Laggan Grazing Demonstration

Results: 2015- 2020

Conducted at Shannon Arnall's, 'Carinya', Laggan

Beginning January 2015




Compiled by:

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Overview

Producer: Shannon Arnall

Location: ‘Carinya’, Laggan

Property size: 606 ha

Soils: Acidic, quartz-based with increasing aluminium to depth. Soil texture is a silty loam topsoil (0-25cm) with a light clay subsoil.

Pastures: Mainly native perennial grasses (microlaena and wallaby grass) with annual grasses and subterranean clover

Enterprises: Merino breeding, mostly to Merino sires

Background: This on-farm demonstration began in January 2015. Shannon Arnall had purchased a block of ‘native’ country that hadn’t received fertiliser for over 13 years and was keen to increase profitability from the existing pasture in the most cost-effective way. A small on-farm nutrient trial showed that phosphorus (P) was the major nutrient limiting pasture growth. This was not surprising given the history of the paddock, however, the question then became: **does it still pay to put fertiliser out in a wool operation?**

Project aim: To investigate the level of pasture and animal production that can be sustainably achieved on a native-based pasture in the Crookwell region. Specifically, the project is investigating the effect of applying fertiliser (single superphosphate) and lime on:

- ✓ **Stocking rates and overall farm profitability (using a fully costed economic analysis)**
- ✓ **Soil fertility and pH**
- ✓ **Pasture composition**
- ✓ **Soil carbon levels**

Treatments:

- **Paddock 1: Lime + Single superphosphate:** – fertiliser applied annually to increase soil P over time to a targeted level. Lime applied as a one-off application (2.5 t/ha) to reduce aluminium levels (by raising soil pH).
- **Paddock 2: Control** – a native pasture of low fertility (i.e. the “do nothing” approach).
- **Paddock 3: Single superphosphate** – fertiliser applied annually to increase soil P over time to a targeted level.

Major points after 6 years

Annual applications of 125 kg/ha to 170 kg/ha of single superphosphate in the two fertilised paddocks led to a gradual increase in soil phosphorus (P) and sulphur (S) in the first 5 years of the grazing demonstration. However, soil sampling at the end of the 2020 saw a sharp decline in residual P and S as a result of exceptional seasonal conditions. Regular (annual) soil testing is the key to identifying trends and checking the appropriateness of fertiliser application rates.

As expected, adding P to the fertilised paddocks led to a rapid and large increase in the amount of sub clover, especially the L+S paddock. The increase in stocking rate has been a function of both increased pasture quantity and quality. Stocking rates for the first 6 years of the demonstration have averaged:

- **L+S:** 7.5 wethers/ha
- **Control:** 4.6 wethers/ha
- **SS:** 6.6 wethers/ha

Higher stocking rates have resulted in the fertilised paddocks cutting more wool per hectare. When averaged over the six years, annual wool production has increased from 16.9 kg/ha (clean) in the control paddock to 24.7 kg/ha in the SS paddock and 29.3 kg/ha in the L+S paddock. Higher stocking rates in the fertilised paddocks also generate more meat income per hectare.

When all the costs are considered (i.e. the costs of fertiliser as well as additional variable costs of running more stock), SS has on average increased net profit by **$78 - $99/ha/yr** above the control (depending on what method of analysis used). The L+S treatment has increased net profit to a far greater extent, boosting returns by **$181 - $185/ha/yr** above the control.

While the difference in stocking rate between the SS and L+S paddock is relatively small (average of 0.9 wethers/ha), the 2015-20 period has coincided with exceptionally strong wool and mutton markets. When markets are favorable, small increases in carrying capacity can make a big difference.

Unlike P, pasture response to lime is highly variable and difficult to predict. At this site lime has had a positive effect on pasture growth, sub clover performance and overall economic returns. However, it is important to note the L+S paddock has a slight eastern facing aspect which could be providing a slight advantage (the Control and SS paddocks have a western aspect). Further work is required to verify the production advantage observed as a result of topdressing lime at this site.

Soil testing to 20 cm shows that the lime has only had an impact on the top 2.5 cm of soil, lifting pH_{Ca} from 4.2 to 5.0. This was achieved within the first 16 months of application. The relatively high organic matter levels at Laggan (>4.0 % in the 0-10 cm sample) is deemed to be the main reason why 2.5 t/ha of lime has struggled to alter soil chemistry below 2.5 cm. Higher rates of lime would be required to achieve deeper penetration.

Annual monitoring of pasture composition shows that all three paddocks have maintained a very strong native perennial grass base. This is despite three drought years occurring during the first 5 years (2017, 18 and 19). Pasture stability is just as important as any production increase. Native pasture species have adapted to shallow acidic soils and maintaining their presence across the landscape is important. Sowing introduced pasture species into these soils is expensive and successful establishment comes with considerable risk. Persistence of these introduced species can also be variable.

About the site

'Carinya' is a 606 ha property located 18 km north of Crookwell. The landscape is gently undulating with an altitude of around 980-1000 m. Long-term average annual rainfall is 860mm with slight winter dominance.

From a pasture perspective the site could be described as a very good, dense native-based perennial grass pasture with the main species being Weeping grass (*Microlaena stipoides*) and Wallaby grass (*Austrodanthonia spp*.). The pasture also contains subterranean clover (*Trifolium subterraneum*), native/naturalised legume species and annual grasses.

The soil is an acidic, brown Kurosol (Australian Soil Classification) with a topsoil (0-10 cm) pH ($CaCl_2$) of around 4.0 - 4.1 and 40 % aluminium (Al). Soil testing to a depth of 20 cm has shown Al % increases to 50 to 66 %. Soil texture changes with depth, with a grey brown silty loam 'A Horizon' (0-25 cm) sitting over a moderately structured light clay subsoil (Figure 1).

The geology of this site means that the soil has very low inherent fertility. Prior to the paddocks being used for the demonstration they had not received any form of fertiliser for at least 13 years. Baseline soil testing showed that soil P was low, with Colwell P levels sitting around 10 mg/kg. The site has a Phosphorus Buffering Index (PBI) of between 110 to 120 indicating the critical Colwell P level to be around 34 mg/kg.

Figure 1: Soil profile from the Laggan Grazing Demonstration site. Note the colour change in the profile where the soil changes from a silty loam topsoil to a light clay subsoil.

Grazing Demonstration

An on-farm nutrient trial showed that phosphorus (P) to be the major nutrient limiting pasture growth (Appendix 1). However, the question then became: *what level of production can be achieved under commercial grazing conditions, and does it pay to put fertiliser and/or lime out in a wool operation?*

To answer this question, an area near the nutrient trial consisting of similar pasture was fenced to create three, 7-hectare paddocks (Figure 2). The selected treatments were:

- **Paddock 1: Lime + Single superphosphate:** – fertiliser applied annually to increase soil P over time to a targeted level. Lime applied as a one-off application (2.5 t/ha) to reduce aluminium levels (by raising soil pH).
- **Paddock 2: Control** – a native pasture of low fertility (i.e. the "do nothing" approach).
- **Paddock 3: Single superphosphate** – fertiliser applied annually to increase soil P over time to a targeted level.

Single superphosphate was selected for topdressing of these pastures as it is one of the most cost-effective ways of applying P. This has been proven in a long-term fertiliser trial at three sites near Yass, NSW (Leech et al. 2019). Superphosphate also provides adequate amounts of sulphur (S) – another key nutrient that is often deficient in tableland soils. Lime was also chosen to be applied across one of the treatments to investigate its economic viability in a native pasture based grazing system. Lime was surface applied at the 'standard' rate of 2.5 t/ha (a common rate used by producers).

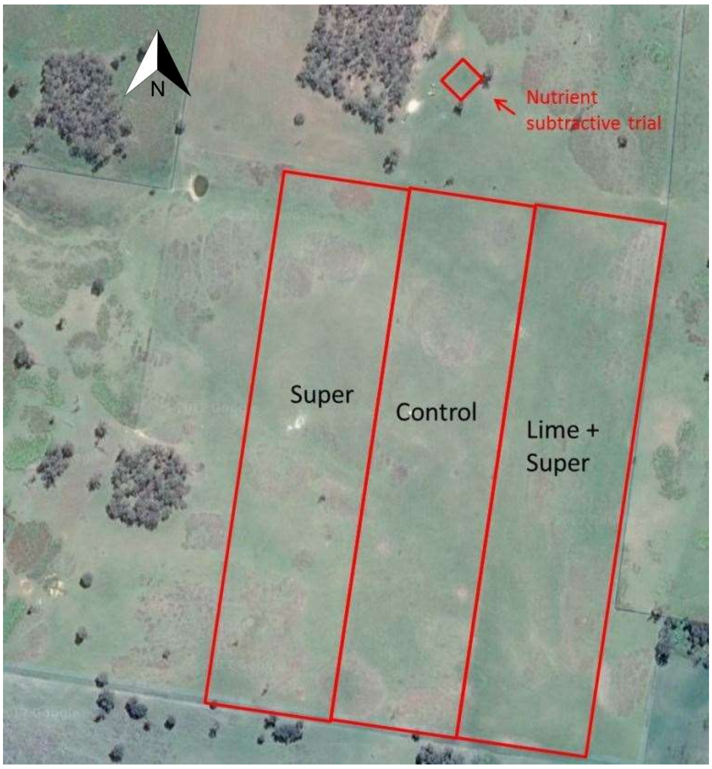

Figure 2: Aerial view of the Laggan Grazing Demonstration.

What information is being collected?

- **Pasture growth rates:** pasture growth rates (kg DM/ha) are collected on a monthly basis using a pasture probe (GrassMaster II). Refer to Appendix 2.
- **Pasture composition:** a botanical analysis is done each spring using the 'End Point Evaluation' technique. This assessment will help identify if there are any major changes in pasture composition across the treatments over time (see Appendix 3).
- **Soil nutrient levels, pH and soil carbon:** baseline soil testing occurred in December 2014 prior to any treatments being applied. This data is summarised in Table 1. Soil tests are taken annually in late spring to a depth of 10 cm to monitor changes over time (see Appendix 4).

