Part 1 - Summary Details

Please use your TAB key to complete Parts 1 & 2.

CRDC Project Number: CSP1705

Project Title: ACRI Field 6 'Rochester' Trial Site Maintenance

Project Commencement Date: 1/7/2016  Project Completion Date: 30/6/2017

Part 2 – Contact Details

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Part 3 – Final Report

(The points below are to be used as a guideline when completing your final report.)

Executive Summary

The impact of legumes after 21 years of rotation (11 legume crops) continue to positively impact soil health. The addition of a legume in a cotton rotation impacts all aspects of the cotton production. The evidence was clear from the soil N status and plant accumulation of N (nitrogen use efficiency (NUE), Carbon:Nitrogen (C:N) ratio and Apparent Nitrogen Fertiliser Recovery (ANFR)), yield, fibre quality to seed nitrogen and protein content. The most significant benefit of including a legume was evident when a legume followed a summer and winter fallow before the next cotton crop was sown (CV~C and CF~C). The long fallow allowed for the legume crop to reach optimum biomass production and time for the fixed atmospheric N to be mineralised and available for the following cotton crop. The addition of wheat into the cotton rotation also had a positive impact when compared to the continuous-cotton rotation. The impact from adding wheat was not as beneficial as a legume, however there were benefits by adding wheat into the cotton system.

The 2016/17 season was the first time a Bollgard® 3 variety had been sown in the long term trial. The new variety responded to high rates of N and positively to the legume rotations. The fitted curves for N rates and N uptake revealed a positive linear relationship for the new Bollgard® 3 variety for the cotton-vetch-summer and winter fallow-cotton rotation. This is something to investigate for Bollgard® 3 response under a legume rotation. Under the continuous cotton rotation, the optimum N rate was calculated as 407 kg N/ha, however only yielding 12 bales/ha. In comparison the CV~C rotation only required 147 kg N/ha to achieve a much higher 14 bales/ha. The new variety responded positively to both vetch and faba bean in rotation and continued to follow the trend to the previously sown Bollgard® II varieties.

The project has provided several opportunities for Dr Tim Weaver. The first is the value in understanding the role of N in cotton based farming systems that have been developed by Dr Ian
Rochester. The project has allowed Dr Weaver time to become established in the new role and plan for the future of Field 6 and the new initiative to exploit the genetic, environment and management of cotton farming systems. The resulting rotations that will be maintained in Field 6 east and west for the future research are listed below.

<table>
<thead>
<tr>
<th>Old Rotation</th>
<th>New Rotation</th>
<th>Summer 2017/18</th>
<th>Winter 2018</th>
<th>Summer 2018/19</th>
<th>Winter 2019</th>
</tr>
</thead>
<tbody>
<tr>
<td><del>C</del>C</td>
<td><del>C</del>C</td>
<td>Cotton</td>
<td>Cotton</td>
<td>Cotton</td>
<td>Fallow</td>
</tr>
<tr>
<td>VCVC</td>
<td>CWc</td>
<td>Cotton</td>
<td>Wheat</td>
<td>Cotton</td>
<td>Wheat</td>
</tr>
<tr>
<td>W~C</td>
<td>W~C</td>
<td>Cotton</td>
<td>Cotton</td>
<td>Wheat</td>
<td>Wheat</td>
</tr>
<tr>
<td>W~VC</td>
<td>W~C</td>
<td>Cotton</td>
<td>Cotton</td>
<td>Wheat</td>
<td>Wheat</td>
</tr>
<tr>
<td>Fb~C</td>
<td>Fb~C</td>
<td>Cotton</td>
<td>Cotton</td>
<td>Faba bean</td>
<td>Cotton</td>
</tr>
<tr>
<td>V~C</td>
<td>W~C</td>
<td>Cotton</td>
<td>Wheat</td>
<td>Cotton</td>
<td>Wheat</td>
</tr>
</tbody>
</table>

- denotes fallow period

The project has also led to developing collaborative links with several researchers within CSIRO - Dr Ben Macdonald and Dr Mark Farrell and with exterior organisations such as the University of New England - Dr Oliver Knox, The University of Western Sydney – Dr Brajesh Singh and a start-up company - FluroSAT. These opportunities will value add to this project studying in greater depth the mineralisation of N under different crop rotations, the use of biologicals for improved nutrient uptake and the calibration of sensors for the estimation of crop N/nutrient status.

