NATIONAL SOILS CONFERENCE
Canberra 18-23 November 2018

Pre-conference Tour, November 17-18, 2018

Riverina Soils and Farming Systems

SOIL SCIENCE AUSTRALIA

Contents

Welcome and itinerary

Welcome to the Riverina Pre-Conference Field Trip!

The south-west slopes region of New South Wales is a highly productive and diverse agricultural region. Mixed farming dominates in a climate with significant summer rainfall, with dryland cropping and pastures for sheep and cattle. Relatively reliable rainfall makes it a productive and safe agricultural region, but a consequence of this is that it is also one of the most highly cleared and altered lands in the state. Major soil constraints in this region are soil acidity, nutrient deficiency and nutrient stratification, with small but significant areas of compaction, surface crusting and sodicity.

We have an interesting and busy couple of days planned exploring the region. Please make sure you ask questions as we go along, and let me know if there is anything that I can do to help.

Regards,

Suz

Dr Susan Orgill (Leader, Soils South)

NSW Department of Primary Industries

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PLEASE READ: Important information for field trip

You'll need to be wearing sturdy foot ware, preferably boots and be capable of walking several hundred meters at some of the sites. As day time temperatures at this time of year in SE Australia can be hot, you will need to bring a hat, sunscreen and a water bottle. A first aid kit will be available on the bus but delegates must bring their own medical requirements. Food and accommodation will be provided.

Field trip itinerary

Day 1 – Saturday 17/11/18

0830am	Depart Canberra Hyatt
10:30-12:00 (TOILET AND COFFEE STOP HARDEN)	STOP 1 Harden - CSIRO long-term trials investigating tillage, stubble and nutrient management
12:45-14:30 (LUNCH) (TOILET STOP STOCKINGBINGAL)	STOP 2: Mixed farming system; “Wattle Flat”, Stockinbingal. View two soil pits on a gentle slope and discuss the reasons for poor crop productivity (rooting depth and subsurface sodicity)
16:00-17:30 (TOILET STOP CSU)	STOP 3 Charles Sturt Winery - an integral part of Australia's leading wine science school
17:45	Finish day 1 in Wagga Wagga Accommodation: Prince of Wales Hotel Dinner at Thirsty Crow at 19:00

Day 2 – Sunday 18/11/18

From 06:30am	Breakfast at Prince of Wales Hotel
08:30am	Depart Prince of Wales Hotel
09:00-10:00 (TOILET STOP CSU)	STOP 4 – Soil profiles as part of teaching soil science at Charles Sturt University Wagga Wagga. View two soil pits.
10:00-11:00 (TOILET AND COFFEE STOP JUNEE)	STOP 5 – Rhizolysimeter at Charles Sturt University, Wagga Wagga. View the rhizolysimeter research facilities - the largest of its kind in the Southern Hemisphere.
1230-1430 (LUNCH) (TOILET STOP HARDEN)	STOP 6: “Ferndale”, Cootamundra to inspect a large-scale, on-farm NSW DPI field trial using various soil organic and inorganic amendments to manage subsoil acidity
17:00	Finish day 2 at Canberra Hyatt

Meet the team

On this field trip you will be joined by leading soil, crop and pasture researchers from NSW Department of Primary Industries, Charles Sturt University and CSIRO. The shared passion of this group is integrating soil science with agronomy and plant physiology to increase agricultural productivity.

Dr Susan Orgill is a soil scientist with NSW Department of Primary Industries based at the Wagga Wagga Agricultural Institute, and also leads the Soils South R&D team for NSW DPI. Susan's research focuses on management strategies to increase carbon in agricultural soil and overcoming soil constraints to pasture production. Her work covers most of NSW with research in extensive grazing systems in the rangelands, pasture systems in southern NSW and rotations in the mixed farming zone of central NSW. Email: susan.orgill@dpi.nsw.gov.au

Dr Jason Condon is Senior Research Fellow (Soils) at the Graham Centre for Agricultural Innovation (Charles Sturt University and NSW Department of Primary Industries) based at Wagga Wagga. Jason's research spans the formation and amelioration of soil acidity, fertiliser input efficiencies, and the interaction of plant and soil fertility. As Senior Lecturer in Soil Science at CSU, he taught introductory and advanced soil management to students of Agricultural Science, Horticulture and Viticultural Science at CSU for more than 20 years. Email: jcondon@csu.edu.au

Dr John Kirkegaard is a Chief Research Scientist at CSIRO Agriculture and Food, based in Canberra and Adjunct Professor at the University of Western Australia and Charles Sturt University. He was raised on the Darling Downs in rural Queensland, studied agriculture at Nambour High School and at The University of Queensland where he received his PhD studying the effects of soil compaction on the growth of grain legumes in 1990. Since 1990 he has been with CSIRO in Canberra focussed on understanding soil-plant interactions to improve the productivity, resource-use efficiency and sustainability of dryland farming systems. He and his teams have worked to improve the productivity of no-till farming systems for 30 years and the Harden long-term field site has been a "field laboratory" to support that work. Email: John.Kirkegaard@csiro.au

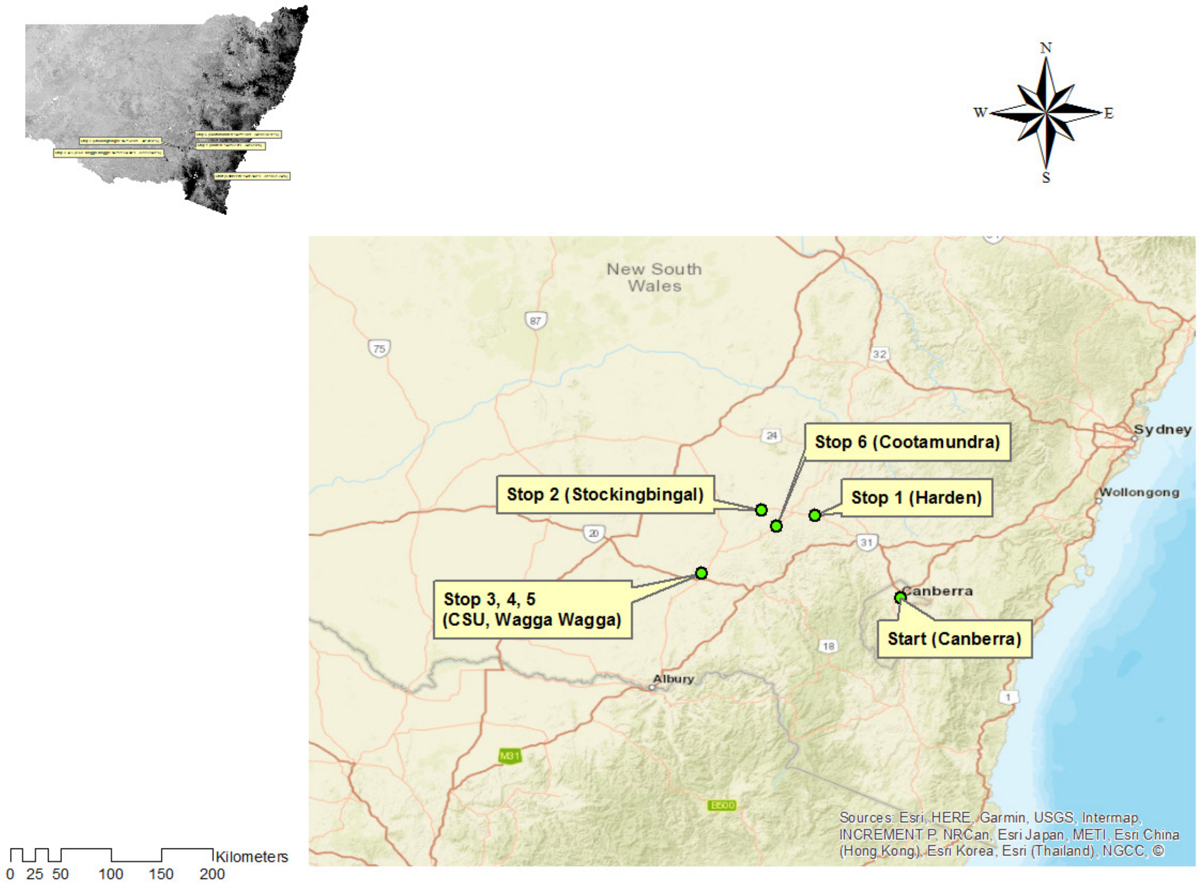
Dr John Angus retired as a Chief Research Scientist from CSIRO in 2010 after working in the Plant Industry and Land Use Divisions since 1973. He also worked in visiting scientist positions at the International Rice Research Institute and the Swedish University of Agricultural Sciences. He retains research interests at CSIRO, CSU and the Graham Centre and operates a crop and livestock farm at Stockinbingal. His research career involved simulation and experimental studies on crop phasic development, water and nitrogen productivity of dryland crops, the effects of crop and pasture sequences and the agronomy of irrigated rice. His research training was in crop physiology at the University of Melbourne. During his career he was President of the Australian Society of Agronomy from 2008 to 2010, co-President of the Asian Crop Science Society and committee member for the fifth International Crop Science Congress. Email: John.Angus@csiro.au

