Final Technical Report

AGC00006 – Improving N fixation in Lentils

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Abstract

Lentils are a relatively new crop grown in the western cropping area of NSW, with growers and agronomists still learning how to best manage them. Unlike other pulses commonly grown in the area, lentils have had issues with nodulation on acid soils. Successful inoculation of lentils is crucial, not only for the performance of the lentil crop but also for the following cereal crop in the rotation.

In 2017 and 2018, trials were conducted in Southern NSW to investigate new and commonly used inoculants, rates, and management techniques. These included acid tolerant rhizobia strains, forms of inoculant, and the use of ameliorants such as lime, all with the aim of improving nitrogen fixation through enhanced nodulation of lentils.

Dry seasonal conditions impacted results in both years. Positive differences were observed early for biomass and nodulation, for the new acid tolerant peat inoculant strains of rhizobia over the current recommended strain of rhizobia. However, given the season, this did not produce a yield response.

Having a suitable acid tolerant strain of rhizobia for lentils, in conjunction with management practices that enhance nodulation, will enable lentils to reliably establish on acid soils. Levels of inoculation will increase and therefore so too will nitrogen fixing capabilities, which in more favourable seasons should translate into yield.

Executive Summary

Legumes are a key part of the western cropping system of SNSW, providing a rotational break option from cereal crops. They may be used for pest/disease management, as well as for an additional source of Nitrogen (N) within the system. The main pulse crops grown in the area include lupins, field peas, vetch, and more recently, lentils. As lentils are a relatively new crop grown in the area, both growers and agronomists are still learning how to best grow them, particularly on acid soils. There have been issues with lentil nodulation on acid soils, with lentils the most effected of all the pulses grown in the area. This has impacts, not only for the lentil crop, but also for the following crop in the rotation. Gaining a better understanding of how they best nodulate, and whether management practices contribute to their success, would encourage further expansion of lentils in the area.

In 2017 and 2018 trials were conducted in Southern NSW to investigate new and commonly used inoculants and rates as well as management techniques, including acid tolerant rhizobia strains, forms of inoculant and the use of ameliorants such as lime, all of which aim to improve nitrogen fixation through enhanced nodulation in lentils. In both seasons the trials were conducted on the Ag Grow Agronomy research farm 'Ridge Top' near Beelbangera, 16km NE of Griffith in southern New South Wales (SNSW). In 2018, the trial was conducted at an additional site further east of Griffith, at Hart Bros Seeds (HBS) Junee.

In both years the trial were conducted, growing season rainfall was well below average, with 2017 also experiencing prolific frosts in August, and 2018 experiencing significant drought conditions. Rain occurred too late in both seasons to benefit the crops, which had already senesced. This had an impact on the final results of the trial, with seasonal conditions preventing translation of any differences measured early, for either biomass or nodulation, into grain yield. This also made it difficult to determine any treatment effects.

At Beelbangera, in 2017, there were no significant differences between treatments for biomass, although there were significant differences for nodulation and grain yield. Given the season and the variability of the trial caution was taken in drawing conclusions from a single trial in 2017. In 2018 the only significant difference at the site was for nodule number, however this did not translate into yield, presumably due to the season. At Junee in 2018, significant differences were observed between treatments, although it is likely that the paddock chosen for the trial had a background population of rhizobia, as it was difficult to interpret any trends in the data.

Using an acid tolerant strain of rhizobia, particularly at Beelbangera given the acidity of the site (4.9 $CaCl_2$), has potential benefits to enhance nodulation in lentils and therefore improve nitrogen fixation. At Beelbangera, although not significant due to the variability of the trial, positive differences were observed for the new acid tolerant peat inoculant strains of rhizobia (SRDI954, SRDI969 and WSM4643) trialled at the site, compared to the current recommended strain of rhizobia early in the season in some reps. This was particularly evident with the acid tolerant strain SRDI969, producing the highest number of nodules at Beelbangera in 2018, although given the season did not produce a yield response. The treatment effects at Junee were masked by the less acidic topsoil and the potential background rhizobia levels.

The positive connections, identified by Ross Ballard in previous years, between acid tolerant strains of rhizobia and plant health, growth and nodulation of lentils on acid soils, paves the way for lentils to become an integral part of our cropping rotations, with implications to further this research for the benefit of the farming community.

Having a suitable acid tolerant strain of rhizobia for lentils, in conjunction with management practices that enhance nodulation, will enable lentils to reliably establish on acid soils with good levels of nodulation and therefore nitrogen fixing capabilities, which in more favourable seasons should translocate into yield.