Dr Ian Rochester had commenced working on the effects of long term rotations on lint yield and quality (HVI). The data collected from this project will add to this research and hopefully assist with developing better management strategies that maintain high fibre quality. The final opportunity that this project has provided is an independent assessment of “Rocky’s” long term trial results under a new Bollgard® 3 variety. The Bollgard® 3 variety performed with the same outcome when compared to the findings of Dr Ian Rochester research under the Bollgard® II varieties. The rotations that included a legume followed by a long fallow continued to be the highest yielding system.

**Background**

1. Outline the background to the project.

The long term rotation experiment at ACRI, established by the late Dr Ian Rochester in 1994, has assisted with the understanding of soil and plant nutrition interactions. It has been a pivotal site in developing the industry crop nutrition requirements (especially N) but has evolved over the years to include the following research initiatives and outcomes:

- Advancing the understanding of legumes and their role in cotton crop systems.
- The role of stubble management in soil fertility.
- Improving the understanding of fertilisers (the role of timing, application and type) in increasing cotton productivity.

In recent times the site has also been important to the following research initiatives

- The dynamics of soil carbon in various rotation systems. (Data published from 1998 to 2008 reported the only increase in soil carbon under a cotton farming system in Australia).
- Greenhouse gas emissions from various cotton rotations and N application practices.
- Increasing attention on soil microbiology because of the sites high fertility.
- The response of cotton genotypes to various fertility regimes.

Since the passing of Dr Rochester the site has been maintained as per the experimental plan as part of the previous CRDC funded project CSP1403. Dr Michael Bange, Mrs Sandra Williams and Mrs Kellie Gordon have been managing the site. Dr Tim Weaver was appointed in May 2017 and will continue the long term rotations with the initiative to exploit the genetic, environment and management strategies to improve yield.
Objectives

2. List the project objectives (from the application) and the extent to which these have been achieved.

The site is to be persevered for future research because of its unique fertility, unique treatments and long term nature. While the focus of the research at the site will change, the major treatments in place are foundational to ongoing research into soil health, greenhouse gas research and crop nutrition. It is proposed that while plans are developed around the site in terms of research that the industry look to preserve the main rotation treatments and continue to undertake baseline sampling of key measure of soil fertility and crop performance.

Methods

3. Detail the methodology and justify the methodology used. Include any discoveries in methods that may benefit other related projects.

The main rotation treatments for Field 6 west are list below in Table 1 and they are repeated twice offset by one year. Each rotation treatment is replicated 4 times.

<table>
<thead>
<tr>
<th>System</th>
<th>Winter</th>
<th>Summer</th>
<th>Winter</th>
<th>Summer</th>
</tr>
</thead>
<tbody>
<tr>
<td><del>C</del>C</td>
<td>~</td>
<td>Cotton</td>
<td>~</td>
<td>Cotton</td>
</tr>
<tr>
<td>VCVC</td>
<td>Vetch</td>
<td>Cotton</td>
<td>Vetch</td>
<td>Cotton</td>
</tr>
<tr>
<td>W~C</td>
<td>Wheat</td>
<td>~</td>
<td>~</td>
<td>Cotton</td>
</tr>
<tr>
<td>W~VC</td>
<td>Wheat</td>
<td>~</td>
<td>Vetch</td>
<td>Cotton</td>
</tr>
<tr>
<td>Fb~C</td>
<td>Faba bean</td>
<td>~</td>
<td>~</td>
<td>Cotton</td>
</tr>
<tr>
<td>V~C</td>
<td>Vetch</td>
<td>~</td>
<td>~</td>
<td>Cotton</td>
</tr>
</tbody>
</table>

