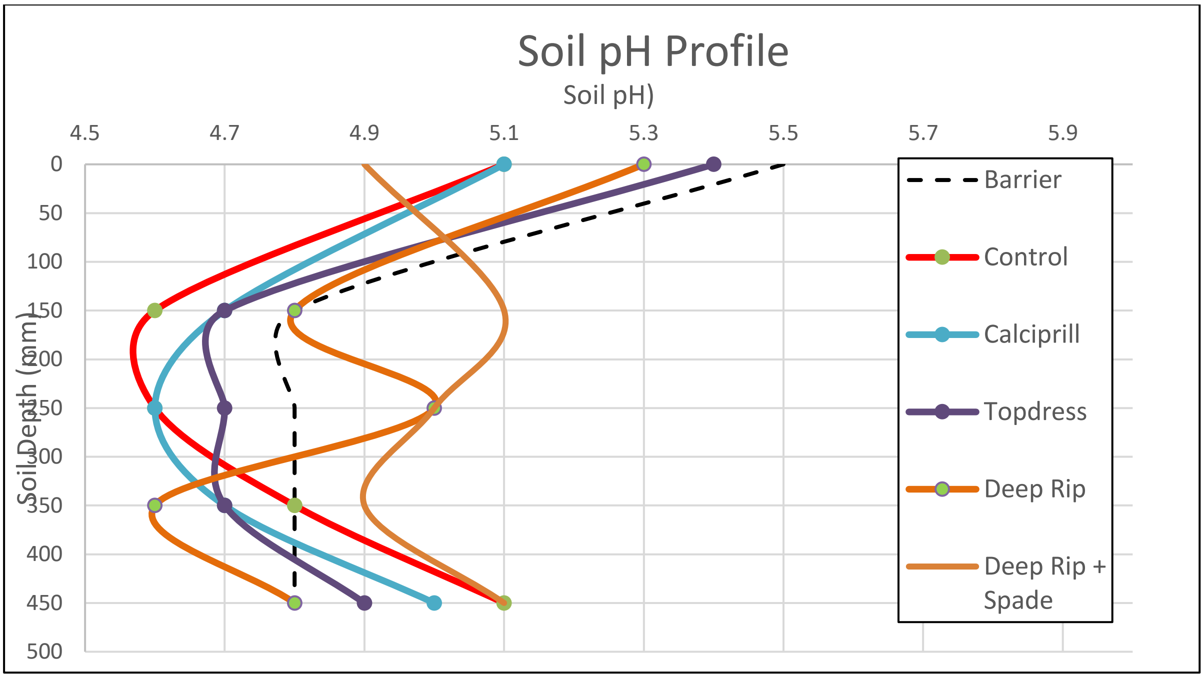


Figure 61: Soil pH values for each treatment showed the undisturbed plots were acidic below the topsoil and that the disturbed treatments had a large variation in soil pH though to be caused by the tillage.

Plant counts and biomass measurements showed large differences across the trial area that corresponded with soil type though no difference existed between the treatments. The UAV imagery and biomass cuts show that there is increased biomass in the north end of the trial and a reduction in biomass in the centre of the area which corresponds with the deep duplex soil type (Figure 9).