Table 1: Baseline soil test results for the three treatments (sampled December 2014).

	pH (CaCl$_2$)	Aluminium %	PBI L/kg	Phos (Colwell) mg/kg	Sulphur mg/kg	Potassium cmol(+)/kg	CEC cmol(+)/kg	Total Carbon %
Lime + Super	4.1	38	120	11	5.4	0.64	4.7	4.7
Control	4.0	38	120	9.4	4.8	0.63	4.5	5.0
Super	4.0	45	110	8.8	3.7	0.4	4.0	4.0

- **Lime movement:** the movement of surface applied lime down through the soil profile will be measured annually in incremental segments to a depth of 20 cm. Complete soil cores were taken in December 2014 down to a depth of 20 cm. The top 10cm was cut into four 2.5 cm segments. The remaining 10-20 cm section was cut into two 5 cm segments. The same sampling protocol is used annually to monitor changes in pH and Al %. Lime movement is being monitored in autumn to ensure a better chance of receiving enough moisture at depth in order to take soil cores.
- **Livestock data:** wethers are weighed regularly so that similar body weights are maintained across the treatments. If body weight is kept the same then wool characteristics will be similar, allowing a fair economic assessment of treatments.
- **Wool data:** wethers are shorn annually in December. Un-skirted fleeces from each animal are weighed and tested (via OFDA 2000) for a range of wool characteristics including micron and staple length. These measurements are then used to calculate an average fleece price for each treatment on a $/head basis using wool prices at the time of shearing (obtained from AWEX weekly wool report).

Results and discussion

Soil nutrients

In reviewing Figures 3 and 4 some interesting trends can be seen.

- Soil phosphorus (P) was static for the first three years. However, this is not surprising given the modest rates of application and the Phosphorus Buffering Capacity of the soil.
- The first three years were also relatively good seasons and a lot of the nutrients would have been utilised by the plants for growth.

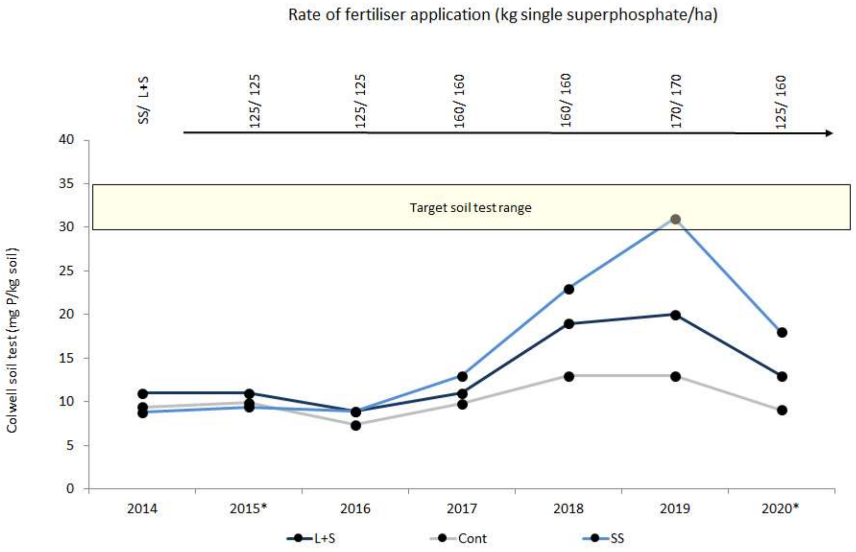

Figure 3: Fertiliser application history and results of annual soil testing on Colwell P (* indicates the years in which superphosphate was applied with molybdenum).

- 2018 is where we first see a significant rise in soil P. This was due to drought conditions. In a drought, pasture does not grow to its full potential and therefore nutrients accumulate in the soil. While this trend can be seen in all treatments, it occurs to a much greater degree in the fertilised paddocks. This seasonal effect can also be seen in the Sulphur results (Figure 4).
- Although the same rates of fertiliser were applied to both the L+S and SS paddocks in the first five years, by the end of 2019 soil P levels in the SS paddock are much higher than the L+S paddock. This can be explained by the fact that the L+S paddock has consistently grown more pasture and supported a higher stocking rate. As such, more nutrients have been used by the plants for growth, which in turn leads to a lower level of residual nutrients in the soil. This effect can also be seen with sulphur (Figure 4).

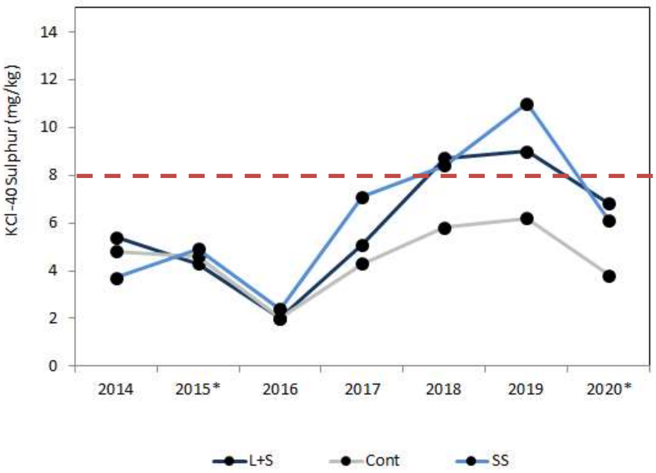

Figure 4: Results of annual soil testing on S levels (KCl-40)

- Exceptional growing conditions in 2020 saw a big decline in P and S levels in all three paddocks. These nutrients haven't disappeared out of the system – rather they are contained in the plant material (herbage and roots). These nutrients (and others) will return to the soil once the plant material has been broken down by the soil microbes. This highlights the impact that the season can have on soil test results - e.g. elevated readings after a dry year and lower than normal readings following a good year.

- It is also worth noting the big decline in S following an extremely wet year (Figure 4). In 2016 Crookwell recorded 1200 mm for the year, which is 1.4 times the long-term average of 857 mm[1]. As can be seen, S returned to 'normal' levels in 2017. These results demonstrate:
  - the mobile nature of sulphur - unlike phosphorus, sulphur is prone to leaching;
  - the advantage of follow-up soil testing (i.e. it enables you to detect abnormal readings and avoid 'rash' decisions).

Soil test results can vary significantly from year-to-year depending on the amount of fertiliser applied, seasonal conditions and when samples are taken. Regular (annual) soil testing is the key to identifying trends and checking the appropriateness of fertiliser application rates.

Soil carbon

- Baseline 0-10 cm soil testing at the end of 2014 showed that soil carbon levels were already high at this site, ranging between 4.0-5.0 %.
- Annual soil testing shows a declining trend in the first two years, before a notable increase in soil carbon levels in 2017 (2017 was a better production year compared to 2015 and 2016). However, this increase was short-lived due to drought conditions in 2018 and 2019.
- Soil carbon levels increased in 2020 on the back of an exceptionally good season.
- At this stage there is no clear effect on soil carbon levels due to the different paddock treatments. The measured changes appear more related to seasonal conditions than treatment.

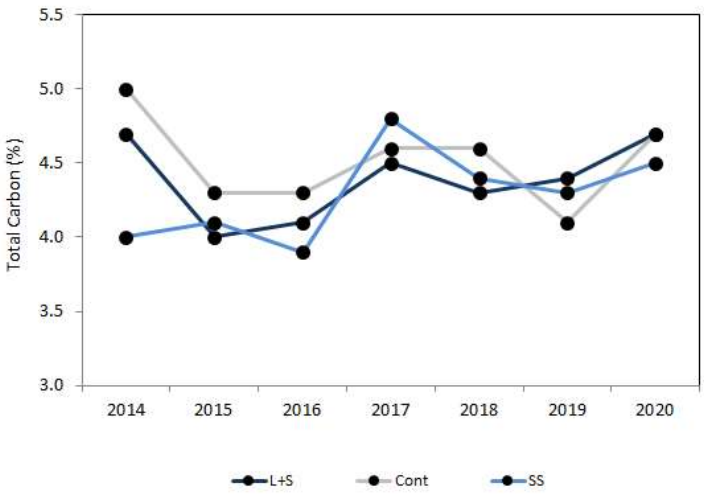

Figure 5: Results of annual soil testing on Total Carbon % (Dumas Combustion method).

- Over time, soil carbon levels at a given location will reach a point where the soil has no more capacity to store carbon (Chan et al 2010). Given the high initial soil carbon levels at this site, it is possible that this site has already reached (or is very close to) this upper threshold. The high starting point also means that modest gains in soil carbon may be difficult to detect.

[1] Crookwell Post Office Bureau of Meteorology weather station (station no. 070025)

Soil pH

Baseline soil testing at the start of the grazing demonstration confirmed all paddocks had a very similar starting point from a soil chemistry perspective, with a 0-10 cm soil sample showing pH_{Ca} sitting around 4.0-4.1 and Al at 38-45 %.

Surface application of 2.5 t/ha of lime increased pH_{Ca} to a maximum of 4.3 (0-10cm), which was recorded in November 2016 (Figure 6). However, the 'lime movement' sampling provides a much greater insight into where the changes occurred (Figures 7 & 8).