Soil and Plant Analysis

The nitrogen treatments (0, 120, 280 and 360 kg N/ha) were applied in late September 2016 and the CSD cotton variety Sicot 746B3F was dry sown on the 19th October 2016 and watered up. The crop received 7 irrigations and was picked on the 9th June 2017. On the 21st June PBA Warda Faba bean was sown and on the 22 June EGA Gregory wheat was sown to follow the normal winter rotations for 2017. Soil samples (depths: 0-30 cm, 30-60 and 60-90 cm) were collected in late September 2016 from each rotation outside of the main plot experiment (eliminating varying N effect) and analysed for pH_{CaCl_2}, electrical conductivity (EC_{1:5}), Total Kjeldahl Nitrogen (TKN%), nitrate-N and soil organic carbon (SOC%) as well as bulk density calculated. Leaf and petiole samples were collected on the 4th January (1018 day degrees) and 16th January 2017 (1251 day degrees). The leaf samples were analysed for TKN% only and the petiole samples were analysed for TKN% and nitrate-N. Dr Ian Rochester has collected readings from the same leaf samples using a Minolta Chlorophyll meter (SPAD-502) in previous seasons. Measurements were also collected from the 2016/17 season samples to add to the SPAD data set. Dry matter cuts were taken at maturity and the samples analysed for TKN% and nitrate-N allowing for the calculation of NUE, apparent nitrogen fertiliser recovery (ANFR%) and N Uptake, building on the data set from 21 years of long term rotation research. Yield was captured from each treatment and HVI analysis was done on the lint samples collected from each plot.

Outcomes

4. Describe how the project’s outputs will contribute to the planned outcomes identified in the project application. Describe the planned outcomes achieved to date.
Soil Analysis Field 6 West

After 21 years of maintaining the rotations in Field 6 west (listed in Table 1), the following are the soil analysis results prior to sowing cotton for the 2016/17 season.

The key outcomes from the soil analysis from the 2016/17 season are: the statistical differences were most evident between depths and not rotation (Figures 1(a), 2 (a), 3 (a) and (b) and 4 (a) and (b)). As the soil cores were removed outside of the nitrogen treatments, they capture the soil status impacted by rotation only after 21 years. Secondly, the only statistical differences shown between rotations were for pH and nitrate-N. The rotation of cotton with a legume was shown to acidify the Field 6 west vertosol across all replicates, (previously published by Dr Ian Rochester). The increase in soil nitrate-N (Figure 2 (a) and (b)) continues to support the benefits of rotating cotton with a legume and conversion of atmospheric nitrogen into soil nitrate-N.

The most interesting outcome from the soil analysis is that the total Kjeldahl nitrogen (%) was not shown to be statistically different between rotations. An explanation to account for this may be the differing species present in the soil due to differing pH. The ammonia and ammonium species could be less affected by the differing pH in the different rotations. The ammonia (NH₃) and ammonium (NH₄⁺) species may not be influenced by the different long term rotations like nitrate-N (NO₃⁻-N). What is most interesting is that the nitrate-N was statistically different due to legume rotations whereas the ammonia...
and ammonium species were not, however, they were statistically different between depths (Figure 4 (a)).

Figure 4. Total Kjeldahl nitrogen (%) across all treatments to a depth of 90 cm (a) and bulk density (b). There were no statistical differences between rotations only between depths for both TKN% and bulk density.

The bulk density (Figure 4b) across all rotations for the 2016/17 season was not statistically different (P<0.05), however, it increased with depth and was statistically different.