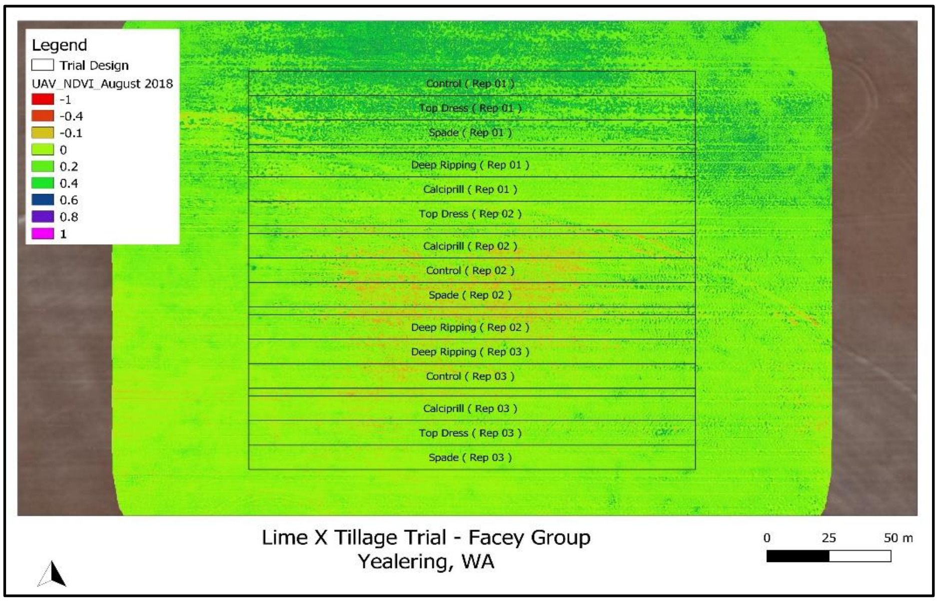


Figure 62: NDVI imagery shows biomass variation across the trial though no difference between treatments

Plant counts were not significantly different across the plots though there was a large variation between plots (Figure 10). The plots in the centre of the trial had much reduced plant numbers when compared to those on the north and south side of the trial.

The spaded plot in the centre of the trial did not have a noticeable difference in plant biomass when compared to the adjacent Deep Rip or Control plots. This suggests that the reduction in plant biomass and plant density was not caused by non-wetting soil as the spading treatment should have removed this as a constraint.

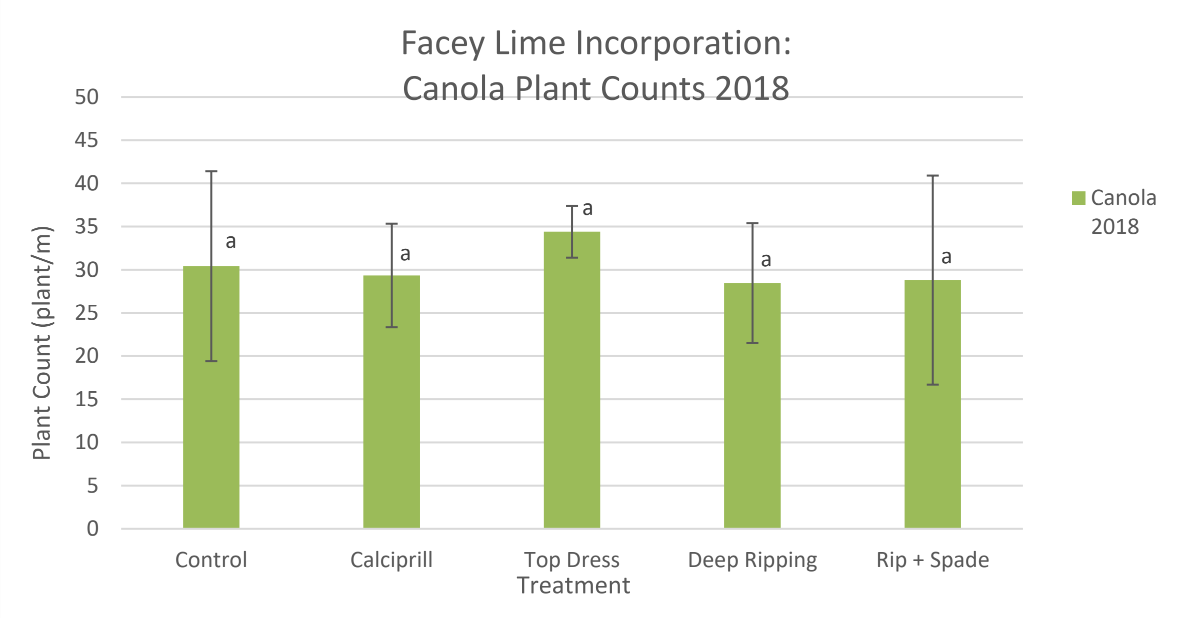


Figure 63: Plant counts were not different across the treatments though there was a large variation across the trial.

Returns of Deep Ripping

The cost of treatments, except the Prilled Lime, has been amortised over three years as it is expected that the impact of the treatment is not constraint to a single year. The Prilled Lime treatment is marketed as an annual application and so the cost of the treatment has been applied to each of the three seasons (Table 3).

None of the treatments recorded a positive return on investment indicating that all investment in lime and tillage cost the grower money in this situation.