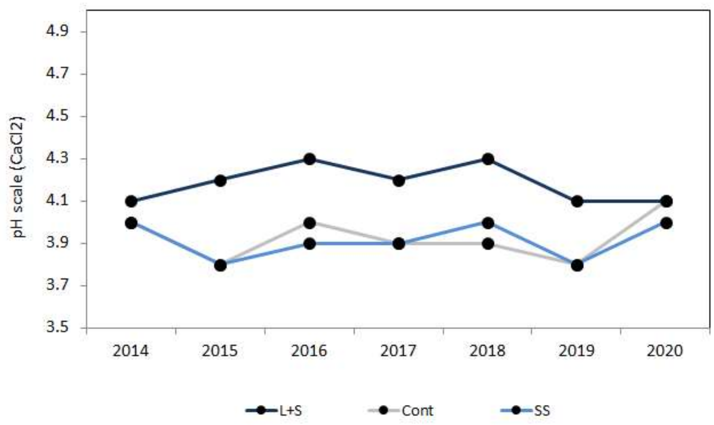

Figure 6: Results of annual soil testing on soil pH_{Ca} levels (0-10 cm).

Lime movement soil testing to 20 cm shows that the lime has only had an impact on the top 2.5 cm of soil, lifting pH_{Ca} from 4.2 to 5.0 and reducing aluminium from 16 % to 0 %. This was achieved within the first 16 months of application. Since May 2016 the impact of lime has not progressed any further down the profile.

Depth (cm)	2014	2016	2017	2018	2019	2020	2021
0 - 2.5	4.2	5.0	5.1	4.9	4.7	4.7	
2.5 - 5	4.1	3.9	4.2	4.1	4.0	4.0	
5 - 7.5	4.0	3.8	4.0	4.0	4.0	4.0	
7.5 - 10	4.0	3.8	4.0	4.0	3.9	3.9	
10 - 15	4.0	3.8	4.0	4.0	4.0	4.0	
15 - 20	4.1	3.8	4.0	4.1	4.0	4.0	

Figure 7: Impact of lime on soil pH ($CaCl_2$) in the L+S paddock

While the purpose of applying lime is to alter the soil chemistry to a large proportion of the soil, history shows that getting lime into the soil to depth is a major challenge and difficult to predict.

Depth (cm)	2014	2016	2017	2018	2019	2020	2021
0 - 2.5	16	0	0	1	3	3	
2.5 - 5	34	29	23	29	25	25	
5 - 7.5	42	41	36	40	39	39	
7.5 - 10	50	48	44	46	42	42	
10 - 15	52	50	50	50	46	46	
15 - 20	55	55	58	52	50	50	

Figure 8: Impact of lime on soil aluminium (% of CEC) in the L+S paddock

Research findings over the last 40 years have ranged from no movement to deep and rapid penetration into the soil (Scott et al 2000). Local work done on the Southern Tablelands (Goulburn, Bungendore, Braidwood, Sutton, Binalong etc.) has shown variable results from topdressing lime, with lime movement varying from 5 cm to 20 cm. Several factors influence lime movement, including:

- Soil type and buffering capacity – soils with higher clay content and/or organic matter offer greater resistance to pH change
- Rainfall – rainfall is required to wash the lime into the soil following lime application. Wet conditions will assist in moving lime further down into the soil
- Amount of lime applied. In general, the higher the rate applied, the greater the depth of pH increase.

The relatively high organic matter levels at Laggan (>4.0 % in the 0-10 cm sample) is probably the main reason why 2.5 t/ha of lime has struggled to alter soil chemistry below 2.5 cm. Higher rates of lime would be required to achieve deeper penetration. A long-term trial at Sutton NSW (on a soil with a very similar pH and Al levels to Laggan) was able to achieve a pH change down to a maximum depth of 17.5 cm (Norton et al. 2018), however much higher rates were used (7.72 t/ha).

More recent soil testing suggests that the lime effect on the top 2.5 cm (L+S paddock) may be waning. It will be interesting to see if this trend continues. Soil testing results from the SS and Control paddocks show slight year-to-year variation in terms of pH_{Ca} and Al levels, but this is considered to be within the realms of natural sampling variation. Further details on the lime movement are detailed in Appendix 5.

Pasture production

Right from the start the fertilised paddocks have measured superior pasture growth rates compared to the control (Figure 9). While the increase in pasture production is evident across all seasons, the additional growth in autumn and winter is of greatest value as this is the period of minimum feed availability and sets the annual stocking rate (Scott et al. 2000).

As expected, adding P into the system led to a rapid and large increase in the amount of sub clover in the fertilised paddocks, especially L+S (Table 2).

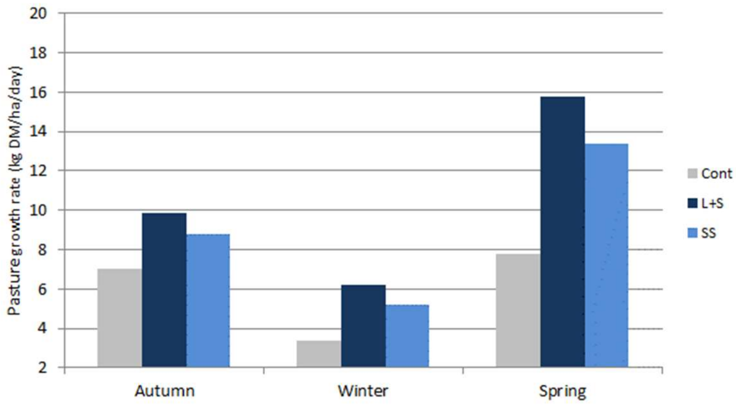

Figure 9: Summary of the average pasture growth rates (kg/ha/day), 2015-20.

This was particularly evident in 2018 and 2019 where the L+S paddock recorded 45-49 % legume in spring. This was more than double the amount of sub clover recorded in the SS paddock (19-20 %). Sub clover has performed poorly in the Control paddock due to low soil fertility (Appendix 3). Sub-clover increases production in two ways:

i. directly through providing grazing animals with highly digestible forage; and
ii. by fixing atmospheric nitrogen and releasing into the soil, which in turn increases pasture growth and quality.

Even though the lime has only had an impact on the top 2.5 cm of soil, it's interesting to note that lime has had a positive effect on both pasture growth (Figure 7) and sub clover performance. This increase in production has meant the L+S paddock has averaged 7.5 wethers/ha versus 6.9 wethers/ha in the SS paddock (across first 5 years). However, it is worth noting that the L+S paddock has a slight eastern facing aspect which could be providing some advantage (the other two paddocks have a western aspect). Further work is required to verify the production advantage that has been observed as a result of topdressing lime at this site.

A review by Scott et al. 2000 highlights that pasture yield response to lime is highly variable and hard to predict. Some studies have reported no measurable yield increase while others have reported large increases in response to lime. It is worth noting that the majority of the pasture research over the years involving lime has been done on introduced perennial pastures (e.g. lucerne, phalaris and cocksfoot) and the lime has been incorporated via cultivation. Minimal work has been done topdressing lime on native perennial grass-based pastures.

Botanical composition

Botanical composition is assessed each spring using the 'End Point Evaluation' technique. This measurement is taken to see if there are significant changes in the composition of the pasture over time. A summary of the botanical composition measurements for the first 5 years is shown in Table 2.

Careful interpretation is required of the botanical composition data as on a first glance it could be interpreted that fertiliser has led to a *decrease* in native perennial grass species (microlaena and Wallaby grass, Table 2). It's not that the native species have started to disappear in the fertilised paddocks, but rather the sub clover in-between the perennial plants (i.e. the 'gaps') has flourished to a much greater degree. This is of critical importance as these native perennial grass species are: 1) common throughout the Tablelands; 2) responsive to increasing soil fertility; and 3) well adapted to shallow, acidic soils.

Sowing introduced pasture species into these soils is expensive and successful establishment comes with considerable risk. Persistence of these introduced species can also be variable. It is also important to note that ground cover was also very similar across all treatments during the drought years and didn't fall below the minimum target of 70 %.

Table 2: Botanical composition of the three treatments at 'Carinya' Numbers indicate the percentage of each species in the sward (spring measurement).

	Average % Composition (2015-20)		
Species	L+S	Control	SS
Microlaena	28	47	37
Wallaby grass	13	21	15
Annual grasses	7	3	5
Legumes	37	7	23
Weeds	4	3	2
Bare ground	3	7	7
Litter	9	13	13

Livestock and economics

The application of fertiliser had an immediate impact, with the fertilised paddocks growing more pasture and sustaining higher stocking rates than the control (Table 3). When averaged over the first 6 years, stocking rates have increased by 144 % in the SS paddock and 162 % in the L+S paddock (above the control).

As previously mentioned, the fertilised paddocks have shown a large increase in the amount of legume present, especially the L+S paddock (Table 2). The increase in stocking rate has been a function of both increased pasture quantity and quality. Higher stocking rates have resulted in the fertilised paddocks cutting more wool per hectare. When averaged over the six years, annual wool production has increased from 16.9 kg/ha (clean) in the control paddock to 24.7 kg/ha in the SS paddock, and 29.3 kg/ha in the L+S paddock.

Table 3: Livestock and economic data comparison across treatments (average annual results from 2015 – 2020).

	Lime + Super	Control	Super
Wethers/ha*	7.5	4.6	6.6
Wool cut (kg wool/ha, clean)	29.3	16.9	24.7
Wool income ($/ha/yr)	533	316	453
Meat income ($/ha/yr)	200	86	149
Total income ($/ha/yr)	732	402	602
Total costs ($/ha/yr)	245	96	197
Profit ($/ha/yr)	487	306	405
Difference to control ($/ha profit/yr)	**+ 181**		**+ 99**

* Adjusted stocking rate which takes grazing area lost to bracken fern into account. A handheld GPS unit is used to map out the amount of bracken fern in all treatments (see Appendix 6 for further details)

Historically, the financial analysis for this demonstration has been based on **both** the **wool income** *plus* change in **mutton value** during the 12-month period (Table 3; Figure 10). This method (Method 1) mimics an annual trading system whereby wethers are purchased off shears, carried for 12 months, shorn and then sold.