Contents

Background

Lentils are becoming an integral part of the rotation in the western cropping region of SNSW. Growers and agronomists in the region are still learning the best way to grow and manage them, particularly given they have had issues with nodulation in the past on the more challenging soils. One of the main soil constraints is acidity, which can impact on the success of nodulation and the performance of the lentil crop.

Previous research, conducted by Ross Ballard and Dr Liz Farquharson from SARDI and Dr Ron Yates from DPIRD WA, tested strains of rhizobia suited to acid soils on faba beans and field peas. As lentils are nodulated with the same strains of rhizobia, the same responses were expected. This work identified the most relevant strains of acid tolerant rhizobia to progress into field work. It also showed the effect that acid soils have on nodulation and the potential benefits of using an acid tolerant strain of rhizobia, in conjunction with management practices, to enhance nodulation and crop performance.

This research was put into practice by Ag Grow Agronomy and Research over the 2017 and 2018 seasons. Trials were conducted investigating management techniques, such as acid tolerant rhizobia strains (using the appropriate acid tolerant strains identified by Ross Ballard), forms of inoculant (Peat v Granular) and ameliorants (lime rates and placement) to improve nodulation, and therefore yield, of lentils.

Project objectives

The aim of the trial was to investigate new and commonly used inoculants and rates as well as management techniques that improve nitrogen fixation through enhanced nodulation in lentils.

The objectives of the trial were to:

- assess new acid tolerant peat inoculant strains of rhizobia suitable for lentils
- assess management practices that enhance nodulation of lentils on acid soil
- make specific inoculant recommendations for growing lentils on acid soil

Methodology

Two trials were established in 2018. The first trial was established on the Ag Grow Agronomy research farm 'Ridge Top' near Beelbangera, 16km NE of Griffith in southern New South Wales. The paddock chosen for the trial had a low level of soil nitrogen, with total N (0-60cm) of 76kg N/ha; an acid pH of 4.9 ($CaCl_2$) with Aluminium base saturation of 2.9% and a P level in the top 10cm of 31ppm (Colwell P). The second trial was established further east at Hart Bros Seeds, Junee. This site was selected under the guidance of the Junee 'Lentil grower group' committee and had a pH ($CaCl_2$) of 5.9 at 0-10cm and a pH of 4.5 ($CaCl_2$) at 10-20cm, a Colwell P level of 36ppm and relatively low soil nitrogen. This site had 1.2 t/ha lime applied before sowing (no incorporation), however this was done after soil testing.

The trials were sown with a Morris Contour Drill plot seeder with 25cm row spacings x 7 rows and replicated three times. Plots were 33m x 1.75m (57.75m^2). They were statistically designed as a randomised block by Peter Martin from Howqua Consulting.

The variety used for the trial at Beelbangera was Ace, and the variety used at Junee was PBA Hallmark. The trials were sown on the 8th May at Beelbangera, figure 1, and 15th May at Junee. Both trials were sown at 40 kg/ha with 80 kg/ha MAP. Appropriate pest and weed control was undertaken pre-emergence, and again in crop. Both trials were desiccated with 1.2L/ha Reglone and 0.8L/ha Gramoxone 250 before harvest and harvested on 4th December and 17th November respectively.

Treatments

Treatments at Junee vary from the Beelbangera site as they cater for the Junee Lentil growers group needs. There were 16 treatments for the Beelbangera trial and 12 treatments for the Junee trial, table 1. Treatments, including the various strains and forms of rhizobia, were applied to the lentils the day before sowing, with specific attention to not contaminate inoculant between treatments. At the Beelbangera site lime incorporated treatments were also applied before sowing.

Table 1: Treatment List of the Beelbangera and Junee lentil inoculation trials, 2018