**Soil Organic Carbon and N Mineralisation**

The soil organic carbon and nitrogen mineralisation to a depth of 90 cm are shown in Figure 5 (a) and (b). The rotation with the highest SOC% and N mineralised at all depths was the cotton-vetch-summer-winter fallow-cotton (CV~C). The cotton-faba bean-summer-winter fallow-cotton (CF~C) rotation was also shown to mineralise similar N to a depth of 90 cm. The cotton-vetch-cotton-vetch-cotton (CvCvC) and cotton-wheat-summer fallow-vetch-cotton (CWv) were found to have the lowest SOC% and N mineralised (Figure 5a and b). Considering the growth period between continuous cotton crops (June-September – 4 months) the vetch produced very poor biomass and the wheat in the CWv would significantly deplete N after the cotton crop. The following winter vetch would not provide enough N to mineralise for the following cotton crop or would have been completely depleted from the continual cotton-wheat cropping sequence.

Figure 5. The soil organic carbon (%) (a) and N mineralised (mg/kg of soil) (b) in field 6 west prior to sowing Sicot 746B3F in 2016. The cotton-vetch-summer winter fallow-cotton rotation continues to sequester the highest carbon and mineralise the most N.

The true value (SOC% and N mineralisation) from rotating a legume with cotton is gained from the long fallow followed with either the vetch or faba bean crop ie. cotton followed by vetch or faba bean and then a summer and winter fallow before the next cotton crop. The extended fallow allows for a much longer growing period for the legume and increased time for N mineralisation.

The carbon:nitrogen (C:N) ratio was not statistically different across the rotations. They were however statistically different with increasing depth. The C:N ratios in September 2016 were 14:1, 16:1 and 18:1
for depths 0-30, 30-60 and 60-90 cm, respectively. Considering the ideal ratio to be 10 to 12:1, suggests that N was limiting. The soils were sampled outside the N treatments therefore a result of rotational effects only as no N had been applied.

**Yield Field 6 West 2016/17**

The new release Bollgard® 3 variety Sicot 746B3F was sown on the 19th October 2016 and picked on the 9th June 2017. The total in-crop rainfall was 290 mm and there were 64 hot days (hot day >=36°C and the long term average is 32) and 70 cold days (cold days <=11°C, long term average 66 days). The yields from the 2016/17 season from Field 6 west are listed in Table 2. The highest yield for the 2016/17 season was from the Cotton-wheat-summer fallow-vetch-cotton (CWv) rotation (Table 2) at 3232 kg lint/ha with 280 kg N/ha applied. The highest yield for the least N applied was from the cotton-faba bean-summer winter fallow-cotton (CF-C) at 3100 kg lint/ha (14 bales/ha). This is the first time the new Bollgard® 3 variety has been sown in the 21 year long term rotation trial, allowing and an excellent opportunity to study the response to varying N rates against the effect of long term rotations.

Table 2. The yields (lint in kg/ha and bales/ha in brackets) for each rotation and N treatment from Field 6 west for the 2016/17 cotton season. (highest yields are shaded for each rotation)

<table>
<thead>
<tr>
<th>N Rate Applied (N kg/ha)</th>
<th>C<del>C</del>C</th>
<th>CvCvC</th>
<th>CW~C</th>
<th>CWv</th>
<th>CF~C</th>
<th>CV~C</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1865 (8)</td>
<td>2905 (13)</td>
<td>1618 (7)</td>
<td>2318 (10)</td>
<td>3018 (13)</td>
<td>3151 (14)</td>
</tr>
<tr>
<td>120</td>
<td>2269 (10)</td>
<td>3020 (13)</td>
<td>2966 (13)</td>
<td>2909 (13)</td>
<td>3100 (14)</td>
<td>3074 (14)</td>
</tr>
<tr>
<td>200</td>
<td>2642 (12)</td>
<td>3181 (14)</td>
<td>3174 (14)</td>
<td>3138 (14)</td>
<td>3063 (13)</td>
<td>3162 (14)</td>
</tr>
<tr>
<td>280</td>
<td>2677 (12)</td>
<td>3055 (13)</td>
<td>3103 (14)</td>
<td>3232 (14)</td>
<td>3081 (14)</td>
<td>3155 (14)</td>
</tr>
<tr>
<td>360</td>
<td>2797 (12)</td>
<td>2991 (13)</td>
<td>3116 (14)</td>
<td>3219 (14)</td>
<td>3034 (13)</td>
<td>3134 (14)</td>
</tr>
</tbody>
</table>