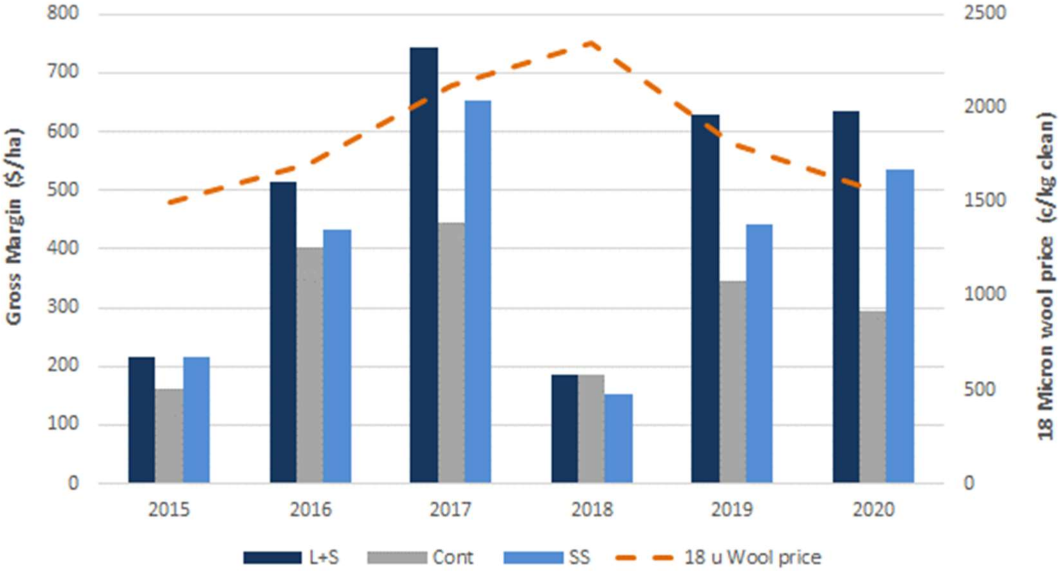

Figure 10: Gross margin comparison between treatments ($/ha). This economic analysis is based on Method 1 (wool income + annual change in mutton value during the 12 month period).

Figure 11 shows the annual fluctuation in wool income, mutton value and expenses. In some years the mutton component lost ground (e.g. 2015 and 2018). This was a result of a drop in mutton price over the 12 month period (2018) or the combination of very little change to mutton price and liveweight (2015). However, the annual change in meat value on a per hectare basis has been extremely strong in most years, especially in the fertilised paddocks. This is due to higher stocking rates, strong mutton prices and liveweight gain.

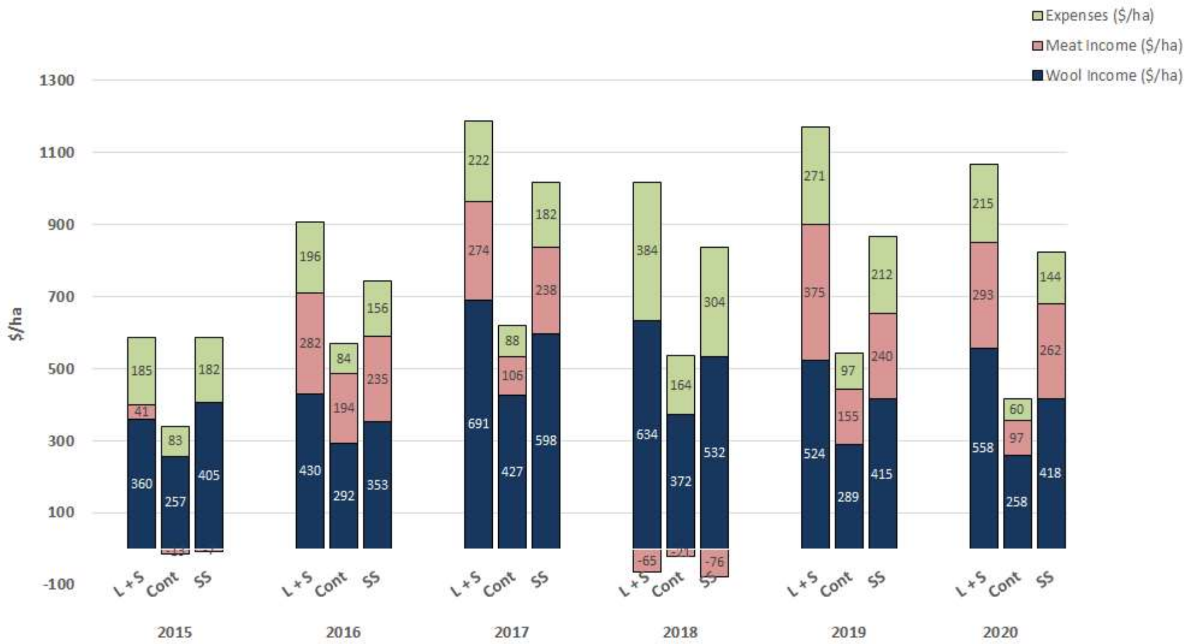

Figure 11: Annual change in wool production, meat value and expenses between treatments using Method 1. All figures are expressed in $/ha.

Like a lot of Merino-based operations, wethers at 'Carinya' are typically run for several years and sold into the mutton market. Method 1 doesn't reflect financial returns in this type of production system because the meat value is only obtained when wethers are sold (not every year). Figures 12 and 13 show the financial performance based on wool returns plus meat income when wethers were sold (Method 2). As can be seen in Figure 13, there have been three 'batches' of wethers during the first 6 years of the grazing demonstration, with wethers sold in 2016, 2019 and 2020.

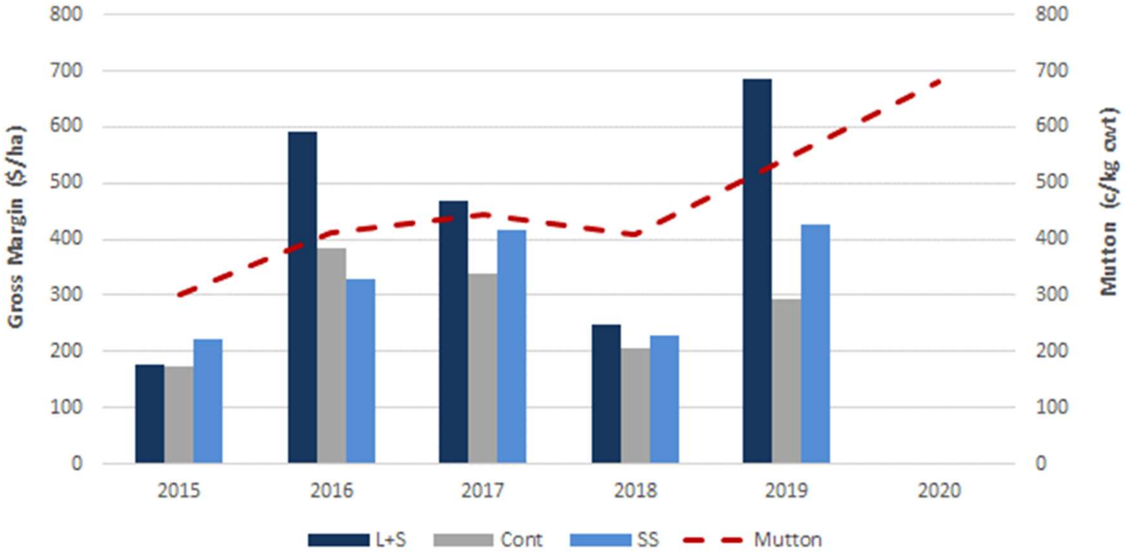

Figure 12: Gross margin comparison between treatments ($/ha). This economic analysis is based on **Method 2** (wool income + meat income when wethers are sold).

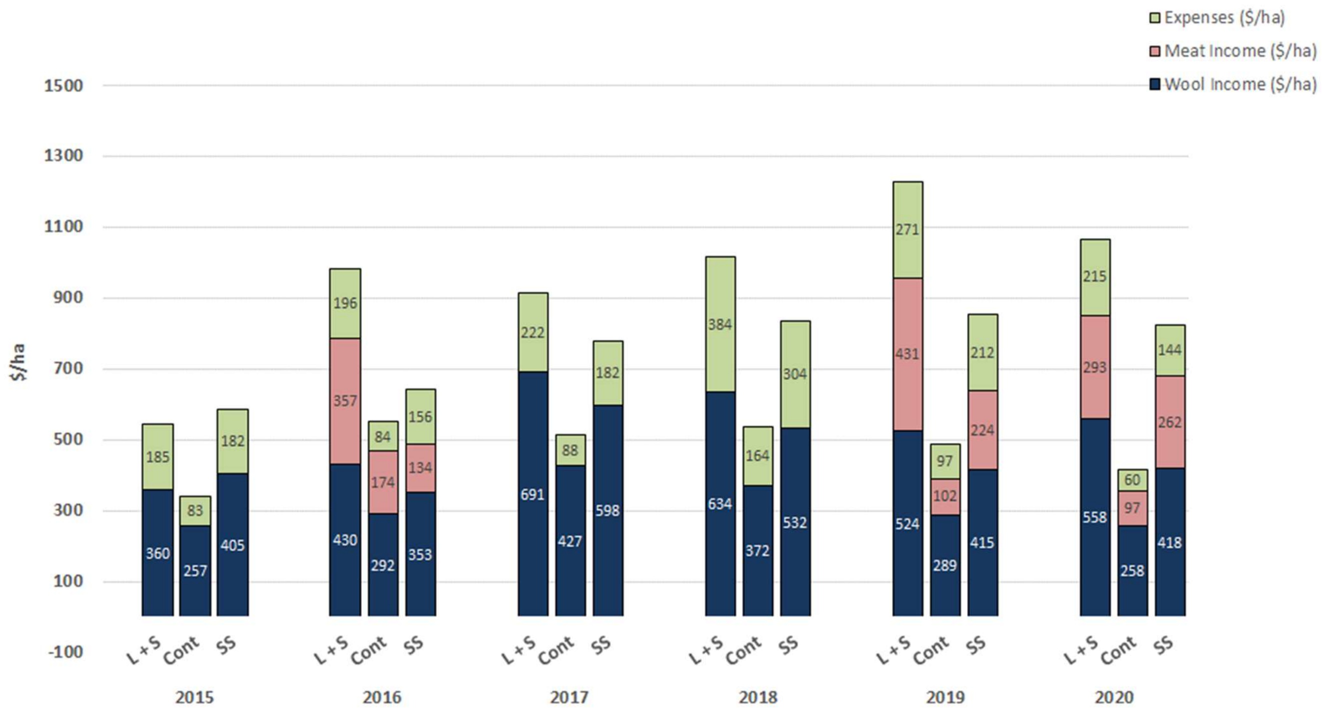

Figure 13: Annual change in wool production, meat value and expenses between treatments using **Method 2**. All figures are expressed in $/ha.