Dr Sergio Moroni is a Senior Lecturer at the School of Agricultural & Wine Sciences at Charles Sturt University. Sergio has over 20 years' experience in plant pre-breeding and crop physiology. Before joining CSU in 2009, Sergio was a Research Agronomist with NSW DPI and worked on the enhancement of crop performance on acidic soils and identification and characterisation of rapeseed tolerant to high manganese as well as rapeseed, wheat and barley germplasm resistant to aluminium. Sergio also worked on the National Brassica Germplasm Improvement Program (NBGIP) where his main area of research was in the development rapeseed (Brassica napus) germplasm adapted to water limited environments. Sergio is currently the lead scientist for the CSU component of 2 GRDC funded projects in collaboration with NSW-DPI, namely CSP00187: Optimised canola profitability - understanding the relationship between physiology and tactical agronomy management and DAN00206: Innovative approaches to managing subsoil acidity in the southern grain region. Email: smoroni@csu.edu.au

Dr Guangdi Li obtained his Bachelor and Master degrees at Gansu Agricultural University, China and did his PhD at Massey University, New Zealand, focused on response of chicory (*Cichorium intybus* L.) to defoliation during 1993-1997. Dr Guangdi Li has been working for NSW Department of Primary Industries since 1997. He has extensive research experience in Australia, New Zealand and China. Over the last 10 years, he published more than 70 refereed journal papers across a wide range of research areas in pasture agronomy, crop and pasture management, pasture species evaluation, soil chemistry and physics, and acid soil management. Currently, he is leading a multi-disciplinary research team across 4 research organizations in partnership with 4 leading growers groups, focusing on innovative approaches to managing subsoil acidity in the southern grain region in Australia. Email: guangdi.li@dpi.nsw.gov.au

Sam North is a Research Hydrologist with NSW Department of Primary Industries based at Deniliquin Research and Advisory Station. He joined the NSW Department of Agriculture in 1989 and in 2002 was appointed to the position of Research Hydrologist, Irrigated Farming Systems, at Deniliquin. Since then he has examined ways of improving the agronomic, hydraulic and operational performance of basin irrigation systems used in rice farming systems; determined benchmarks for profitable use of centre pivot and linear move irrigation; and developed management guidelines for sustainable use of saline-sodic groundwater for irrigation. Between 2010 and 2014 Sam led research into the salinity tolerance of Australian rice cultivars which has been used to update crop and water management guidelines for groundwater irrigated rice in the Riverina. This work was part of a larger ACIAR funded project looking to improve rice establishment and productivity in Australia and Cambodia. Sam is currently leading a GRDC project (Soils under an irrigated environment) which aspires to increase grain production and profitability from surface irrigated soils in the Southern Murray-Darling Basin by improving grower understanding of the interaction between crops, soils and irrigation and their effect on productivity. Email: samuel.north@dpi.nsw.gov.au

Field trip map



STOP 1: CSIRO Harden long term tillage site 2018

Oxton Park, Harden (O'Connor family)

(*Dr John Kirkegaard, CSIRO*)

Background

Established as a part of CSIRO Land and Water Care Project in 1990, the experiment was designed to investigate the effects of tillage and stubble management on soil conditions and crop productivity. The site became a focal point of collaboration and discussions with local farmers, consultants and the Harden/Murrumburrah Landcare Group, and numerous field days have been held at the site. Since the original CSIRO Land and Water Care funding ceased in 1994, the site has been maintained by CSIRO in collaboration with other research groups interested in sampling the site, and numerous research projects have utilized the site. The first 20 years of research were celebrated in 2009 with a Symposium and release of a booklet detailing some of the research outcomes. A copy has been provided as background. On this tour we will discuss some of the recent research conducted in the last decade (2009 to 2018). The site is likely to be closed in 2019 after 30 years of on-farm research with the local agricultural community through the Harden/Murrumburrah Landcare Group.

The last decade (2009-2019)

During the last decade the long-term site has continued to be a focus for research related to the sustainable management of soils in modern and productive farming systems. There are three main projects that have been conducted at the site during that time and some brief background and outcomes are reported here with an intentional "soils" flavour.

Project 1. (2007-2012): GRDC PhD on Soil Carbon Sequestration

Theme: Nutrients are needed to build soil organic matter (Kirkby PhD, Kirkegaard, Richardson)

Why has retaining stubble rather than burning it after 25 years made so little difference to the levels of soil organic matter at Harden? Soil organic matter is more than carbon (C) – we simply use C as a simple way to monitor organic matter (you don't find much pure C in soil!). The stable organic matter in soil (humus) has relatively stable ratios of C:N:P:S and these are similar to those found in bacteria and fungi as it is dead micro-organisms and not dead plant material that makes humus. So could it be a lack of nutrients, and not a lack of carbon that limits the sequestration of more organic matter ((and C) in soil?

To test this Clive Kirkby used the long-term "stubble incorporate" treatment at the site and divided it into two treatments in 2007. Each year after harvest as stubble was incorporated (around 9 t/ha to both sides), he added supplementary nutrients (as starter fertiliser NPS) to one side only and then incorporated both sides with a rotary hoe. He did this for 6 years (5 wheat crops and 1 canola crop). After 6 years the soil carbon **on the "no nutrient" side had LOST 3.3 t/ha C**, while the **"plus nutrient" side had GAINED 5.5 t/ha C.**

This work explained the lack of C sequestration despite the high levels of C input. We had been "mining" nutrients in the system with associated loss of soil organic matter DESPITE retaining stubble.

Kirkby CA, Richardson AE, Wade LJ, Conyers M, Kirkegaard JA (2016) Inorganic nutrients increase humification efficiency and C-sequestration in an annually cropped soil PLoS One DOI:10.1371/journal.pone.0153698

Project 2. (2011-2015) GRDC Strategic Tillage Project (Clive Kirkby Post-Doc, Conyers, Kirkegaard)

Theme: Does one-off tillage do irreparable damage to long-term (20 year) no-till soil?

Many long-term no-till farmers are concerned that cultivation of long-term, no-till soil will do irreparable damage to soil structure and soil health and they would "lose" all the benefits to the soil. Yet tillage is needed to incorporate lime, deal with *Rhizoctonia,* alleviate compaction and assist in integrated weed management.

We speculated that one-off cultivation would do little lasting damage to the soil, but had no specific data to reassure growers. We set up four field sites (including Harden) where long-term, no-till soil treatments were cultivated once in 2011 (at Harden with a rotary hoe!). We then tracked soil biology, chemistry and structure was monitored along with crop growth for 5 years.

We found:

- Tillage reduced aggregate stability in Year 1, but recovered within 12-18 months (Figure 1).
- Tillage redistributed P, C and lime from the surface layers (0-5) into deeper layers but had no effect on the total levels of C, P or pH – it helped reduce "stratification"
- No significant impact of the one-off "strategic tillage" on crop yield over 5 years (Table 1).

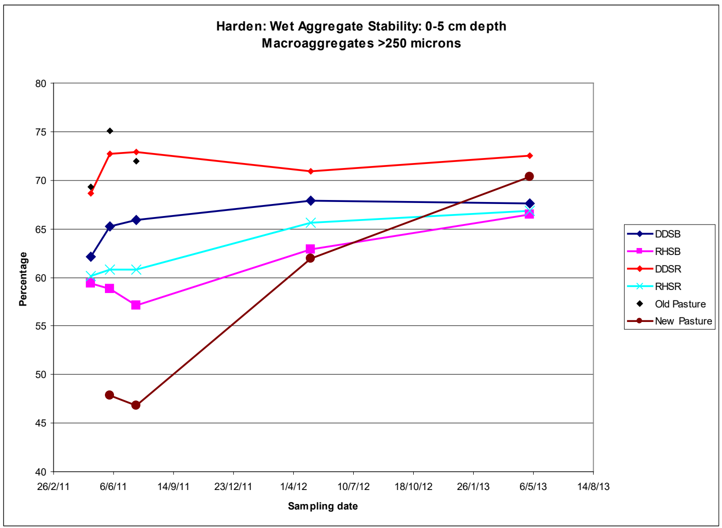


Figure 1. Wet aggregate stability took about 12-18 months to return to initial levels after tillage in both stubble retained or stubble burn treatments. A clover pasture sown into a roadway that was also rotary hoed (lower brown line) regenerated structure very effectively.

Table 1. One-off tillage in 2011 had little impact on crop yield over the subsequent 5 years.