	Beelbangera	Junee
1.	Nil	Nil
2.	Peat inoculant at 5kg/t	Peat inoculant at 5kg/t
3.	Peat inoculant at 10kg/t	Peat inoculant at 10kg/t
4.	Granular Legume Inoculant 10kg/ha with fertiliser	Granular Legume Inoculant 10kg/ha with fertiliser
5.	Peat inoculant at 5kg/t + Granular Legume Inoculant 10kg/ha	Peat inoculant at 5kg/t + Granular Legume Inoculant 10kg/ha
6.	Peat inoculant 5kg liquid inject	Peat inoculant 5kg liquid inject
7.	Peat inoculant at 5kg/t + inoculant food	Peat inoculant at 5kg/t + inoculant food
8.	Peat inoculant at 10kg/t + inoculant food	Peat inoculant at 10kg/t + inoculant food
9.	Peat inoculant at 5kg/t + liquid lime	Peat inoculant at 5kg/t + liquid lime
10.	Acid tolerant 1 - SRDI954	Acid tolerant 1 - SRDI954
11.	Acid tolerant 2 - SRDI969	Acid tolerant 2 - SRDI969
12.	Acid tolerant 3 - WSM4643	Acid tolerant 3 - WSM4643
13.	1t/ha lime IBS + Peat inoculant at 5kg/t	
14.	3t/ha lime IBS + Peat inoculant at 5kg/t	
15.	1t/ha lime incorporated + Peat inoculant at 5kg/t	
16.	3t/ha lime incorporated + Peat inoculant at 5kg/t	

Note: *Inoculant food in this trial refers to pulse seed coat product Foundation, by Lovelands, which contained zinc, manganese, molybdenum and Seasol with <1% microorganisms.*

The Granular Legume Inoculant used in this trial was the BASF product Nodulator, a clay-based granular inoculant specific for Group E & F.

The liquid lime used in the trial was a Soil Solution Product PH-PLUS, a liquid suspension of technical grade calcium carbonate.

The acid tolerant peat inoculant strains of rhizobia used in the trial, strains SRDI954, SRDI969 and WSM4643 were provided by Ross Ballard, SARDI.

Figure 1: Sowing of the Beelbangera Trial, May 2018. Lime treatments to be IBS .

Assessments **-** Ag Grow Agronomy Liaised with Nikki Seymour (DAF) in 2017 in relation to assessments to be carried out on the trial. The same assessments were carried out on the trials in 2018 including:

1. An establishment score on individual plots - Establishment was scored from 0 to 9, with 0 being very poorly established and uneven and 9 being very evenly established.
2. NDVI at flowering - Crop vigour was measured at flowering using a hand held NDVI
3. Nodulation assessment at early flowering – Nodulation was assessed by digging up plants and washing off the soil and rinsing the roots, nodules were then counted.
4. Grain yield from small plot header.
5. Yield data analysed by biometrician - Peter Martin, Howqua Consulting.

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 "Ridgetop" Beelbangera	-34.187752	146.082443
Nearest Town	Griffith, NSW 2680	
Trial Site #2 HBS, Junee	-34.697659	147.482147
Nearest Town	Junee, NSW 2663	

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	
Improving N fixation in Lentils	Northern Region Southern Region	☐ 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 ☒ SNSW ☐ Vic High Rainfall ☐ SA Vic Mallee ☐ SA Vic Bordertown-Wimmera ☐ WA Central ☐ WA Sandplain

Results

Seasonal conditions:

The trials were conducted at Beelbangera, and Junee in the 2018 growing season. In 2018 Drought conditions were experienced, with the season characterised by high temperatures and low rainfall. Growing season rainfall (GSR), from 1st April to 31st October, at Beelbangera was well below average with 124mm falling in 2018, compared to the long term average of 238mm (table 1).

The Junee trial, although a higher rainfall zone, also experienced below average rainfall in 2018 with a total of 300 mm falling for the year and 148mm falling in the growing season (1st April to 31st October).

Table 1: Monthly Rainfall (mm) - Griffith Airport and Junee Breffni, 2018 compared to the long-term average.

MONTH	*Rainfall Data - Griffith Airport*		*Rainfall Data -Junee Breffni*	
	2018	**Long Term Average (1958-2018)**	**2018**	**Long Term Average (1968-2018)**
January	17.6	*33.7*	56	*44.1*
Februray	2.2	*28.5*	9.2	*39.5*
March	2.6	*35.2*	5	*35.8*
April	0.4	*27.1*	5.2	*37.6*
May	19	*35.1*	21.9	*38.5*
June	33	*35.3*	45	*40.4*
July	8.2	*33.5*	10.8	*49.4*
August	6.4	*35.2*	20	*41.7*
September	8	*33*	24.8	*48.2*
October	48.8	*38.5*	20.3	*44.4*
November	52.8	*34*	73.4	*44*
December	21.8	*33.7*	7.6	*42.3*
TOTAL	220.8	*397.6*	299.2	*505.9*

note: highlighted area represents the GSR from 1st April to 31st October.