Table 4 compares the average annual profit over the first 6 years between the two different analysis methods. When all the costs are taken into account (i.e. fertiliser cost as well as additional variable costs of running more stock), SS has on average increased net profit by **$78 - $99/ha/yr** above the control (depending on what method of analysis used). The L+S treatment has increased net profit to a far greater extent, boosting returns by **$181 - $185/ha/yr** above the control. Appendices 7, 8 and 9 contain a full breakdown of the economic analysis and comparison between treatments.

While average figures over the long term are essential in assessing the merit of any given practice, important detail is often lost. For example, Figures 10 and 12 show the year-on-year price movements for both wool (18 micron) and mutton. Growing more pasture and running a higher stocking rate meant that the fertilised paddocks were in a much better position to capitalise on the strong wool prices in 2017 and the significant rise in red meat prices in 2019 and 2020.

Even though the wool market continued a strong upward trend in 2018 (Figure 8), drought conditions and higher feeding costs in the fertilised treatments (due to higher stocking rates) meant there was very little economic difference between treatments.

Table 4: Comparison of average annual profit ($/ha) between the two different analysis methods (2015-20).

	Lime + Super	Control	Super
Method 1			
Profit (2015-2020) ($/ha)	487	306	405
Difference to control ($/ha)	**+ 181**		**+ 99**
Method 2			
Profit (2015-2020) ($/ha)	467	282	360
Difference to control ($/ha)	**+ 185**		**+ 78**

Comments from years

2015

- Significant rainfall in January resulted in wethers grazing around 1000 kg DM/ha (green) at the start of the demonstration, however, dry conditions in February and March meant that pastures dried out quickly. The site received good rainfall and growth in April but May growth rates were very low – possibly due to lack of nitrogen as a result of the previous summer rainfall.
- Winter was particularly tough with the district receiving in excess of 30cm of snow in mid July. The negative pasture growth rates associated with July are a result of frost burning the leaves and shifting green material into the 'dead' pool.
- Although there was good soil moisture at the end of winter, lack of rainfall in September and October meant that the topsoil dried out, restricting pasture growth. This is reflected in very modest pasture growth rates for these months.

2016

- Following a dry start to autumn, the season broke on 9 May with around 60 mm falling over five days. Good soil moisture combined with warmer than average temperatures meant that pastures responded quickly.
- Despite good growth in May, extremely wet and overcast conditions meant that pastures and livestock did it tough during winter. The wet winter was immediately followed by the wettest September on

record and above average rainfall in October. Cold temperatures however meant that spring growth was slow – it wasn’t until late November that the pasture exceeded 1000 kg DM/ha and pasture started to get ahead of the stock.

2017

- Unlike large parts of NSW, graziers in the Crookwell region experienced a good season where the timing of key rainfall events proved to be just as important as the amount. Excellent rainfall in March provided a solid early break to the season with Crookwell recording 114 mm, all of which fell in the second half of the month.
- After a strong start to the growing season, pasture growth during winter was heavily restricted by exceptionally dry conditions (NSW recorded its 10th driest winter on record) and cold nights. The frequent and large number of heavy frosts had a big impact on pasture growth.
- Dry conditions extended into September with annual grasses quickly running to seed. Good rain in late September and early October provided valuable moisture for the perennials, however, the end result was a spring that didn’t produce a lot of bulk but enough rain to keep pastures green and extend out the growing season.

2018

- While the Tablelands received good rainfall at the end of February (113 mm recorded at Crookwell), warm and exceptionally dry conditions meant that by the end of March soil moisture was starting to severely restrict plant growth. Crookwell recorded its fifth driest autumn since 1960.
- The dry autumn meant that the region went into winter with very little feed in the paddock. Cold temperatures heavily restricted pasture growth. Paddocks were destocked on 24 July due to lack of pasture. Wethers from all treatments were combined and run together in a neighbouring paddock. Paddocks were restocked on 3 October.
- A dry September and below average rainfall in October limited early spring growth. Pastures in the Crookwell region at higher elevation were able to withstand this dry spell to some degree and pastures responded well to the late spring rainfall.

2019

- Good rain fell during the second half of March, but unfortunately an extremely dry April (4 mm) meant that pasture availability going into winter was low.
- Wethers were removed from the grazing demo on 6 June due to drought conditions, low herbage mass and pasture grub damage, especially in the fertilised paddocks. Paddocks were re-stocked on 5 August. Site received 38 mm for August, with the majority of the moisture coming from two snowfall events.
- Dry conditions in September and October resulted in a tight spring, but stock performed well due to high pasture quality. While 2019 was much drier than the previous year, stock performed much better in 2019 due to the earlier break (March) and the resulting clover content in pastures.

2020

- Like large parts of NSW, the 2020 season in the Crookwell district was exceptional. The season broke in mid-February with around 125mm falling over 10 days, resulting in a strong germination of sub clover. Above average rainfall right through autumn ensured high pasture growth rates and good pasture availability heading into winter.

– Good leaf area and mild weather conditions resulted in above-average pasture growth rates right through winter. The exceptional growing conditions continued through spring and the fertilised paddocks were dominated by sub-clover. Due to the high amount of sub-clover, the fertilised paddocks were crash-grazed at shearing to open the pastures up and let light in. Pastures were destocked after shearing (10 December).

The Bookham grazing demonstration

A similar study was conducted over a 13-year period at 'Kia-Ora', Bookham, NSW. The Bookham Grazing Demonstration (520 m elevation) showed that applying single superphosphate resulted in a 2-fold increase in stocking rate, generating an additional $79/ha in profit (Appendix 10). When comparing the two demonstrations it is important to note that the Bookham work did not take the meat component into account.

A summary of the financial results from the Bookham Grazing Demonstration is shown in Figure 12. From a financial perspective, the key points to note are:

- Apart from 2003, the fertilised paddock (blue line) consistently generates more profit than the control (red line)
- The big advantage from applying fertiliser and running a higher stocking rate came in the 2000 – 2002 period where there was a step jump in the wool price. If you look at the total amount of profit generated over the 13-year period, 67 % was made in those 3 years.
- The big profits occur when seasons and markets align. The alignment of these two elements is completely random, so it's important that you have your system in a state that is ready to take advantage of the random event.

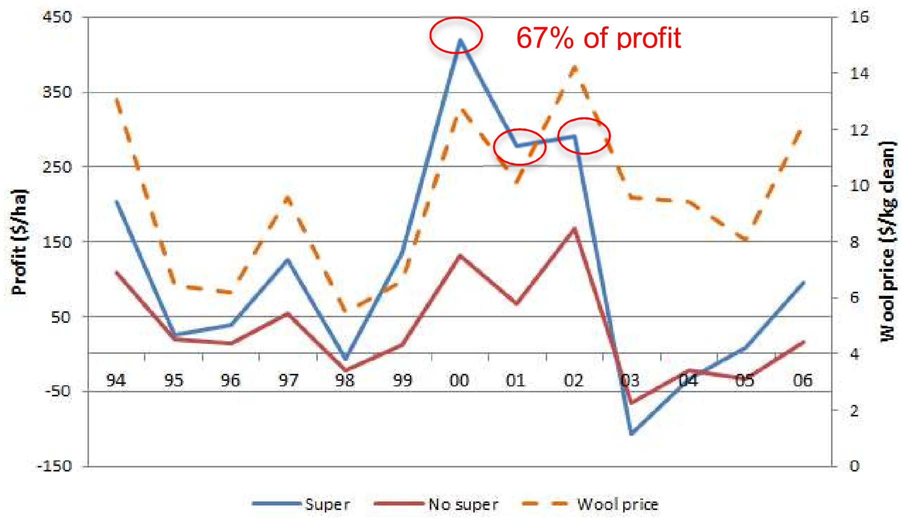

Figure 12: Financial results from the Bookham Grazing Demonstration (1994-2006).

References

Chan KY, Oates A, Liu DL, Li GD, Prangnell R, Poile G and Conyers MK (2010). A farmer's guide to increasing soil organic carbon under pastures. Industry and Investment NSW, Wagga Wagga NSW.

Gourley CJP, Melland AR, Waller RA, Awty IM, Smith AP, Peverill KI and Hannah MC (2007). Making better fertiliser decisions for grazed pastures in Australia. Department of Primary Industries, Victoria.

Leech FJ, Richardson AE, Kertesz MA, Orchard BA, Banerjee S and Graham P (2019). Comparative effect of alternative fertilisers on pasture production, soil properties and soil microbial community structure. *Crop and Pasture Science* 70 (12), 1110-1127.

Norton MR, Garden DL, Orchard BA and Armstrong P (2018). Ameliorating acidity of an extensively-managed permanent pasture soil. *Soil Use and Management* 34, 343–353.

Scott, BJ, Ridley AM and Conyers MK (2000). Management of soil acidity in long-term pastures of south-eastern Australia: a review. *Australian Journal of Experimental Agriculture*, 40, 1173-1198.