Residue	Tillage	Mean yield (t/ha)					
		1990-2010	2011[C] (wheat)	2012 (wheat)	2013 (wheat)	2014 (lupin)	2015 (canola)
Burnt	**Min-Till**	**4.7**	**4.9** (0.2)	**5.9** (0.3)	**4.0** (0.1)	**2.1** (0.1)	**2.7** (0.2)
	No-till	**4.5**	**4.9** (0.2)	**6.1** (0.1)	**4.2** (0.1)	**2.1** (0.1)	**2.7** (0.2)
	No-till - ST	**-**	**4.8** (0.3)	**6.4** (0.2)	**4.0** (0.1)	**2.2** (0.1)	**2.9** (0.1)
Retain	**Min-Till**	**4.3**	**4.4** (0.2)	**4.9** (0.4)	**3.5** (0.1)	**2.1** (0.1)	**2.8** (0.2)
	No-till	**4.3**	**4.2** (0.3)	**5.1** (0.2)	**3.3** (0.1)	**2.2** (0.1)	**2.5** (0.2)
	No-till - ST	**-**	**4.4** (0.3)	**5.4** (0.2)	**3.3** (0.1)	**2.2** (0.1)	**2.6** (0.2)

Project 3. (2014-2017) GRDC Stubble Initiative: (Kirkegaard, Swan, Richardson, Bullock)

Theme: Overcoming the negative impacts of retained stubble – it's all about nitrogen

Over the long-term at the Harden site, stubble retention has reduced yield by an average of 0.3 t/ha. The yield penalty has tended to be worse in wetter years (Figure 2, but the mechanism was unknown. We originally discounted nitrogen immobilisation as the cause because pre-sowing mineral N did not differ between treatments. However recent work at Temora with more intensive N measurements, as well as simulation studies suggested post-sowing N immobilisation was a likely mechanism reducing growth and yield in stubble-retained systems.

In 2017 we applied additional nitrogen at sowing to stubble-retained and stubble burnt plots to investigate the role of N-immobilisation in the yield reductions with retained stubble. We found that both additional surface-applied N as well as N placed deeper in the soil could both alleviate the early growth penalties in SR systems (Table 1). Impacts on yield were confounded by the water retention benefits in the dry spring conditions, however the work has focussed attention on improved N supply in stubble-retained systems.

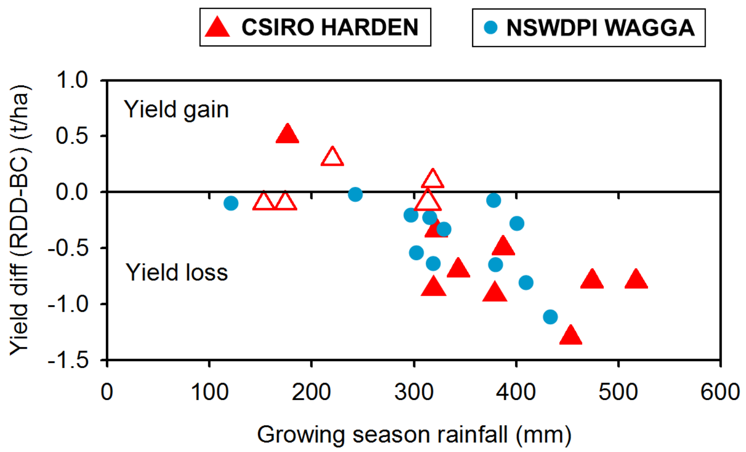


Figure 2. Yield penalties in wheat associated with stubble retention are worse in wetter years (data for Harden long-term site and for SATWAGL in Wagga) from Giller et al., 2015.

Table 2. Effect of added N on wheat growth, yield and protein in stubble-retained and burnt treatments at Harden in 2017

Treatment		Anthesis		Harvest (@12.5%)	
Stubble	N	Biomass (t/ha)	Tillers (/m^2)	Yield (t/ha)	Protein (%)
Retain	50	7.1	324	4.3	8.8
	100	8.4	401	4.9	9.6
Burn	50	8.8	352	4.2	9.3
	100	8.7	372	4.5	10.5
LSD (P<0.05)	*Stubble*	*0.9*	*ns*	*0.2*	*ns*
	N	*0.5*	*33*	*0.1*	*0.2*
	Stubble x N	*0.8*	*38*	*0.2*	*ns*

Giller KE, Andersson JA, Corbeels M, Kirkegaard JA, Mortensen D, Erenstein O, Vanlauwe B (2015) Beyond Conservation Agriculture, Frontiers in Plant Science, 6 Article 870 doi: 10.3389/fpls.2015.00870

STOP 2: Mixed farming system, “Wattle Flat”, Stockinbingal

Wattle Flat, a mixed farm operated by John and Patricia Angus in Stockinbingal

Wattle Flat is in a relatively flat landscape (1 in ~400 sloping to the NW) intersected every 2-3 km by small east-west creeks that flow into Bland Creek and thence to the Lachlan River via Lake Cowell. Elevation is 300 m, annual average rainfall is 570 mm, ~60% in winter (April – October), ~40% summer. 2018 rainfall until 15 October was 220 mm and April to 15 October was 83 mm.

Of the 330 ha in Wattle Flat, crops (canola, wheat, barley, lupin and mustard) make up about 150 ha, and there is an equal area sown to perennial pastures (lucerne, clover, cocksfoot, and sometimes chicory and plantain). The pastures carry self-replacing merino ewes and cross-bred lambs. The proportion of crop has decreased by one-third in the past decade, replaced by pasture. There is also about 30 ha of remnant vegetation (grassy box woodland mostly in 30 m-wide “green roads” marking the boundaries of the original 640 ac blocks). All the cleared land is on its second or third liming and the pHCa >5.5 in the 0-0.1m layer but <4.8 in the 0.1-0.2 m layer. Colwell P is 40-50 mg/kg.

The soil is duplex, grey-brown in colour and apparently sodic at depths > 0.8 m. Boomers and older would call it a red-brown earth. We hope to provide 2 soil pits and invite the visiting group to suggest a name from Isbell.

The soils seem to have a thicker A horizon on the creek levees than on the lower parts of the landscape. These lower-lying zones are prone to flooding and frost, and the root zone of annual crops is probably <1.1 m. The water–holding capacity is low compared to the Kandosols in the region and yields are low in dry seasons. In years of average rainfall yields are comparable to those on Kandosols. Because of these problems we have stopped growing wheat and canola on the lower-lying land and replaced them with more pasture and with barley, either a spring variety or a grazed winter variety. The sheep enterprise is currently more profitable than crops and the barley is the most profitable crop. At the soil pits we can look at lucerne roots and whether they penetrate the sodic subsoil as well as comparing profiles at the high and low-lying sites.

STOP 3: Charles Sturt Winery

The Charles Sturt Winery is an integral part of Australia's leading wine science school and is at the forefront of viticultural practices and wine making techniques.

The winery focuses on excellence, using state of the art technology without sacrificing tradition. We are a professionally run winery reflecting the commercial environment of the Australian wine industry, being market driven and producing the quality and styles of wine that obtain ready acceptance from wine consumers in the market.

http://winery.csu.edu.au/

STOP 4: CSU Soil pits

Students studying Science at CSU spend 6 weeks in lab practical classes learning basic skills in profile description and interpretation. To reinforce the development of those skills, a field trip is conducted which aims to create a soil map of a section of the CSU farm. Students identify areas that, based on knowledge of soil forming factors, should exhibit different soils. They then visit those sites to ground truth their maps. We experience an abbreviated version of the trip and will visit 2 soils which are common in the area around Wagga Wagga. They also represent the soils used in the rhizolysmeter.