Establishment:

Establishment was assessed on the 27th June, 2018 at Beelbangera when the lentils were at 1 to 5 nodes and on the 26th June, 2018 at Junee when the lentils were at 4 nodes. Both trials established well, with scores ranging from 7.5 to 8.5 at Beelbangera and a score of 9 for all treatments at Junee. Crop vigour was also assessed at establishment, this was a visual assessment of crop effects such as colour and overall plant health. There were no treatment differences at Junee, but at Beelbangera the treatments which included incorporating lime before sowing, the 1t/ha lime incorporated + Peat inoculant at 5kg/t; and the 3t/ha lime incorporated + Peat inoculant at 5kg/t treatment, were slightly reduced, figure 2. Although not significant, this shows the negative impact that cultivation before sowing had on establishment and early vigour in 2018.

Figure 2: Establishment of Nil (left) and 3t/ha lime incorporated + Peat inoculant at 5kg/t (right) at Beelbangera, 27th June 2018.

NDVI at Flowering:

Measurements were taken on 4th September 2018 at Beelbangera and 23rd August, 2018 at Junee. At Beelbangera, there were no significant differences for NDVI, with NDVI values ranging from 0.21 for the 1t/ha lime incorporated + Peat inoculant at 5kg/t treatment to 0.26 for the Peat inoculant at 5kg/t treatment. At Junee there were also no significant differences for NDVI, with NDVI values ranging from 0.30 for the Peat inoculant at 10kg/t + inoculant food treatment to 0.37 for the Acid tolerant 1 - SRDI954 treatment.

Nodulation number:

At Beelbangera nodulation assessments were carried out on 6th September 2018 at flowering.

The only significant difference was for nodule number, with the nil treatment having zero nodules and significantly lower than 6 of the inoculant treatments. There were not a lot of nodules observed in this trial and nodules were mostly found below the crown and at depth. The Acid tolerant 2 - SRDI969 treatment had a significantly higher nodule number than all but two of the other treatments, with a nodule count of 10, figure 3.

Figure 3: Nodulation of Nil (left) and Acid tolerant 2 – SRDI 969 (right) at Beelbangera, 6th September, 2018.

At Junee nodulation assessments were carried out on 23rd August, 2018 at flowering. This trial had good nodulation across all treatments, with some treatments having evenly distributed nodules throughout the root and others having nodules concentrated in crown area, with not a lot a depth. The Peat inoculant at 10kg/t + inoculant food treatment had the lowest number of nodules with 37, whilst the Nil treatment had the highest number of nodules with 70, which was significantly higher than half of the treatments in the trial, figure 4.

Figure 4: Nodulation of Peat inoculant at 10kg/t + inoculant food (left) and Nil (right) at Junee, 23rd August, 2018.

Plant Height and Root Length:

At Beelbangera plant height and root length assessments were carried out on 6th September 2018 at flowering. There were no significant differences at Beelbangera for plant height or root length, with the average plant height 21.2cm and the average root length 17.4cm.

At Junee plant height and root length assessments were carried out on 23rd August, 2018 at flowering. Significant differences were found for plant height, root length and nodule number. The Peat inoculant at 5kg/t + liquid lime treatment had the highest plant height of 21cm, whilst the Peat inoculant at 5kg/t treatment had the shortest plant height of 18.4cm. For root length the Peat inoculant at 5kg/t + Granular Legume Inoculant 10kg/ha treatment had the longest root length of 20.6cm, which was significantly higher than the shortest root length of 17.8cm for the Peat inoculant at 10kg/t + inoculant food treatment.

Grain Yield:

The trials were harvested on 17th November, 2018 at Junee and 4th December, 2018 at Beelbangera

There were no significant differences between treatments for grain yield at Beelbangera, given the season. The average grain yield of the trial was 289 kg/ha, with yields ranging from 151 kg/ha for 3t/ha lime incorporated + peat inoculant @ 5kg/t to 348 kg/ha for Peat inoculant 5kg liquid inject.

Junee had a much higher average grain yield of 969 kg/ha, with the Granular Legume Inoculant 10kg/ha with fertilser the highest yielding treatment, with 1063 kg/ha which was statistically higher than half of the other treatments in the trial. The Peat inoculant at 5kg/t + liquid lime treatment was the lowest yielding treatment, yielding 878 kg/ha. In this trial no significant trends in the data were observed to explain the differences in yield observed between the treatments applied.

Table 2: Beelbangera statistically analysed data for NDVI, plant height, root length, nodulation and yield.