Acknowledgments

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Appendix 1: Nutrient subtractive trial

A nutrient subtractive trial is a simple way to identify which nutrients are limiting growth. This works by applying all nutrients to a measured area/plot ('All Nutrient') and then systematically removing a single nutrient from subsequent plots and comparing pasture growth. For example, the '**- P**' plot is all nutrients excluding phosphorus (Figure 1). The nutrient trial commenced in July 2013 on a native perennial grass based pasture containing some legume.

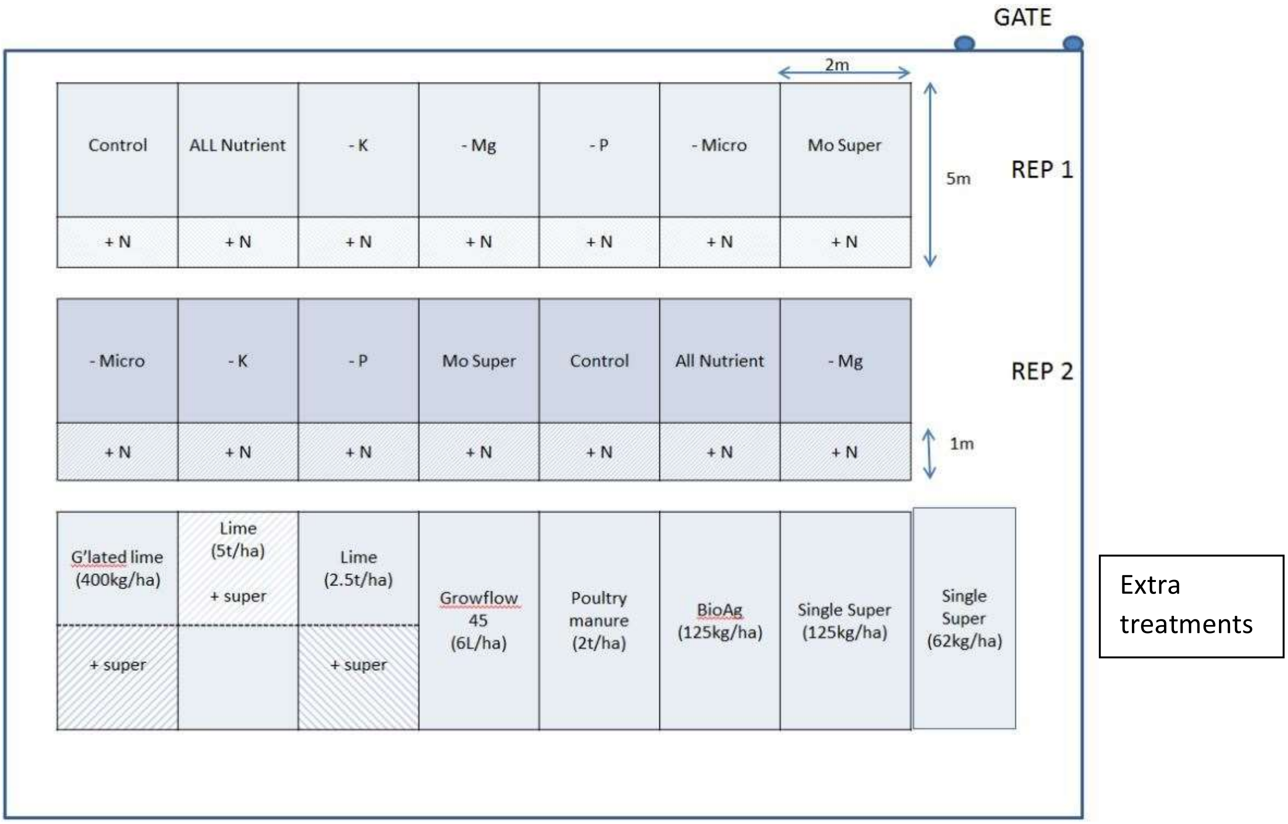

Figure 7: Nutrient subtractive trial layout at 'Carinya', Laggan*

*The only nutrient that cannot easily be 'removed' is sulphur. This is because most of the nutrients are applied in a sulfate form (e.g. magnesium is applied as Magnesium Sulfate). The '- Micro' treatment consisted of All Nutrients minus the micronutrients Copper, Zinc, Molybdenum and Boron.

Timeline of events

4 July 2013

- Rep 1 and Rep 2 established and nutrients applied

17 April 2014

- Top up nutrients applied to Rep 1 and 2
- Shannon was also interested in a range of other products. The 'extra' treatments were also applied on 17 April

2 April 2015

- Top up nutrients applied to all treatments (except 125kg Molybdenum Super on the lime treatments and the BioAg Superb treatment– see below)

14 April 2015

- It was decided that half of the 3 x lime treatments should receive 125kg/ha of Mo single super. This was done on 14 April 2015.
- 125kg/ha of BioAg Superb treatment was also applied on the 14 April.

2015 Results

Herbage mass (kg DM/ha) was measured using a pasture probe (GrassMaster II) on 18 November 2015. Results for the two replicate plots were averaged and are presented in Figure 2. Note this data has not been statistically analysed.

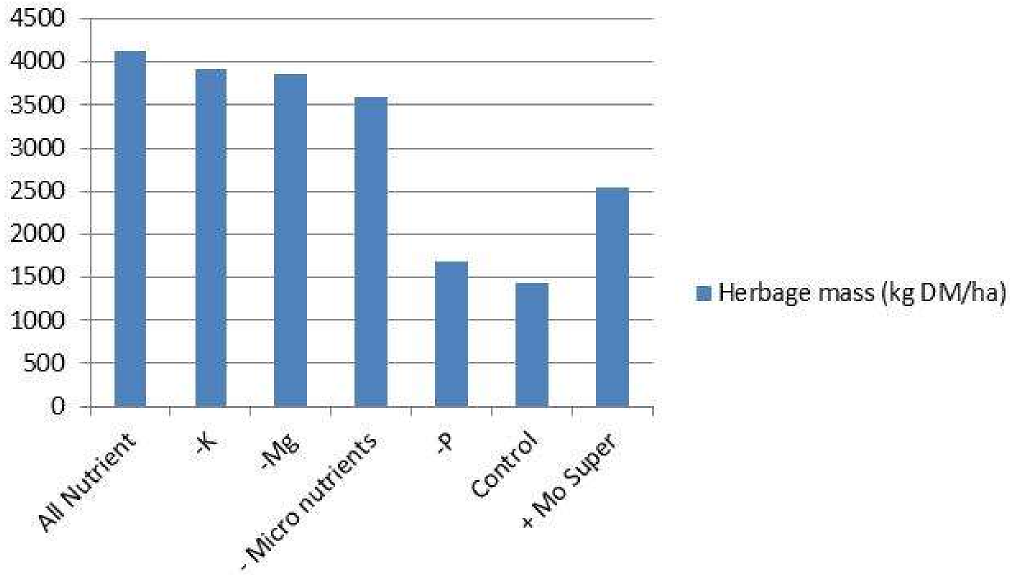

Figure 8: 2015 results from the nutrient subtractive trial at 'Carinya', Laggan.

Appendix 2: Pasture growth rates

Laggan Grazing Demonstration - Average Monthly Pasture Growth Rates (kg DM/ha/day)

Year	Treatment	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2020	Lime + Super	green	14	17	19	7	10	13	15	34	59	51	nc
	Control	green	11	12	5	6	5	7	5	9	13	32	nc
	Super	green	12	14	12	7	9	9	8	20	35	64	nc
2019	Lime + Super	green	green	16	7	4*	7*	0*	7	11	-1	green	nc
	Control	green	green	13	5	3*	4*	-2*	5	4	1	green	nc
	Super	green	green	15	5	4*	6*	-1*	5	6	1	green	nc
2018	Lime + Super	green	3	8	4	12	5	1	4	3	13	-5	green
	Control	green	2	7	2	9	2	0	1	3	3	1	green
	Super	green	3	7	2	12	5	0	2	4	6	2	green
2017	Lime + Super	green	18	23	8	10	5	6	5	12	21	-6	green
	Control	green	12	22	4	5	3	5	3	6	12	-2	green
	Super	green	16	22	6	8	4	6	4	10	16	-5	green
2016	Lime + Super	nc	-8	2	2	17	7	6	7	13	4	29	nc
	Control	nc	-8	0	2	15	5	5	4	9	2	19	nc
	Super	nc	-5	2	2	15	6	5	6	10	4	25	nc
2015	Lime + Super	nc	2	-1	19	3	5	-2	11	11	16	3	nc
	Control	nc	-3	-3	15	4	4	-4	9	10	8	2	nc
	Super	nc	5	4	19	2	7	2	11	10	13	7	nc

nc = not collected   green = pasture contained a green component, but the amount of green was not measured   * pasture affected by grubs

Appendix 3: Botanical Composition

Botanical composition is assessed each spring using the 'End Point Evaluation' technique. This measurement is taken to see if there are significant changes in the composition of the pasture over time. In other words, is there an increase, decrease or no change of certain species as a result of treatment and/or management?

Botanical composition of the three treatments at 'Carinya' *

Species	Pdk 1: Lime + Super						Pdk 2: Control						Pdk 3: Super					
	2015	2016	2017^	2018	2019	2020	2015	2016	2017^	2018	2019	2020	2015	2016	2017^	2018	2019	2020
Microlaena	40	38	39	20	16	17	52	47	49	43	42	47	43	45	45	32	35	21
Wallaby Grass	22	15	13	6	14	7	25	25	17	19	20	21	23	20	9	16	13	8
Annual Grasses	6	9		12	2	4	1	6		2	0	4	5	8		11	1	1
Legumes	19	27	11	49	45	71	8	10	2	7	3	9	13	20	5	19	20	63
Weeds	6	4	9	4	1	1	2	3	7	1	0	5	1	1	6	0	1	2
Bare ground	1	3	2	3	8	0	2	2	3	7	18	11	2	3	3	12	18	1
Litter	5	4	26	6	14	0	10	7	22	18	17	3	13	3	32	10	13	4
Other	2																	

*Numbers indicate the percentage of species present in the pasture sward

^ The 2017 botanical composition was delayed and done much later in the season compared to previous years. As such, a lot of the 'litter' that was recorded was sub clover (and other plant material including microlaena and Wallaby grass) that had senesced due to drying conditions.