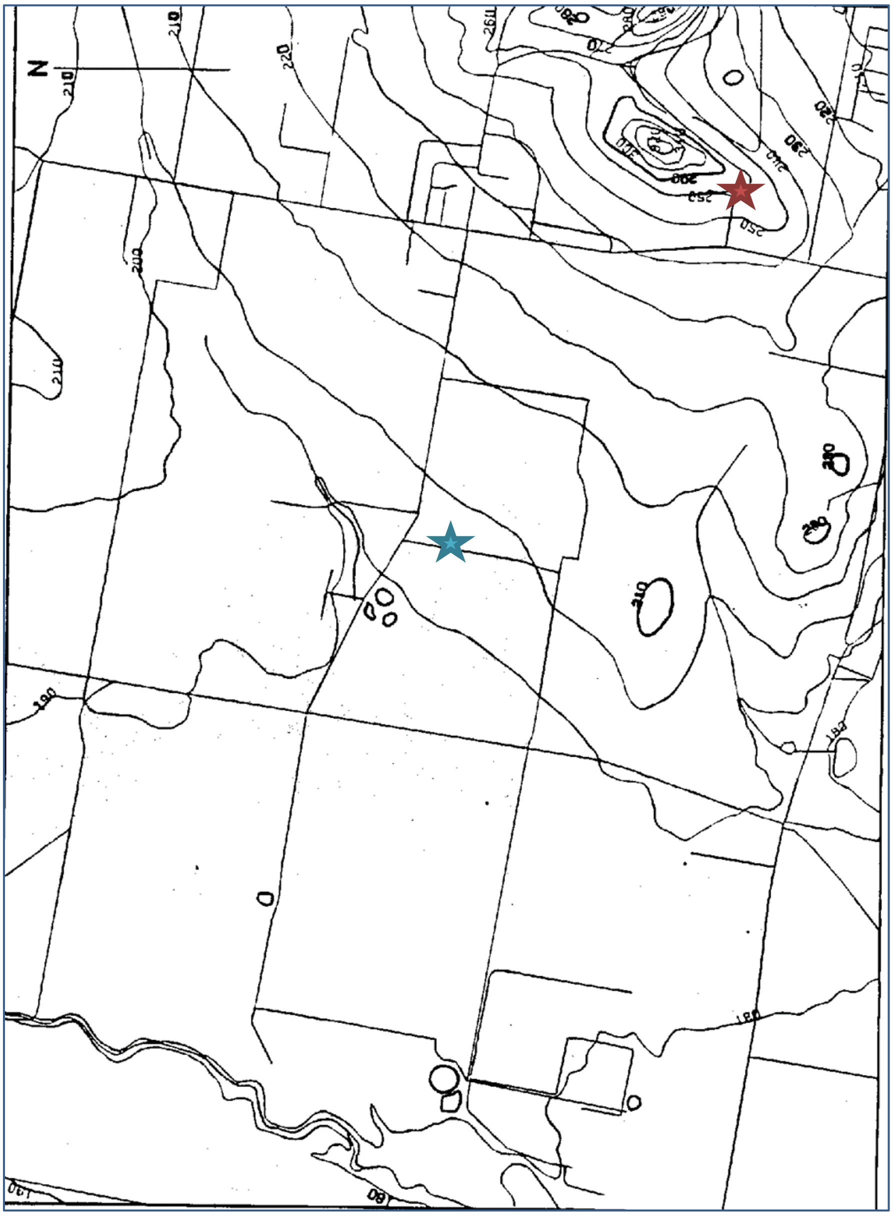


Figure 3. Topographical map of the original Charles Sturt University farm (10 m isolines, scale 1:25,000

Site 1 Red Chromosol - Granite Hill

Lat: -35.064410°, Long: 147.350064°

	A_1 Horizon 0-10 cm	Greyish brown to brown, micaceous loamy sand, weak angular blocky to massive, firm, many roots, pH 6.5, clear to
	A_2 Horizon 10-30 cm	Light greyish brown, coarse sandy to gravelly loam, massive, few roots, firm, pH 6.8, clear to
	B Horizon 30-60 cm	Dark reddish brown, fine sandy light clay, weakly developed sub-angular blocky, pH 7.0, diffuse to
	C Horizon 60- cm	Weathering granite

Depth	**pH_{water}**	**pH_{CaCl2}**	**Exchangeable cations (cmol +/kg)**						**Particle size analysis (%)**		
(cm)	**(1:5)**	**(1:5)**	**Mg^{++}**	**K^{+}**	**Na^{+}**	**Mn^{++}**	**Ca^{++}**		**sand**	**Silt**	**Clay**
0-10	6.5	5.5	0.90	0.87	0.31	0.18	7.20		77	6	17
10-30	6.8	5.4	0.86	0.74	0.20	0.24	7.60		78	11	11
30-60	7.0	5.9	1.32	1.30	0.28	0.05	3.80		36	8	56

Site 2 Red Kandosol - Parna

Lat: -35.052881°, Long: 147.333485°

	A Horizon 0-16 cm	Brown, light clay, granular and weakly developed sub-angular blocky, friable, many roots, pH 6.0, gradual to
	B_1 Horizon 16-56 cm	Reddish brown, medium to heavy clay, massive to weakly developed sub-angular blocky, firm, pH 6.5, gradual to
	B_2 Horizon 56 - cm	Mottled yellowish and red brown with black inclusions, heavy clay, massive to weakly developed sub-angular blocky, firm, pH 7.0

Depth	**pH_{water}**	**pH_{CaCl2}**	**Exchangeable cations (cmol +/kg)**						**Particle size analysis (%)**		
(cm)	**(1:5)**	**(1:5)**	**Mg^{++}**	**K^{+}**	**Na^{+}**	**Mn^{++}**	**Ca^{++}**		**sand**	**Silt**	**Clay**
0-16	6.0	5.4	1.64	0.74	0.15	0.25	6.38		54	8	38
16-56	6.5	5.8	4.44	0.90	0.39	0.01	6.30		30	3	67
56-	7.0	6.1	5.30	0.74	0.63	0.04	4.30		30	8	62

STOP 5: CSU Rhizolysimeter

FACULTY OF SCIENCE

Charles Sturt University

RHIZOLYSIMETER

FACILITY

- The CSU Rhizolysimeter Facility is one of the largest root growth and soil water research facilities in the Southern Hemisphere located at the CSU Wagga Wagga Campus.
- The Rhizolysimeter has been designed to simulate crop growth in a phase farming rotation. It allows for the integrated quantification of the canopy, root growth and water dynamics in a crop phase of a pasture/crop rotation.
- The complex contains 72 soil monoliths (2.5 m height and 0.74 m inside diameter) encased in 6 mm steel tubes. The encased soil monoliths represents 2 soils common to the region and are arranged in rows in 2 underground laboratories which allows access to the side of the soil monolith from 0.6-2.5 m beneath the soil surface.
- The design of the facility allows for non-destructive, high resolution *in situ* measurements at 8 soil depths of root growth and soil water dynamics with the placement of 576 minirhizotrons and TDR sensors. The soil monoliths can also be fitted with a wide range of monitoring instruments.

Charles Sturt University

CURRENT PROJECT: CSP00187 Optimised Canola Profitability

Objectives: to quantify the root and water dynamics of diverse canola germplasm that may be suitability to early sowing in environments with a dry finish.

GRAHAM CENTRE

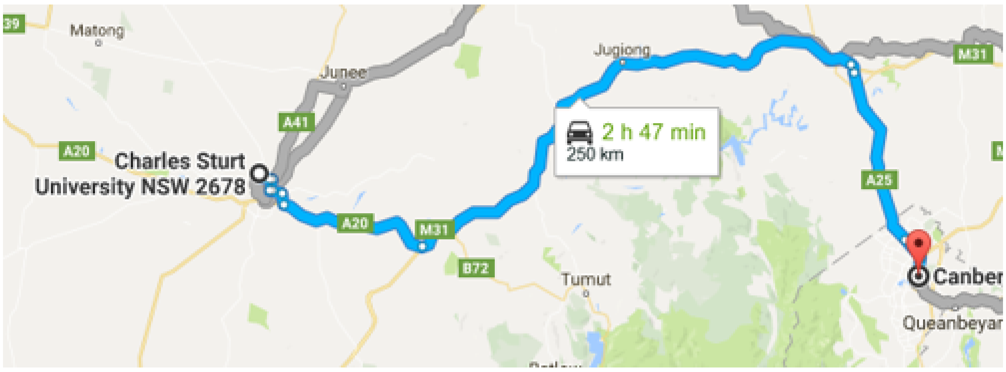
GRDC GRAINS RESEARCH & DEVELOPMENT CORPORATION

CSIRO

NSW GOVERNMENT Department of Primary Industries

Directions

The CSU Wagga Wagga Campus is located about 3 hrs west of Canberra by vehicle.



FURTHER INFORMATION

Further information may be obtained from:

Dr. J. Sergio Moroni

smoroni@csu.edu.au

STOP 6: Subsoil acidity amelioration experiment at "Ferndale", Cootamundra

Research update for the long-term subsoil acidity experiment at Ferndale site at Cootamundra, NSW

Dr Guangdi Li, Richard Hayes, Dr Ehsan Tavakkoli, Helen Burns, Richard Lowrie, Adam Lowrie, Graeme Poile, Albert Oates and Andrew Price (NSW DPI, Wagga Wagga), Dr Jason Condon, Dr Sergio Moroni and Dr Alek Zander (Charles Sturt University, Wagga Wagga)

Key findings

- Deep placement of organic amendments (e.g. lucerne pellets) did not increase soil pH as high as measured in lab/glasshouse experiments, but it did reduce exchangeable aluminium (Al) significantly at 10–20 cm and 20–30 cm, indicating that the organic amendment would relieve aluminium (Al) toxicity by combining Al^{3+} to form insoluble compounds, hence reducing toxicity to plant growth.
- There was a large crop yield response to deep organic amendments in year 1 due to extra nutrient supplied from the lucerne pellets, but no crop response was detected in year 2, partly due to lack of soil moisture during the crop growing season. To date, soil treatments have had little effect on soil water.
- Soil chemical, physical and biological properties will continue to be monitored to understand the soil–plant interactions, the factors driving the differences in crop response to the various treatments, and the residual value of the amendments over the long term.