**Optimum N for optimum Yield**

The fitted curves for each N rate and rotation for the 2016/17 season are listed in Table 3. The optimum N rate (kg N/ha) was calculated using R console and the fitted curves and corresponding optimum N rate were then used to determine the optimum yield that could be attained under each respective rotation. As expected, the rotation systems with a legume required less than half the N rate/ha in comparison to the continuous cotton or cotton wheat rotations. The yields were very similar, however, only for those with an additional rotation crop. The continuous cotton crop, even with 407 kg N/ha, could only reach an optimum yield of 12 bales/ha for the 2016/17 season.

Table 3: The optimum N required to achieve the optimum yield in Field 6 west for the 2016/17 season under each rotation.

<table>
<thead>
<tr>
<th>Rotation</th>
<th>N Rate required for optimum yield kg/ha</th>
<th>Optimum Lint Yield (kg/ha)</th>
<th>Optimum Yield (bales/ha)</th>
<th>Fitted curve for Optimum N rate to achieve optimum yield</th>
<th>R²</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>C<del>C</del>C</td>
<td>407</td>
<td>2802</td>
<td>12</td>
<td>y = -0.0058x² + 4.696x + 1851.4</td>
<td>R² = 0.99</td>
<td>40</td>
</tr>
<tr>
<td>CWv</td>
<td>306</td>
<td>3243</td>
<td>14</td>
<td>y = -0.01x² + 6.0779x + 2319.8</td>
<td>R² = 0.99</td>
<td>40</td>
</tr>
<tr>
<td>CW~C</td>
<td>258</td>
<td>3285</td>
<td>14</td>
<td>y = -0.0244x² + 12.52x + 1677.8</td>
<td>R² = 0.96</td>
<td>40</td>
</tr>
<tr>
<td>CvCvC</td>
<td>207</td>
<td>3110</td>
<td>14</td>
<td>y = -0.0052x² + 2.1241x + 2893.3</td>
<td>R² = 0.79</td>
<td>40</td>
</tr>
<tr>
<td>CF~C</td>
<td>189</td>
<td>3088</td>
<td>14</td>
<td>y = -0.0018x² + 0.6858x + 3023</td>
<td>R² = 0.75</td>
<td>40</td>
</tr>
<tr>
<td>CV~C</td>
<td>147</td>
<td>3166</td>
<td>14</td>
<td>y = -0.0006x² + 0.1865x + 3151.3</td>
<td>R² = 0.99</td>
<td>40</td>
</tr>
</tbody>
</table>


**Apparent Nitrogen Fertiliser Recovery**

The apparent nitrogen fertiliser recovery (ANFR) percentage for each rotation during the 2017/17 season is shown in Figure 6 (a). The rotation with the highest ANFR was the CW~C at 42%. The lowest ANFR, and understandably, were the rotations with a legume. The CV~C, CF~C and CvCvC rotations ranged from 11 to 13%. The N status for optimum yield for each rotation, calculated from Nopt (Table 3) and applied rates (Table 2) is shown in Figure 6(b). The mean shortfall across all N rates for the C~C~C treatment was estimated at 215 kg N/ha in comparison to the oversupply from the CV~C of 45 kg N/ha (Figure 6b). The range of N applied was
from 0 to 360 kg N/ha for all rotations and the $N_{opt}$ for the C–C–C was 407 kg N/ha. The average rate of applied N was 192 kg N/ha, therefore a shortfall on average of 215 kg N/ha. The $CV_{C}$ $N_{opt}$ was 147 kg N/ha and therefore on average was 45 kg N/ha oversupplied to reach optimum yield. This reinforces the value of legumes in rotation with cotton farming systems and their supply of mineralised N for subsequent cotton crops in comparison to the continuous cotton sequence.

Figure 6. The apparent nitrogen fertiliser recovery (a) calculated from the applied N, N uptake in dry matter collected at maturity and uptake in zero N plots and N status for each rotation at maturity (b) for the Sicot 746B3F in 2016.