Appendix 4: 0-10cm soil test results (summary)

Treatment	pH (CaCl₂)	Al %	Colwell P mg/kg	Sulphur mg/kg	Potassium cmol(+)/kg	CEC cmol(+)/kg	Total Carbon %
2014 (baseline, sampled 10 Dec)							
Paddock 1 (Lime + Super)	4.1	38	11.0	5.4	0.64	4.7	4.7
Paddock 2 Control)	4.0	38	9.4	4.8	0.63	4.5	5.0
Paddock 3 (Super)	4.0	45	8.8	3.7	0.4	4.0	4.0
2015 (sampled 26 Nov)							
Paddock 1 (Lime + Super)	4.2	17	11.0	4.3	0.47	5.7	4.0
Paddock 2 Control)	3.8	38	9.9	4.6	0.68	5.0	4.3
Paddock 3 (Super)	3.8	46	9.4	4.9	0.36	4.4	4.1
2016 (sampled 30 Nov)							
Paddock 1 (Lime + Super)	4.3	18	8.9	<2	0.45	4.5	4.1
Paddock 2 Control)	4.0	39	7.4	<2	0.51	6.1	4.3
Paddock 3 (Super)	3.9	46	8.9	2.4	0.38	5.0	3.9
2017 (sampled 13 Dec)							
Paddock 1 (Lime + Super)	4.2	26	11.0	5.1	0.43	6.0	4.5
Paddock 2 Control)	3.9	46	9.8	4.3	0.54	5.1	4.6
Paddock 3 (Super)	3.9	45	13.0	7.1	0.45	4.9	4.8
2018 (sampled 7 Dec)							
Paddock 1 (Lime + Super)	4.3	17	19.0	8.7	0.58	6.1	4.3
Paddock 2 Control)	3.9	40	13.0	5.8	0.63	4.8	4.6
Paddock 3 (Super)	4.0	36	23.0	8.4	0.48	4.8	4.4
2019 (sampled 22 Jan 2020)							
Paddock 1 (Lime + Super)	4.1	23	20.0	9.0	0.54	6.1	4.4
Paddock 2 Control)	3.8	44	13.0	6.2	0.68	4.9	4.3
Paddock 3 (Super)	3.8	40	31.0	11.0	0.57	5.1	4.1
2020 (sampled 30 Nov)							
Paddock 1 (Lime + Super)	4.1	27	13.0	6.8	0.48	5.6	4.7
Paddock 2 Control)	4.0	46	9.1	3.8	0.48	4.4	4.7
Paddock 3 (Super)	4.0	43	18.0	6.1	0.40	4.7	4.5

Note: Baseline soil testing showed a PBI in the range of 100 to 120 across the demonstration site.

Appendix 5: Lime movement results

Soil pH (CaCl2) profiles

PADDOCK 1: Lime + Super							
Depth (cm)	2014	2016	2017	2018	2019	2020	2021
0 - 2.5	4.2	**5.0**	**5.1**	**4.9**	**4.7**	4.7	
2.5 - 5	4.1	3.9	4.2	4.1	4.0	4.0	
5 - 7.5	4.0	3.8	4.0	4.0	4.0	4.0	
7.5 - 10	4.0	3.8	4.0	4.0	3.9	3.9	
10 - 15	4.0	3.8	4.0	4.0	4.0	4.0	
15 - 20	4.1	3.8	4.0	4.1	4.0	4.0	

PADDOCK 2: Control							
Depth (cm)	2014	2016	2017	2018	2019	2020	2021
0 - 2.5	4.3	4.0	4.2	4.1	4.0	4.0	
2.5 - 5	4	3.8	4.1	4.0	3.9	3.9	
5 - 7.5	4.0	3.8	4.0	4.0	4.0	4.0	
7.5 - 10	4.0	3.8	4.1	4.0	4.0	4.0	
10 - 15	4.1	3.8	4.1	4.1	4.0	4.0	
15 - 20	4.1	3.7	4.1	4.1	4.0	4.0	

PADDOCK 3: Super							
Depth (cm)	2014	2016	2017	2018	2019	2020	2021
0 - 2.5	4.2	4.0	4.1	4.1	4.0	4.0	
2.5 - 5	4	3.8	4.0	3.9	3.9	3.9	
5 - 7.5	4.0	3.8	4.0	4.0	3.9	3.9	
7.5 - 10	4.0	3.8	4.0	4.0	3.9	3.9	
10 - 15	4.1	3.8	4.1	4.0	4.0	4.0	
15 - 20	4.1	3.9	4.1	4.1	4.0	4.0	

Key: (red dashed line) **"Lime Effect"** >0.3 unit change

(blue double line) **Reduced Al% to < 5%**

Soil aluminium (% of CEC) profiles

PADDOCK 1: Lime + Super							
Depth (cm)	2014	2016	2017	2018	2019	2020	2021
0 - 2.5	16	**0**	**0**	**1**	**3**	3	
2.5 - 5	34	29	23	29	25	25	
5 - 7.5	42	41	36	40	39	39	
7.5 - 10	50	48	44	46	42	42	
10 - 15	52	50	50	50	46	46	
15 - 20	55	55	58	52	50	50	

PADDOCK 2: Control							
Depth (cm)	2014	2016	2017	2018	2019	2020	2021
0 - 2.5	12	18	21	24	29	29	
2.5 - 5	35	36	37	40	43	43	
5 - 7.5	42	44	41	44	45	45	
7.5 - 10	46	48	43	46	47	47	
10 - 15	52	52	47	50	50	50	
15 - 20	57	54	48	51	52	52	

PADDOCK 3: Super							
Depth (cm)	2014	2016	2017	2018	2019	2020	2021
0 - 2.5	16	18	21	21	25	25	
2.5 - 5	41	39	39	42	42	42	
5 - 7.5	48	46	46	47	47	47	
7.5 - 10	52	52	49	50	52	52	
10 - 15	62	61	56	55	54	54	
15 - 20	66	63	61	59	59	59	

Appendix 6: Stocking rates across years

The table below shows the stocking rates across all treatments. Wethers are weighed and stocking rates are adjusted accordingly to try and maintain similar liveweights across the treatments. If liveweight is kept the same then wool characteristics will be similar, allowing a fair economic assessment of treatments.

Paddocks are assessed for bracken (*Pteridium esculentum*) each spring to account for differences in the amount of bracken across treatments and therefore effective grazing area. Each 'patch' of bracken is measured using a handheld GPS unit and then visually assessed in terms of its impact on grazing (i.e. a patch containing 100% bracken is rated as having zero grazing value and hence removed from the overall grazing area). The table below shows the adjusted stocking rate once the bracken fern is taken into account.

The number of wethers grazing each paddock and the adjusted stocking rate*

	2015			2016			2017		
Month	**Lime + Super**	**Control**	**Super**	**Lime + Super**	**Control**	**Super**	**Lime + Super**	**Control**	**Super**
Jan	45	35	45	53	35	42	53	35	40
Feb	45	35	45	53	35	42	55	35	40
Mar	45	35	45	53	35	42	55	35	40
Apr	45	35	45	53	35	42	55	35	40
May	45	35	45	53	35	42	55	35	40
Jun	45	35	45	53	35	42	55	35	40
Jul	45	35	45	53	35	38	55	35	40
Aug	45	35	45	53	35	38	55	35	40
Sep	45	35	45	53	35	38	55	35	40
Oct	45	35	45	53	35	38	55	35	40
Nov	45	35	45	53	35	38	55	35	40
Dec	45	35	45	53	35	38	55	35	40
No. of wethers/paddock (averaged over 12 months)	**45**	**35**	**45**	**53**	**35**	**40**	**55**	**35**	**40**
Paddock size (ha)	7.02	6.98	6.97	7.02	6.98	6.97	7.02	6.98	6.97
Total area affected by bracken fern	0.82	0.66	1.84	0.27	0.51	1.22	0.03	0.20	1.22
Adjusted area	6.2	6.32	5.13	6.75	6.47	5.75	6.75	6.47	5.75
Stocking rate (wethers/ha)	6.41	5.01	6.46	7.55	5.01	5.74	7.55	5.01	5.74
Adjusted stocking rate (wethers/ha)	**7.26**	**5.54**	**8.77**	**7.85**	**5.41**	**6.96**	**7.87**	**5.17**	**6.96**

*Adjusted stocking rate which takes grazing area lost to bracken fern into account. A handheld GPS unit was to map out the amount of bracken fern in all treatments

Appendix 6 (cont'd): Stocking rates across years

	2018			2019			2020		
Month	Lime + Super	Control	Super	Lime + Super	Control	Super	Lime + Super	Control	Super
Jan	57	30	40	57	30	40	0	0	0
Feb	57	30	40	57	30	40	0	0	0
Mar	57	30	40	57	30	40	57	30	40
Apr	57	30	40	57	30	40	57	30	40
May	57	30	40	0	0	0	65	30	40
Jun	57	30	40	0	0	0	65	30	40
Jul	57	30	40	51	27	36	65	30	40
Aug	57	30	40	51	27	36	65	30	40
Sep	57	30	40	51	27	36	65	30	40
Oct	57	30	40	51	27	36	65	30	40
Nov	57	30	40	51	27	36	65	30	40
Dec	57	30	40	44	23	31	65	30	40
No. of wethers/paddock (averaged over 12 months)	**57**	**30**	**40**	**44**	**23**	**31**	**53**	**25**	**33**
Paddock size (ha)	7.02	6.98	6.97	7.02	6.98	6.97	7.02	6.98	6.97
Total area affected by bracken fern	0.01	0.23	0.87	0.01	0.23	0.87	0.01	0.23	0.87
Adjusted area	7.01	6.75	6.1	7.01	6.75	6.1	7.01	6.75	6.1
Stocking rate (wethers/ha)	8.12	4.30	5.74	6.27	3.30	4.45	7.55	3.57	4.76
Adjusted stocking rate (wethers/ha)	**8.13**	**4.44**	**6.56**	**6.26**	**3.43**	**5.07**	**7.54**	**3.70**	**5.46**