Introduction

Subsoil acidity is a major constraint to crop productivity in the high rainfall zone (500–800 mm) of south-eastern Australia (Pinkerton and Simpson 1986; Scott *et al.* 1997). Approximately 50% of Australia's agriculture zone (~50 M ha) has a surface soil pH < 5.5 in calcium chloride (pH_{Ca}) and half of this area also has subsoil acidity (Dolling *et al.* 2001). Soil acidification is accelerated by nitrate leaching under certain crop rotations, by the use of ammonium-based fertilizers, and by the regular removal of plant products, such as grain or hay. The major constraint to plant production on acid soils is aluminium (Al) toxicity which inhibits root growth even at very low concentrations. Smaller root systems limit nutrient and water uptake and increase the vulnerability of plants to periodic droughts.

The surface application of lime is a common practice used to combat soil acidity. However, lime moves very slowly down the soil profile so subsoil acidity will only be ameliorated after decades of regular application which is inefficient and expensive. Li *et al.* (2010) reported that pH increased at 0.044 pH units per year at 15-20 cm by maintaining an average pH_{Ca} of 5.5 at 0-10 cm with lime, indicating that it would take approximately 23 years to raise the subsurface soil pH by one unit based on 20 years of data from a long-term liming experiment (known as MASTER) near Wagga Wagga, NSW. Indeed, at the current commercial recommended rate of 2.5 t/ha every 6-10 years, most of the alkalinity added is consumed in the topsoil with very little remaining to counteract subsoil acidification. Thus more aggressive methods, such as deep ripping in conjunction with lime or other amendments, are required to deliver soil amendments to the subsoil directly and achieve more rapid changes to pH at depth.

It has been reported that organic amendments could be used to improve the subsoil acidity because the decarboxylation reactions that they promote have the potential to increase soil pH, decrease Al toxicity and generally improve conditions for root growth (Tang *et al.* 2013). This has not previously been tested in a field environment in the target region.

This project investigates the deep placement of lime to the subsoil where it is most needed, with or without organic amendments to achieve more rapid changes to pH at depth. Novel amendments, such as magnesium silicate, reactive phosphate rock, and calcium nitrate, are being tested in different soils with different crop species in both controlled environments and under field conditions.

A long-term field experiment was set up in 2016 at Ferndale, west of Cootamundra, NSW. The soil type is Red Chromosol (Isbell 1996). Long-term annual rainfall is 608 mm. The objectives are to *a*) manage subsoil acidity through innovative amelioration methods that will increase productivity, profitability and sustainability; and *b*) study soil processes, such as the changes in soil chemical, physical and biological properties under vigorous soil amelioration techniques over the longer term.

Crop rotation and treatments

There were four crops in rotation arranged in a fully phased design. The crops sequence is wheat (*Triticum aestivum*), canola (*Brassica napus*), barley (*Hordeum vulgare*), pulse, either Faba bean (*Vicia faba*) or field peas (*Pisum sativum*) depending on the season. Each crop appears once in any given year so that *a*) responses of different crops to different soil amendments can be assessed; *b*) underlying treatment effects, taking account of seasonal variation, can be compared.

Table 3. Soil amendment and treatment description at Ferndale, west of Cootamundra, NSW

ID	Treatment	Treatment description
1	No amendment	No amendment, representing the ‘do nothing’ approach
2	Surface liming	Lime was applied at 4.0 t/ha, incorporated into 0–10 cm depth, to achieve an average pH_{Ca} of 5.5 over 8 years
3	Deep ripping only	Soil was ripped down to 30 cm to quantify the physical effect of ripping. No amendment was applied below 10 cm, but lime was applied at 2.5 t/ha at the surface, incorporated into 0–10 cm depth after plots were ripped, to achieve an average pH_{Ca} of 5.0 over 8 years
4	Deep liming	Lime was placed at three depths (surface, 10–20 cm and 20–30 cm). Approximately 5.5 t/ha of lime was applied in total to achieve a target pH >5.0 throughout the whole soil profile, which should eliminate pH restrictions to plant growth for most crops
5	Deep organic amendment (OA)	Organic amendment (in the form of lucerne pellets) at 15 t/ha was placed at two depths (10–20 cm and 20–30 cm). The surface soil was limed to pH 5.0
6	Deep liming plus OA	Treatments 4 and 5 were combined to maximise the benefits of lime and organic amendment

Key results in 2016 and 2017

Soil chemical properties

There was no difference in soil pH at any depth in year 1 before treatments were imposed in 2016. In autumn 2017, one year after treatments were applied, surface liming increased pH to 5.9 at 0–10 cm. The deep liming treatment with and without OA significantly increased soil pH at 10–20 cm and 20–30 cm (Figure 4), showing the efficacy of the 3-D Ripper (Figure 5) to deliver soil ameliorants to depth (Li & Burns 2016).

However, the deep OA treatment did not increase pH as high as measured in lab/glasshouse experiments (data not shown). There are two possible explanations for this. First, the organic amendment was normally fully mixed with soil when it was incubated in the laboratory or put in soil columns in the glasshouse compared to that in the field where it was placed in a concentrated row in the rip line. Lack of homogenisation of the soil with OA makes it difficult to demonstrate what is more easily observed in a controlled environment with adequate water supply, usually maintained at field capacity. Secondly, all controlled environment experiments were conducted for 1–3 months, which would capture the initial soil pH increase due to decomposition of organic materials as demonstrated by Butterly et al (2010b). However, the subsequent nitrification processing would reduce soil pH (Butterly et al. 2010a). Nitrate leaching, if it occurs, will exacerbate the acidifying process. As a result, the net effect would keep soil pH unchanged in the longer term.

A number of soil column experiments demonstrated that the soluble component from organic material moves faster down the soil profile with alkali if combined with lime, compared with lime alone (Meda et al. 2002; Diehl et al. 2008) However, there is no evidence to show the lime being moved under lime plus OA in the field condition yet. Monitoring soil pH will continue for the next few years to observe whether evidence of this emerges at the field site.

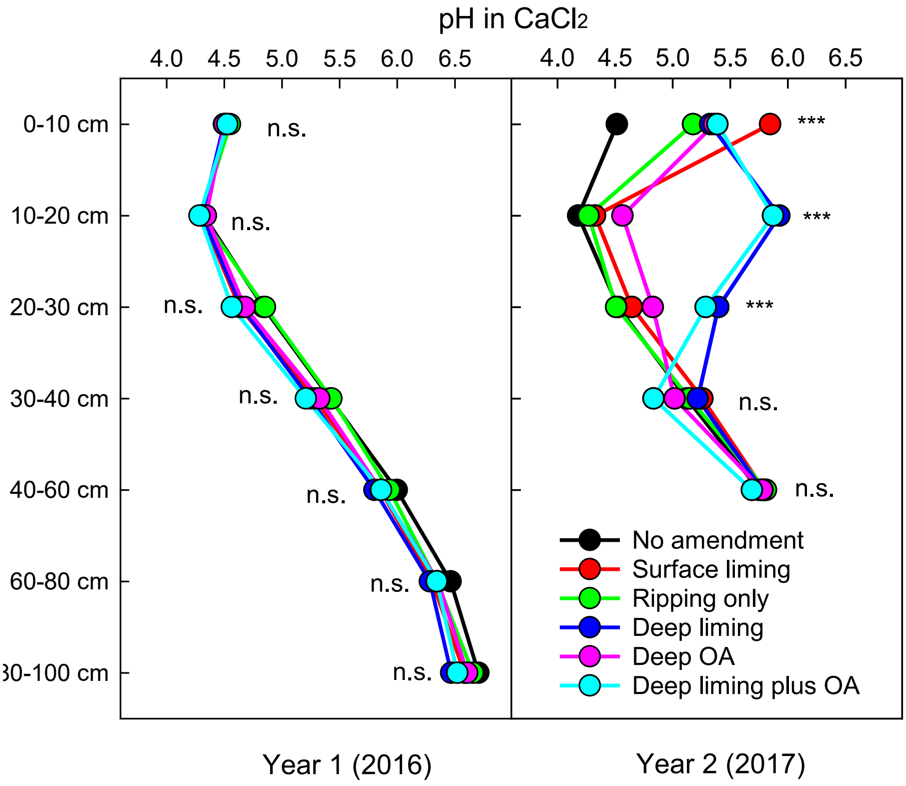


Figure 4. Soil pH in CaCl2 under different soil amendment treatments in autumn in years 1–2 at the Cootamundra site. n.s., not significant.

Figure 5. 3-D Ripper, designed and fabricated by the NSW Department of Primary Industries

Although OA did not increase soil pH, it did reduce exchangeable Al% significantly at 10–20 cm and 20–30 cm (Figure 6) compared with the no amendment treatment, indicating that the soluble organic molecules from OA could combine active Al^{3+} to form insoluble hydroxy-Al compounds (Haynes & Mokolobate 2001), which would reduce Al toxicity to plant growth.