N Uptake

Nitrate-N uptake was the highest in the CV~C rotation at 326 kg N/ha and the least in the continuous cotton rotation 163 kg N/ha (Figure 7a). The uptake of nitrogen increased with applied N (kg/ha) (Figure 7b), however plateaued from the 280 to 360 kg N ha applied from 267 to 271 kg N/ha, respectively (Figure 7 b). The fixing of atmospheric nitrogen by faba beans and vetch also improved the uptake of N in cotton. The soil health was improved, supplying more mineralised N for the following cotton crop when compared to a continuous cotton crop rotation.

Figure 7. Nitrate-N uptake (kg/ha) during the 2016/17 cotton season under rotations: cotton-vetch-summer and winter fallow-cotton (CV–C), cotton-vetch-cotton-vetch (CcCc), cotton-wheat-summer fallow-vetch-Cotton (CWv), cotton-faba bean-summer and winter fallow-cotton (CF–C), continuous cotton (C–C–C) and cotton-wheat- summer and winter fallow-cotton (CW–C) and under different N Uptake kg/ha.

The fitted curves for each rotation and their respective N uptake are also shown in Figure 8. The interesting trend of the fitted curves for the new Bollgard® 3 variety is the linear trend for the CV~C, CcCc and C–C–C rotations. The question for these systems is the increased demand for N for the newer Bollgard® 3 varieties. This is only one seasons results for the new variety, and further studies will be undertaken in the GxE research to examine the nitrogen use efficiency (NUE) and N uptake and comparisons made with older varieties.
Figure 8. The response fitted curves for crop nitrate-N uptake (kg/ha) to N Fertiliser applied (kg N/ha). (N rates applied in 2016 were: 0, 120, 200, 280 and 360 kg N/ha). (C–C–C = continuous cotton, CWv = cotton-wheat-summer and winter fallow-cotton, CW–C = cotton-wheat-summer fallow-vetch-cotton, CvCvC = cotton-vetch-cotton-vetch-cotton, CF–C = cotton-faba bean-summer and winter fallow-cotton, CV–C = cotton-vetch-summer and winter fallow-cotton.)

**Nitrogen Use Efficiency**

The average NUE for cotton is suggested to be between 13 and 18 kg lint per kg of N applied. The 2016/17 season was shown to vary depending on rotation (Figure 9). The rotations that fell below the average NUE were the CV–C, CvCvC and CF–C rotations. This is no surprise as they included legumes in their rotations and under high N applied rates they would have more than adequate N mineralised for the 2016/17 cotton season.

Figure 9. The nitrogen use efficiency (lint kg/ N kg) for cotton during the 2016/17 in Field 6 west for: cotton-vetch winter summer fallow, Cotton vetch Cotton vetch, Cotton Faba bean summer and winter fallow, cotton-wheat-summer fallow-vetch-Cotton and continuous cotton at nitrogen rates of 120, 200, 280 and 360 kg N/ha. (dashed lines indicate optimum from 13 to 18 kg lint / kg N).

**High Volume Instrument (HVI) Analysis**
The HVI analysis from the lint collect during the 2016/17 cotton season revealed the impact crop rotation and varying N rates have on fibre quality. The lint turnout was highest under the CWv rotation (Figure 11d) and the lowest for the CF–C. Applying the correct amount of nitrogen effected the turnout as well (when analysed separately ignoring rotation), with the highest turnout achieved with 120 kg N/ha, and the least under the 360 kg N/ha rates (Figure 11c). The higher the N rate/ha applied the stronger the fibre became (Figure 11b). The CF–C rotation produced the strongest fibre whereas the CWv rotation produced the weakest (Figure 11a).

Micronaire and fibre length were also impacted by nitrogen rate and by rotation. The CV–C and CvCvC rotation produced the finest micronaire cotton. Analysing N rate separately it was shown that the higher the N rate/ha the finer the micronaire of the cotton fibre.