TREATMENT		NDVI Flowering	Plant Height (cm)	Root Length (cm)	Nodule Number	Grain Yield (kg/ha)
Trt1	Nil	0.25	20.0	16.5	0	328
Trt2	Peat inoculant at 5kg/t	0.26	19.4	18.2	2	322
Trt3	Peat inoculant at 10kg/t	0.24	21.8	18.1	7	311
Trt4	Granular Legume Inoculant 10kg/ha with fert	0.25	23.7	18.0	3	336
Trt5	Peat inoculant at 5kg/t + Granular Legume Inoculant 10kg/ha	0.24	20.7	17.2	4	294
Trt6	Peat inoculant 5kg liquid inject	0.25	23.9	17.2	3	348
Trt7	1t/ha lime IBS + Peat inoculant at 5kg/t	0.23	22.5	17.6	8	244
Trt8	3t/ha lime IBS + Peat inoculant at 5kg/t	0.24	20.9	17.4	8	296
Trt9	1t/ha lime incorporated + Peat inoculant at 5kg/t	0.21	20.0	18.7	6	201
Trt10	3t/ha lime incorporated + Peat inoculant at 5kg/t	0.22	19.6	15.6	5	151
Trt11	Peat inoculant at 5kg/t + inoculant food	0.22	21.1	19.3	10	286
Trt12	Peat inoculant at 10kg/t + inoculant food	0.25	20.8	17.9	6	316
Trt13	Peat inoculant at 5kg/t + liquid lime	0.22	20.8	15.4	6	271
Trt14	Acid tolerant 1 - SRDI954	0.25	21.1	17.4	5	329
Trt15	Acid tolerant 2 - SRDI969	0.23	22.7	16.5	15	301
Trt16	Acid tolerant 3 - WSM4643	0.24	19.9	17.8	10	291
	mean	***0.24***	***21.2***	***17.4***	***6***	***289***
	lsd (p=0.05)	***ns***	***ns***	***ns***	***6.9***	***ns***

Table 3: Junee statistically analysed data for NDVI, plant height, root length, nodulation and yield.

TREATMENT		NDVI Flowering	Plant Height (cm)	Root Length (cm)	Nodule Number	Grain Yield (kg/ha)
Trt1	Nil	0.34	20.7	18.5	70	948
Trt2	Peat inoculant at 5kg/t	0.35	18.4	19.3	60	911
Trt3	Peat inoculant at 10kg/t	0.36	19.8	20.3	68	1010
Trt4	Granular Legume Inoculant 10kg/ha with fert	0.35	19.8	19.1	62	1063
Trt5	Peat inoculant at 5kg/t + Granular Legume Inoculant 10kg/ha	0.34	20.6	20.6	59	1014
Trt6	Peat inoculant 5kg liquid inject	0.32	20.4	19.5	59	1006
Trt7	Peat inoculant at 5kg/t + inoculant food	0.31	20.1	18.2	41	1025
Trt8	Peat inoculant at 10kg/t + inoculant food	0.30	19.1	17.8	37	918
Trt9	Peat inoculant at 5kg/t + liquid lime	0.34	21.0	19.2	61	878
Trt10	Acid tolerant 1 - SRDI954	0.37	19.5	19.2	44	910
Trt11	Acid tolerant 2 - SRDI969	0.36	19.4	18.3	45	983
Trt12	Acid tolerant 3 - WSM4643	0.34	20.0	18.2	41	958
	mean	***0.34***	***19.9***	***19.0***	***54***	***969***
	lsd (p=0.05)	***0.05***	***0.95***	***2.57***	***19***	***103.2***

Discussion of Results

Results in 2018 trial results were affected by the dry seasonal conditions, with growing season rainfall well below the long-term average at both the Beelbangera and Junee trial sites.

The Beelbangera site had no significant differences for NDVI and grain yield. Responses in nodulation number were measured at Beelbangera, but seasonal conditions prevented its translation into biomass measured in plant height and rooting depth and grain yield.

At Junee, although there were significant differences between treatments, it is likely that the paddock chosen for the trial had a background population of rhizobia, as it was difficult to interpret any trends. The nil treatment at Junee had the highest number of nodules and yield was above the trial average. The paddock had a previous history of field peas, with field peas grown in 2011, which the commercial strain used may have carried through to the current season. The pH in the top 10cm at Junee was 5.9 ($CaCl_2$), was also less acidic than Beelbangera, and more favourable for current rhizobia strains.

Conclusion

Using an acid tolerant strain of rhizobia, particularly at Beelbangera given the acidity of the site (4.9 $CaCl_2$), has potential benefits to enhance nodulation in lentils and therefore improve nitrogen fixation.