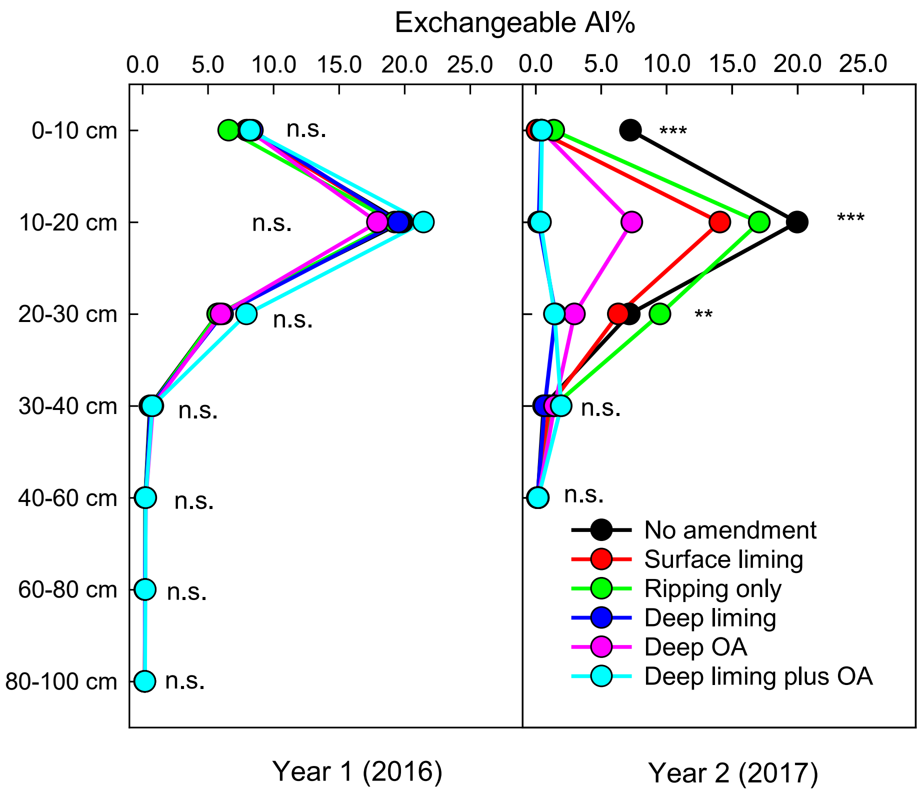


Figure 6. Soil exchangeable Al% under different soil amendment treatments in autumn in years 1–2 at the Cootamundra site. n.s., not significant.

There was significantly more soil mineral N under the deep OA treatments with and without lime in spring 2016 (six months after treatments were implemented, $P<0.01$) and in autumn 2017 (12 months after treatments were implemented, $P<0.001$) (Figure 7), most likely due to the high N content (3.15%) of the lucerne pellets. On average, there was more than double the mineral N available on the deep OA and deep lime plus OA treatments compared with the remaining treatments.

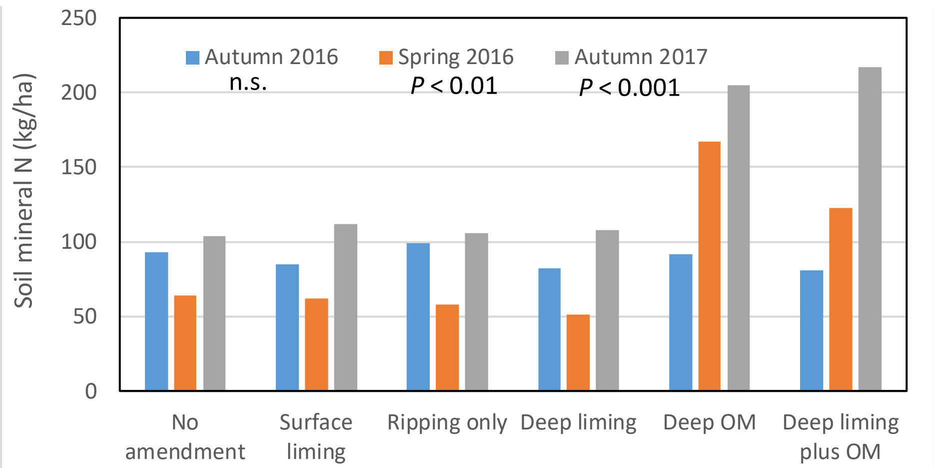


Figure 7. Soil mineral N (kg/ha) in 0–60 cm soil profile under different soil amendment treatments in autumn and spring in year 1, and autumn in year 2 at the Cootamundra site. n.s., not significant.

Rooting depth and root density

Rooting depth and root density was measured at crop anthesis at the end of October 2017 using the core-break method. Two soil cores were taken on each plot, one on the ripping line and the other between ripping lines. Data are presented on the average of two cores for each plot as no significant difference was found between two locations.

Canola was the deepest rooting crop, down to 140 cm and faba bean had the shallowest rooting depth (90–100 cm), whereas wheat and barley were intermediate. There was no significant difference in average maximum rooting depth between treatments (Figure 8).

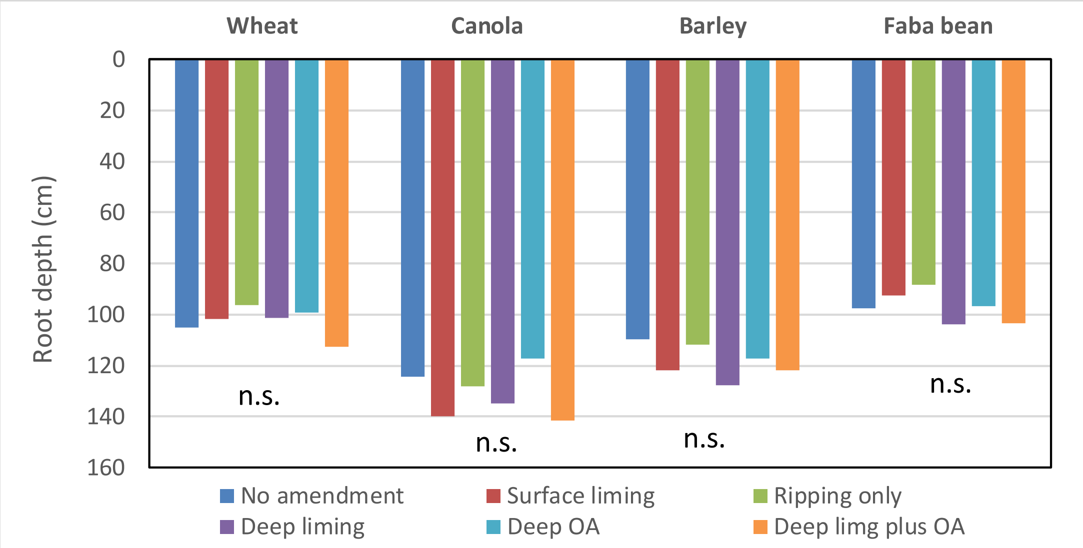


Figure 8. Maximum rooting depth (cm) under different soil amendment treatments at crop anthesis in year 2 at the Cootamundra site. n.s., not significant

Soil total water

Neutron probe access tubes were inserted in autumn each year immediately after crops were sown then monitored for 12 months before new crops were sown in autumn the following year. One access tube was inserted between two ripping lines on each plot. Measurements were taken at six depths every 25 cm from 15 cm below soil surface down to 140 cm at 4–6 week intervals. The neutron probe reading was calibrated twice a year at the wettest and driest periods and the soil volumetric moisture content and soil total water in the profile were calculated.

The amount of soil water, in general, followed the rainfall pattern. In year 1, the soil profile was nearly full under all crops at the end of October due to the site receiving 676 mm of rainfall in that year. Late in the growing season, soil water decreased sharply for all crops due to high evapo-transpiration rates during the grain fill period. There was more soil water under the field pea crop at the end of November due to its earlier maturity and shallower rooting depth (Figure 9). The autumn and winter of year 2 were very dry and soil water remained at similar level until the end of August before crop growth took off and water demands increased. During spring, soil water decreased to the lowest level due to vigorous crop growth and limited rainfall during that period among all treatments. The early summer rainfall re-filled the soil profile to different levels depending on soil moisture status in spring for different crops and treatments (Figure 9).

For wheat and canola in year 1, crops on treatments with deep soil amendments had lower soil water at the end of November 2016, particularly for the deep liming plus OA treatment (Figure 9a and Figure 9b) due to vigorous crop growth(Figure 10). In year 2, the deep liming treatment had the lowest soil water on the canola crop following the wheat crop (Figure 9a), whereas the deep liming plus OA treatment had lowest soil water on the barley crop following canola for the whole season (Figure 9b).

For the barley crop in year 1, the ripping only treatment had the lowest soil water among all treatments during early growing season, possibly due to more evaporation (Figure 9c). Later in the growing season during November, soil water on deep liming plus OA decreased sharply, reflecting the vigorous crop growth. Soil water on the deep liming treatment, however, was much higher than other treatments. In year 2, it was a very poor faba bean crop. Soil water on different treatments remained similar through the season with the highest soil water on the deep liming treatment and the lowest on the deep liming plus OA treatment.