The longest fibre was produced from the CV–C rotation and when analysing overall N rates applied (irrespective of rotation), the highest N rate 360 kg N/ha produced the longest fibre. High fibre quality is important for the Australian cotton industry, understanding the management systems (variety x
nutrient x environment) that produce higher quality fibre will ensure growers receive the highest return on investment.

**SPAD Leaf nitrogen estimation and correlation with Petiole nitrate-N**

Over the past few seasons Dr Ian Rochester had been experimenting with a SPAD Chlorophyll meter to monitor nitrogen during the cotton crops growth in January. The SPAD meter is an easy to use handheld meter and has shown a very good fit to TKN % over the past few seasons. The hand held chlorophyll meter is ideal as a seasonal tool and once calibrated could be used to monitor the crop nitrogen status for researchers to monitor crop N status. The fitted curves for the 2016/17 season are shown in Figure 13. There are strong correlations between SPAD and TKN% (Figure 13 a) as well as between leaf and petiole TKN% (Figure 13b) and Leaf TKN% and petiole nitrate-N (Figure 13c). Establishing these relationships could assist in monitoring crop nitrate-N status using models like NUTRILogic where it is necessary to know the petiole nitrate-N status in December and January.

![Figure 13. The SPAD meter relationship with TKN% for leaf (a) TKN % relationship between leaf and petiole (b) and Leaf TKN% and Petiole nitrate-N relationship (c). These relationships allow the SPAD meter to monitor cotton in real-time converting leaf TKN% into nitrate-N petiole values for crop models like NUTRILogic. This would allow crops to be adjusted if they are deficient/oversupplied in nitrogen.](image)

**Seed Total Nitrogen, Protein and Oil Content**

The CV–C rotation produced the highest seed nitrogen (4.3%) and protein content (25.2%) (Figure 14 a,b and c). There were statistical differences (P<0.001) between rotations and N Rates applied as well as an interaction between N rate and rotation. There was no significant difference for oil content in the seed between rotations or N rate for the 2016/17 season. The mean oil content was 15.28%.

![Figure 14. The total Kjeldahl nitrogen (%) (a) NIR N(%) (b) and NIR Protein (%) content of cotton seed from the 2016/17 cotton season. N rate for optimum seed N% and protein was 280 kg N/ha.](image)

**Budget**

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5. Describe how the project’s budget was spent in comparison with the application budget. Outline any changes and provide justification.

Jo Cain submitted the budget in December 2017.

Conclusion

6. Provide an assessment of the likely impact of the results and conclusions of the research project for the cotton industry. What are the take home messages?

The impact of legumes after 21 years of rotation (11 legume crops) continue to positively impact soil health. The addition of a legume in a cotton rotation impacts all aspects of the cotton production. The evidence was seen from the soil N status and plant accumulation of N (NUE, C:N ratio and ANFR), yield, fibre quality to seed nitrogen and protein content. The main benefit of including a legume was greatest when the legume followed a summer and winter fallow before the next cotton crop was sown. The long fallow allowed for the legume crop to reach optimum biomass production and time for the fixed atmospheric N to be mineralised and available for the following cotton crop. The addition of wheat into the cotton rotation also had a positive impact when compared to the continuous-cotton rotation. The impact from adding wheat into the system was not as beneficial as a legume, however there were benefits by adding wheat into the cotton system.

The 2016/17 season was the first time a Bollgard® 3 variety had been sown in the long term trial. The new variety responded to high rates of N and positively to the legume rotations. The fitted curves for N rates and N uptake revealed a positive linear relationship for the new Bollgard® 3 variety for the cotton- vetch-summer and winter fallow-cotton rotation. This is something to investigate in terms of variety response under a legume rotation. Under the continuous cotton rotation, the optimum N rate was calculated as 407 kg N/ha, however only yielding 12 bales/ha. In comparison the CV–C rotation only required 147 kg N/ha to achieve a much higher 14 bales/ha. The new variety responded positively to both vetch and faba bean in rotation and continued to follow the trend to the previously sown Bollgard® II varieties.