Table 18: The annual gross margin for each treatment and cumulated return over the three years examined.

Treatment	Treatment Cost ($/ha)	Amortised Treatment Cost over three years ($/ha/yr)	Benefit from Treatment 2015 ($/ha)	Benefit from Treatment 2016 ($/ha)	Benefit from Treatment 2018 ($/ha)	Return on Investment over three years ($/ha)
Control	-	-	-	-	-	-
Prilled Lime @ 100kg/ha	57*	57	16	117	9.5	-28.5
Top Dress Lime @ 2t/ha	86	29	2.5	-72	10.5	-145
Deep Rip + Lime @ 2t/ha	126	42	-8.5	102	-19.5	-52
Deep Ripping + Spade + Lime @ 2t/ha	256	85	--11.5	78	61	-128.5

The Prilled lime treatment gave the smallest loss at -$28.5/ha and the largest being the top dressed lime costing $145/ha. Though the Deep Rip + Spade treatment showed a significant increased yield in 2018, the lack of yield differences in previous years and the high cost of treatment resulted in none of the tillage treatments returning an increased return over the control with losses ranging from -$128/ha for the Deep Rip + Spade treatment and approximately -$52/ha for the Deep Rip and Top Dressed Treatments.

Conclusion

Kojaneerup site:

There have been positive yield and economic responses seen in each season since the deep ripping treatments were established in 2015. The cumulative yield increase provided a positive return on investment to the farm business for the 700mm ripping depth though not for the other treatments.

South Stirling site:

There have been positive yield and economic responses seen in each season since the deep ripping treatments were established and the effects seem likely to continue into 2019. The cumulative yield increase provided a positive return on investment to the farm business and the 350mm ripping depth was more profitable than the other treatments

Broomehill site:

There have been positive yield and economic responses seen in each season since the deep ripping treatments were established in 2015. The cumulative yield increase of 560 kg/ha of grain across the 2015, 2016 and 2017 season has provided an additional $177/ha to the farm business. The yield response from the upcoming 2019 season will give an indication as to the longevity of the deep ripping effect and therefore how likely it is an ongoing economic advantage will be realized from the practice.

Kojonup site:

Ongoing yield increases, like the positive result from barley in 2016 are likely to have provided a positive return on investment to the farm business. The yield response from the 2018 crop and the upcoming 2019 season will give an indication as to the longevity of the deep ripping effect and therefore how likely it is that an ongoing economic advantage will be realized from the practice.

Nyabing site:

The significant yield increases have made deep ripping economically profitable in the two seasons this trial has been run. Ongoing yield increases are likely to continue and will provide a positive return on investment to the farm business. The longevity of the deep ripping effect will determine how large the economic benefit will become although it has already provided a profit.

Beverley site:

Deep ripping provided mixed results on the various soil types found in this paddock and suggest that deep ripping will be profitable only on the sand over shallow clay and deep sand soil types. The significant yield increases in these zones were profitable although the benefit was negated by the loss incurred in the soil types of the medium and low productions zones. This indicates that deep ripping should be restricted to the higher production zones that have sand over shallow clay or the low production zones that have deep sand avoiding the deep sand over gravelly clay that make up the medium production zones. Ongoing yield increases are likely to continue and will provide a positive return on investment to the farm business. The longevity of the deep ripping effect will determine how large the economic benefit will become although it has already provided a profit.

Quairading site:

There have been very large positive yield responses to the deep ripping and spading in 2017. Increased yield is likely to have provided a positive return on investment to the farm business. The yield response from the upcoming 2018 season will give an indication as to the longevity of the deep ripping and spading effect and therefore how likely it is an ongoing economic advantage will be realized from the practice.

Northam site:

The significant yield increases have made deep ripping economically profitable in the two seasons this trial has been run. Ongoing yield increases are likely to continue and will provide a positive return on investment to the farm business. The longevity of the deep ripping effect will determine how large the economic benefit will become although it has already provided a profit.