For the field pea crop in year 1, there was not much difference in soil water during the growing season (Figure 9d); soil water was higher on this crop than other crops in year 1. The surface lime treatment had the highest soil water among all treatments after the crop was harvested. In year 2, vigorous wheat crops used more soil water and brought soil water down to a level similar to the other crops in the rotations (Figure 9d). Overall, soil amendment had little apparent effect on soil water values.

Agronomic performance

There was no significant difference in seedling density for all crops except for the barley crop where two treatments with deep OA had a higher seedling density in year 1 (Figure 10). There was no treatment difference in seedling density for any crops in year 2 due to the extremely dry conditions during crop establishment. The site only received 3.2 mm in June.

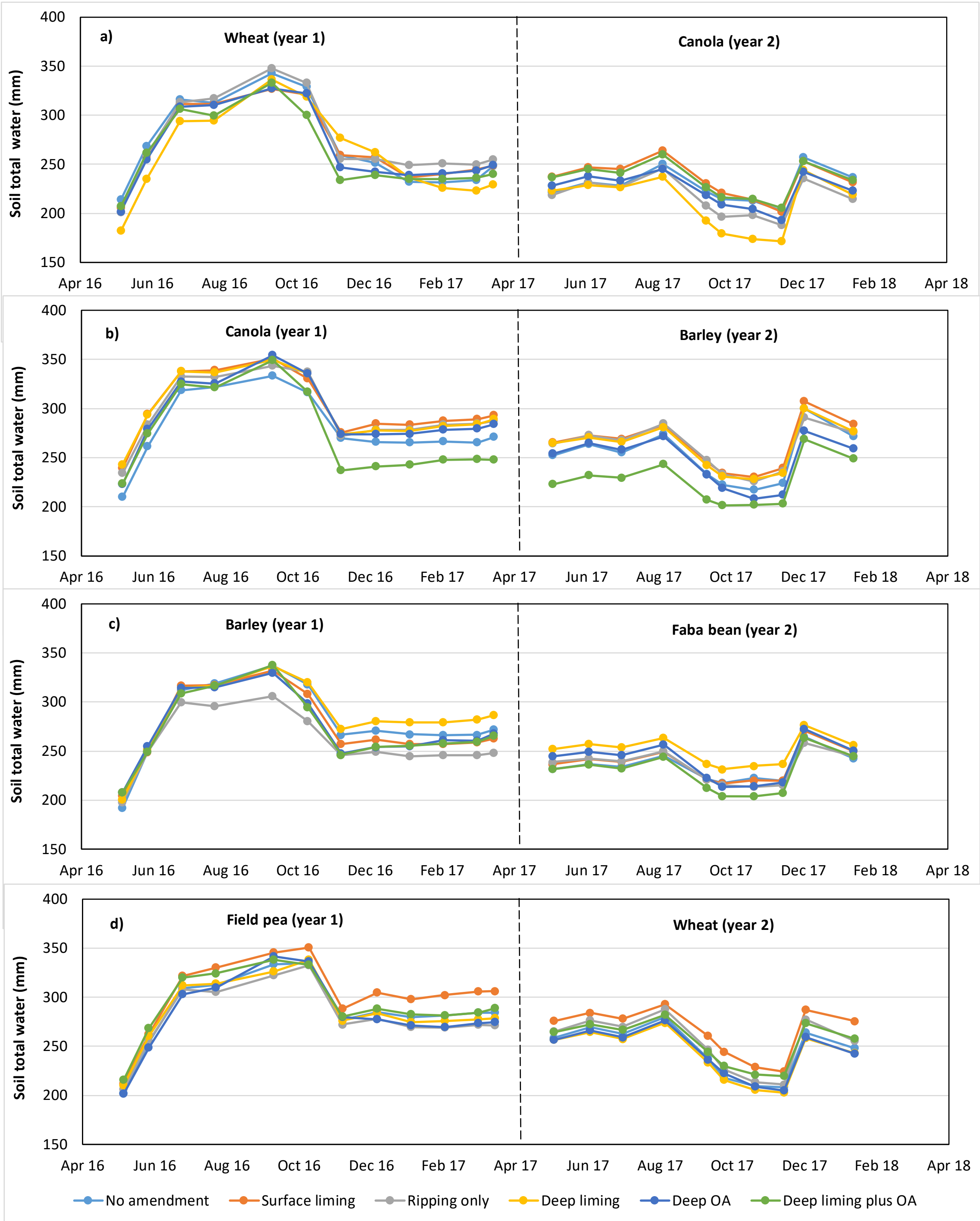


Figure 9. Soil water (mm) in the profile under different soil amendment treatments over two growing seasons (2016 and 2017) at the Cootamundra site

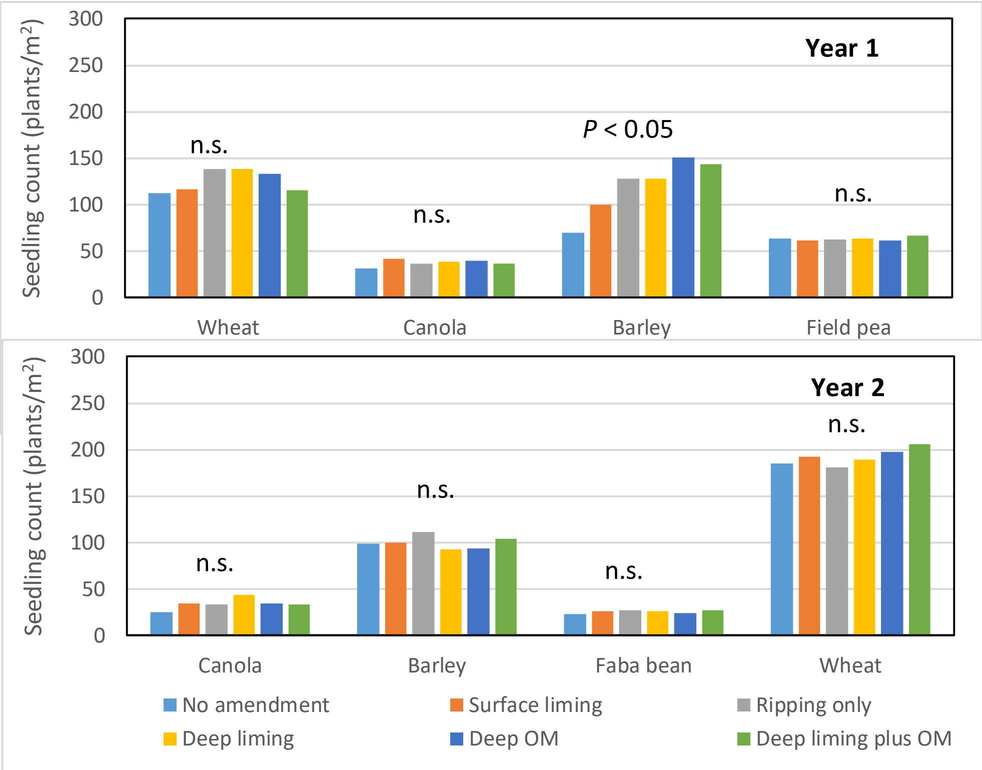


Figure 10. Seedling density (plants/m2) at crop establishment in response to different soil amendments in years 1–2 at the Cootamundra site. n.s., not significant

At anthesis, significant crop biomass responses were observed on wheat, barley and canola crops (Figure 11). The large crop biomass responses in year 1 under treatments with organic amendments applied were largely due to extra nutrients supplied by lucerne pellets (Figure 7). The dramatic crop biomass responses observed at anthesis on canola and barley crops did not translate into grain yield under treatments with lucerne pellets (Figure 12) due to severe lodging. In 2017, no significant difference was found for anthesis dry matter and grain yield between treatments for all crops (Figure 11). However, both deep OA and deep lime plus OA treatments tended to have a lower grain yield despite significantly higher mineral N at sowing (Figure 7). Lack of rainfall early in the growing season in 2017 (3.2 mm in September) and severe frost damage in late winter almost wiped out the canola and faba bean crops and severely suppressed the barley and wheat crops. The later growing season rainfall (53 mm and 70 mm in October and November, respectively) certainly boosted cereal crop grain yield (Figure 12).