Like 2017, in 2018 the new acid tolerant peat inoculant strains of rhizobia visually appeared to have higher biomass over the current recommended strain of rhizobia early in the season, but due to the variability within the reps of the trials they were not significantly different.

At Beelbangera in 2018, the significance in nodulation was not able to translate into yield. In particular, the acid tolerant strain SRDI969 produced a significantly higher nodule number than most other treatments but did not produce a yield response. This was most likely due to the below average growing season rainfall experienced.

These results are different to what has been observed across a range of trials in other seasons, conducted by Ross Ballard. In these trials, when acid tolerant strains were evaluated alongside commercially available strains of rhizobia, increased nodulation produced a yield response.

At Junee, the pH in the top 10cm was not as acidic as Beelbangera, and coupled with the potential background rhizobia levels, made it difficult to determine any trends in the data.

Lime is still being recommended, even with the development of acid tolerant strains of rhizobia, to raise pH above 5.0 ($CaCl_2$). The use of lime, in conjunction with suitable acid tolerant strains of rhizobia, has the potential to improve nodulation and therefore nitrogen fixation in lentils, further benefiting other crops in the rotation.

Implications

The observations made throughout the trial, over the 2017 and 2018 seasons, have implications to further this research for the benefit of the farming community. The positive connections between acid tolerant strains and plant health, growth and nodulation of lentils on acid soils paves the way for lentils to become an integral part of our cropping rotations.

Having a suitable acid tolerant strain of rhizobia for lentils, in conjunction with management practices that enhance nodulation and rooting depth will enable lentils to reliably establish and grow on acid soils with good levels of nodulation and therefore nitrogen fixing capabilities, which in more favourable seasons should translocate into yield.

Recommendations

The two seasons the trials were conducted were not favourable, with frost and drought like conditions experienced. These conditions were likely responsible for the lack of statistical differences seen in the trials, particularly at Beelbangera. At Junee, the history of pulses in combination with the less acidic pH made it difficult to interpret the results, with the nil treatment performing just as well.

Although it is hard to draw conclusions from the trials due to the variability, the visual differences observed early in the season in some reps, and the nodulation of the lentils with the acid tolerant strains show the potential of some of the treatments to enhance nodulation in lentils, and therefore improve nitrogen fixation.

In order to improve the validity of the data, and also recommendations of using an acid tolerant rhizobia strain as part of management practices when growing pulses on an acid soil, more research needs to be undertaken. Conducting the trials over multiple seasons, and sites, would ensure the risks are spread and capture data over a range of seasons.

When choosing a site, it is important to ensure it is rhizobia free, so background levels of rhizobia do not impact on the results. Conducting a pre-season assessment, to check if the soil has a background level of rhizobia, is important for future site selection.

Appendix A.
Scoring system used for the classification of nodules, adapted from Corbin, Brockwell and Gault (1977)

Classification of Nodules:

Nodule Score	Distribution and Number of Nodules	
	0-5cm of root	>5cm root
0	0	0
0.5	0	1-4
1	0	5-9
1.5	0	>10
2	Few	0
2.5	Few	Few
2.75	Few	Many
3	Many	0
4	Many	Few
5	Many	Many

Nodules were counted on 6 plants per plot and nodulation was given a score.

Note: A score of 2.75 was added to the original scoring system to cover plants with few nodules in the crown and many greater than 5cm.

- Many > 10 nodules
- 0-5cm of root is crown
- > 5cm root is elsewhere

Glossary and Acronyms

Below is a sample Abbreviations and Acronyms list.

DAF	Department of Agriculture and Fisheries
GSR	Growing Season Rainfall
IBS	Incorporated by Sowing
N	Nitrogen
NDVI	Normalised Vegetation Index
NE	North East
MAP	Mono-Ammonium Phosphate
P	Phosphorous
SARDI	South Australian Research and Development Institute

References

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

Nicole Baxter (2017). New rhizobia tested in the south. GroundCover™ Issue: 127 Mar - Apr 2017. Ross Ballard, Dr Liz Farquharson and Ron Yates.

Elizabeth Drew, David Herridge, Ross Ballard, Graham O'Hara, Rosalind Deaker, Matthew Denton, Ron Yates, Greg Gemell, Elizabeth Hartley, Lori Phillips, Nikki Seymour, John Howieson and Neil Ballard (1994). Inoculating Legumes: A Practical Guide. GRDC Booklet.