Goomalling site:

On deep yellow sand at Goomalling repellence removal was important to achieve better crop establishment and subsequent tiller number. Very deep ripping greatly improved tiller survival while ploughing treatments suffered significant tiller loss between August and November resulting in loss of production potential. Deep compaction removal below a working depth of 400mm was important again in 2018, as it was in 2017, to improve root access to more of the moisture deeper in the soil profile and deliver a yield benefit. A lack of subsoil water holding capacity at this site appears to greatly reduce the potential yield that can be achieved at this site. Some amelioration treatments set up yield potentials during the crop development stage that appear too high to be regularly met for this deep sand.

Narembeen site:

The result of deep ripping was varied in this situation and showed the risk that is present when carrying out high-cost amelioration activities. Significant yield increases and large economic returns have been achieved through deep ripping in the two seasons this trial has been run. The negative consequences of not using the tillage type, failing to get a successful crop establishment or not getting the high returns required to be profitable have also been demonstrated in this trial. Ongoing yield increases from deep ripping are likely to continue and will provide a positive return on investment to the farm business. The longevity of the deep ripping effect will determine how large the economic benefit will become though it has already provided a profit.

Yealering site:

Though there may have been a positive yield increase from some of the ripping treatments, the high cost of lime, deep ripping and spading has not made the practices economically viable in this situation. The trial is located on a poor performing part of the paddock and it is difficult to establish a crop even in ideal circumstances and may be the cause of the lack of return lack or return. Though the benefits of tillage may continue over time it seems unlikely that an acceptable return will be realized in the near future.

Acknowledgments

The research undertaken as part of this project is made possible by the significant contributions of growers through both trial cooperation and GRDC investment, the author would like to thank them for their continued support. The authors acknowledge the Dempster family for hosting, implementing and assisting with the management of the research site. Some additional technical research support from the GRDC supported and DPIRD led DAW00244 soil water repellence project is acknowledged.

Implications

The major implication of this research is that subsoil compaction mitigation and topsoil amelioration in the Kwinana West and Albany port zones produces a wide variety of economic responses. In order to identify where the best economic responses occur, long term on-farm trials over a range of soil types are needed.

This project has provided growers in the Albany and Kwinana West port zones evidence that removing soil compaction can deliver significant yield increases and economic benefits over multiple years and suggests that removing deep (>500mm) soil compaction can give the largest benefits. It also very clearly shows that the cost of treatments and post-amelioration seed bed preparation needs to be carefully managed to ensure the benefit observed is profitable.

While benefits have been recorded in the time frame of this project, next step would be continue monitoring these sites to measure how much longer the benefits persist and if there are improvements to some of the treatments that gave negative returns.

Overall, this project suggests that the $333M loss to production due to soil compaction is able to be reduced or completely removed if growers are able to improve their management of soil compaction.

Recommendations

The results from this project should give growers in the Albany and Kwinana West port zones confidence to start or continue management practices, such as deep ripping that remove subsurface compaction as a constraint to farm productivity.

Carefully designed amelioration strategies, in which soil physical and chemical constraints are measured should be developed prior to ground work implementation to assist growers knowing what is required to remove soil compaction on their farm. For example, soil strength measurements with a digital cone penetrometer will help determine what depth of ripping is required and soil pH measurements can determine if there is an opportunity to fix soil acidity issues via liming during the ripping process.

Growers need to consider amelioration treatment costs and not expect short term (1-4 years) returns on high-cost treatments options, though returns are likely to be realized in the longer term.

The soil needs to be left in a condition that will promote good crop establishment post-treatment to achieve the highest returns in the shortest timeframe. Growers will need to look at rolling or packing options that gives the best final seed bed or cropping rotation options that have a lower risk of reduced establishment (eg. cereal vs canola post treatment).

Appendix A.
Appendix Title

Key words

Soil amelioration; soil water repellence; soil compaction; soil acidity; strategic deep tillage

Glossary and Acronyms

Below is a sample Abbreviations and Acronyms list. Be sure to include on this page all abbreviations and acronyms that appear in the report

DAFWA	Department of Agriculture and Food, Western Australia
RCSN	Regional Cropping Solutions Network
GRDC	Grains Research and Development Corporation
CTF	Controlled Traffic Farming
Db	bulk density
DPIRD	Department of Primary Industries and Regional Development

References

This section provides the information a reader would need to locate the articles, journals, and/or other publications referred to in the report.

Department of Primary Industries and Regional Development, 2018. Soil Compaction Overview. Available at: https://agric.wa.gov.au/n/106