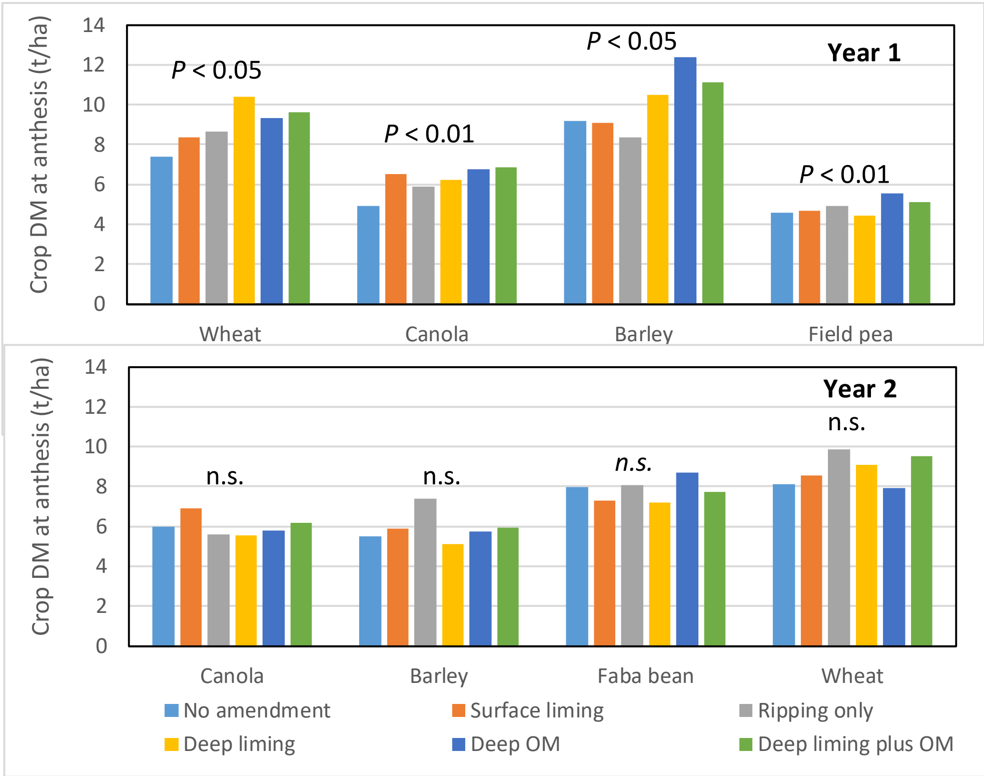


Figure 11. Crop dry matter at anthesis (t/ha) in response to different soil amendments in years 1–2 at the Cootamundra site. n.s., not significant.

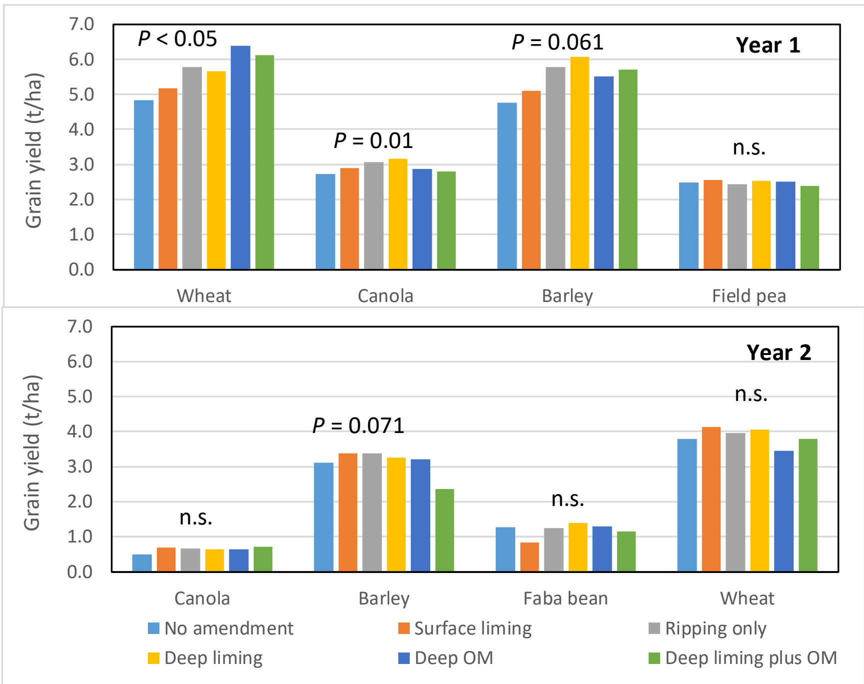


Figure 12. Grain yield (t/ha) in response to different soil amendments in years 1–2 at the Cootamundra site

Conclusion

Deep placement of organic amendments (lucerne pellets) did not increase soil pH as much as that measured in lab experiments, but it did reduce exchangeable Al% significantly at 10–20 cm and 20–30 cm depth, indicating that the organic amendment would relieve Al toxicity by combining Al^{3+} to form insoluble compounds, hence reducing toxicity to plant growth.

There were large crop yield response to deep organic amendment in year 1 due to extra nutrients supplied from the organic amendment, but no crop response was detected in year 2, partly due to a lack of soil moisture during the crop growing season. To date, soil treatments have had little effect on soil water.

Soil chemical, physical and biological properties will continue to be monitored to understand the soil–plant interactions, the factors driving the differences in crop response to the various treatments, and the residual value of the amendments over the long term.

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Abstract in the National Soil Science Conference Proceedings, Canberra 2018

Alleviation of subsurface acidity through addition of lucerne (*Medicago sativa* L.) pellets in combination with lime in the soil surface layer in the field conditions

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Keywords: Lucerne pellets amendment, subsoil acidity, combination of organic and inorganic amendments, surface amelioration

Introduction

Plant growth is negatively affected by soil acidity due to the toxicity of ion aluminium (Al^{3+}) and/or manganese (Mn^{2+}) and nutrients deficiency. The most successful strategy in agricultural practices to improve plant productivity in acidic soils is to apply alkaline amendments to increase its pH. It is relatively simple to increase surface soil pH by incorporating lime ($CaCO_3$) or dolomite [$CaMg(CO_3)_2$]. However, it is very difficult to alleviate subsurface soil (soil layer below 10 cm) acidity. The results from glasshouse experiments under controlled conditions has shown that organic matter (*e.g.* lucerne pellets) is able to increase soil pH not only where it was placed but also in the soil layers below its placement. However, application of fine ground (< 2 mm) lucerne pellets did not improve plant growth but actually had negative effects on growth. In a subsequent pot experiment, a number of lucerne pellet sizes (*i.e.* approximately 20 mm, 10 mm, 5 mm and 1-2 mm) were evaluated with or without incorporation of lime in the soil surface layer. Results showed that the lucerne pellet size of approximately 5 mm was proved to be the most suitable size to improve the plant growth and enhanced the movement of alkaline down to the soil profile. However, the increased in soil pH of the organic amended soil commenced to decline at 21 days after its incorporation in this pot experiment. This effect might be the result of net nitrification of organic nitrogen from organic materials. Interestingly, when lucerne pellets in combination with lime incorporated in the soil surface boosted the increase of soil pH at the layers below the placement layer. Therefore, it is hypothesed that incorporation of lucerne pellets with lime in the soil surface layer will have a long-term alleviating subsurface soil acidity and improving crop growth in the field.

Current experiment

In autumn 2018, a two-year field experiment was established at the Ferndale field site, Dirnaseer, west of Cootamundra, NSW, Australia (34°38'S, 147°49'E). The surface 5 cm soil layer was incorporated either with lime, lucerne pellets (~5 mm), lucerne pellets in combination with lime, or no addition (nil control) with four replicates (Figure). Two wheat cultivars Lancer (acid soil sensitive) and Gregory (acid soil resistant) were used as reference crops. The experiment was designed as a split-plot with genotypes as the main plots and amendments as the subplot. Lime and lucerne pellets were applied at 2.5 t/ha and 15.0 t/ha, respectively. Soil samples will be collected at 0-5, 5-10, 10-15, 15-20, 20-30 and 30-40 cm of the soil profile before incorporation, during plant growing and after harvest for analysing soil pH, exchangeable Al^{3+}. Ammonium and nitrate of the soil samples will be also analysed to identify the nitrification occurrence. Total root length, root area and root dry weight will be measured at each soil layer to compare the effects of treatments on root growth. Agronomic measurements will include seedling counts, anthesis biomass, and grain yield for both sensitive and resistant wheat cultivars. The experiment was sown on 9th May 2018 and the data will be collected as per experimental protocol and the experiment will be continued in 2019.

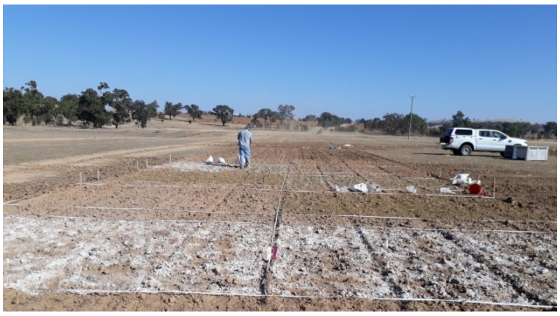

Figure 1 Incorporation of amendments into 5 cm of the soil profile

Photo: "Ferndale" subsoil acidity trial. Source: Dr Jason Condon

Photo: Subsoil amelioration. Source: Dr Guangdi Li

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