Appendix 7: Wether production and financial comparison – 2015 to 2020

2015

Wool income				
		LIME + SUPER	CONTROL	SUPER
Production				
Area of paddock	ha	6.20	6.32	5.13
Number of wethers	per paddock	45	35	45
Stocking rate	per ha	7.3	5.5	8.8
GFW (kg)	per head	4.7	4.5	4.4
Clean wool (kg)	per head	3.3	3.2	3.0
Micron	average	18.0	18.4	17.6
Wool Price (Dec 2016)	cents/kg clean	1500	1470	1514
Clean Wool (kg)	per ha	24.0	17.5	26.7
Wool income ($/HA):		359.71	257.09	404.71
Meat income				
Livestock value as of Jan '15				
Average Liveweight	kg	45.0	45.0	45.0
Purchase price	c/kg cwt	300	300	300
Livestock value/hd	$/hd	52.7	52.7	52.7
Livestock value/ha	$/ha	382.1	291.6	461.8
Livestock value as of Dec '15				
Average liveweight off shears	kg	49.8	43.0	44.3
Mutton price	c/kg cwt	300	300	300
Livestock value/hd	$/hd	58.3	50.3	51.8
Livestock value/ha	$/ha	422.9	278.6	454.7
Meat income ($/HA):		40.76	-12.96	-7.18
TOTAL INCOME ($/HA)		400.47	244.13	397.52
Costs				
Variable Costs	$/ha			
Animal health ($3.50/hd)		25.40	19.38	30.70
Wool harvesting ($9.00/hd)		65.32	49.84	78.95
Selling costs (5.5% of wool income)		19.78	14.14	22.26
Fertiliser costs	$/ha	74	0	50
Feeding costs	$/hd	0	0	0
TOTAL COSTS ($/ha)		184.51	83.36	181.91
PROFIT				
$/ha		215.96	160.76	215.62
Difference (to control)		55.20		54.85

2016

Wool income				
		LIME + SUPER	CONTROL	SUPER
Production				
Area of paddock	ha	6.75	6.47	5.75
Number of wethers	per paddock	53	35	40
Stocking rate	per ha	7.9	5.4	7.0
GFW (kg)	per head	4.4	4.4	3.9
Clean wool (kg)	per head	3.2	3.2	2.9
Micron	average	18.0	18.3	17.4
Wool Price (Dec 2016)	cents/kg clean	1710	1689	1750
Clean Wool (kg)	per ha	25.1	17.3	20.2
Wool income ($/HA):		429.65	292.38	353.04
Meat income				
Livestock value as of Dec '15				
Average Liveweight	kg	49.8	43.0	44.3
Purchase price	c/kg cwt	300	300	300
Livestock value/hd	$/hd	58.3	50.3	51.8
Livestock value/ha	$/ha	457.5	272.2	360.6
Livestock value as of Feb '17				
Average liveweight off shears	kg	53.0	48.5	48.2
Mutton price	c/kg cwt	413	413	413
Livestock value/hd	$/hd	94.1	86.1	85.6
Livestock value/ha	$/ha	739.0	465.9	595.5
Meat income ($/HA):		281.54	193.78	234.90
TOTAL INCOME ($/HA)		711.19	486.15	587.95
Costs				
Variable Costs	$/ha			
Animal health ($3.50/hd)		27.48	18.93	24.35
Wool harvesting ($9.00/hd)		70.67	48.69	62.61
Selling costs (4% of wool income)		23.63	16.08	19.42
Fertiliser costs	$/ha	74	0	50
Feeding costs	$/hd	0	0	0
TOTAL COSTS ($/ha)		195.78	83.70	156.37
PROFIT				
$/ha		515.42	402.45	431.57
Difference (to control)		112.96		29.12

2017				
Wool income				
		LIME + SUPER	**CONTROL**	**SUPER**
Production				
Area of paddock	ha	6.99	6.78	5.75
Number of wethers	per paddock	55	35	40
Stocking rate	per ha	7.9	5.2	7.0
GFW (kg)	per head	5.8	5.1	5.7
Clean wool (kg)	per head	4.2	3.6	4.1
Micron	average	17.8	17.3	17.9
Wool Price (Dec 2017)	cents/kg clean	2116	2272	2116
Clean Wool (kg)	per ha	32.7	18.8	28.2
Wool income ($/HA):		690.95	426.92	597.63
Meat income				
Livestock value as of Feb '17				
Average Liveweight	kg	35.9	36.9	35.6
Purchase price	c/kg cwt	500	500	500
Livestock value/hd	$/hd	70.0	72.0	69.4
Livestock value/ha	$/ha	550.8	371.4	482.9
Livestock value as of Dec '17				
Average liveweight off shears	kg	54.9	48.4	54.3
Mutton price	c/kg cwt	444	444	444
Livestock value/hd	$/hd	104.8	92.4	103.7
Livestock value/ha	$/ha	824.7	477.0	721.2
Meat income ($/HA):		273.90	105.57	238.26
TOTAL INCOME ($/HA)		964.85	532.49	835.89
Costs				
Variable Costs	$/ha			
Animal health ($3.50/hd)		27.54	18.07	24.35
Wool harvesting ($9.00/hd)		70.82	46.46	62.61
Selling costs (4% of wool income)		38.00	23.48	32.87
Fertiliser costs	$/ha	86	0	62
Feeding costs	$/hd	0	0	0
TOTAL COSTS ($/ha)		222.36	88.01	181.83
PROFIT				
$/ha		742.50	444.48	654.06
Difference (to control)		298.01		209.58

2018				
Wool income				
		LIME + SUPER	**CONTROL**	**SUPER**
Production				
Area of paddock	ha	7.01	6.75	6.10
Number of wethers	per paddock	57	30	40
Stocking rate	per ha	8.1	4.4	6.6
GFW (kg)	per head	4.6	5.0	4.9
Clean wool (kg)	per head	3.2	3.4	3.4
Micron	average	17.0	17.2	17.6
Wool Price (Dec 2018)	cents/kg clean	2450	2430	2400
Clean Wool (kg)	per ha	25.9	15.3	22.2
Wool income ($/HA):		633.50	371.52	531.93
Meat income				
Livestock value as of Dec'17				
Average Liveweight	kg	54.9	51.4	54.3
Purchase price	c/kg cwt	444	444	444
Livestock value/hd	$/hd	104.8	98.1	103.7
Livestock value/ha	$/ha	852.3	436.1	679.8
Livestock value as of Dec '18				
Average liveweight off shears	kg	54.9	53.0	52.2
Mutton price	c/kg cwt	410	410	410
Livestock value/hd	$/hd	96.8	93.4	92.0
Livestock value/ha	$/ha	787.0	415.3	603.5
Meat income ($/HA):		-65.26	-20.86	-76.33
TOTAL INCOME ($/HA)		568.24	350.66	455.60
Costs				
Variable Costs	$/ha			
Animal health ($3.50/hd)		28.46	15.56	22.95
Wool harvesting ($9.00/hd)		73.18	40.00	59.02
Selling costs (4% of wool income)		34.84	20.43	29.26
Fertiliser costs	$/ha	86	0	62
Feeding costs	$/ha	161.65	88.36	130.36
TOTAL COSTS ($/ha)		384.13	164.34	303.58
PROFIT				
$/ha		184.11	186.31	152.02
Difference (to control)		-2.21		-34.30

2019

Wool income		LIME + SUPER	CONTROL	SUPER
Production				
Area of paddock	ha	7.01	6.75	6.10
Number of wethers	per paddock	44	23	31
Stocking rate	per ha	6.3	3.4	5.1
GFW (kg)	per head	6.9	6.7	6.6
Clean wool (kg)	per head	4.7	4.6	4.5
Micron	average	18.9	18.7	19.2
Wool Price (Feb 2020)	cents/kg clean	1774	1840	1809
Clean Wool (kg)	per ha	29.5	15.7	22.9
Wool income ($/HA):		524.05	288.86	414.93
Meat income				
Livestock value as of Dec'18				
Average Liveweight	kg	54.9	53.0	52.2
Purchase price	c/kg cwt	410.0	410.0	410.0
Livestock value/hd	$/hd	96.8	93.4	92.0
Livestock value/ha	$/ha	607.5	318.4	467.7
Livestock value as of Dec '19				
Average liveweight off shears	kg	66.9	59.4	59.5
Mutton price	c/kg cwt	544	544	544
Livestock value/hd	$/hd	156.5	138.9	139.2
Livestock value/ha	$/ha	982.3	473.5	707.3
Meat income ($/HA):		374.75	155.07	239.63
TOTAL INCOME ($/HA)		898.80	443.93	654.56
Costs				
Variable Costs	$/ha			
Animal health ($3.50/hd)		21.97	11.93	17.79
Wool harvesting ($9.00/hd)		56.49	30.67	45.74
Selling costs (4% of wool income)		28.82	15.89	22.82
Fertiliser costs	$/ha	92.20	0	68.20
Feeding costs	$/ha	71.55	38.84	57.93
TOTAL COSTS ($/ha)		271.04	97.32	212.48
PROFIT				
$/ha		627.76	346.60	442.08
Difference (to control)		281.16		95.48

2020

Wool income		LIME + SUPER	CONTROL	SUPER
Production				
Area of paddock	ha	7.01	6.75	6.10
Number of wethers	per paddock	53	25	33
Stocking rate	per ha	7.5	3.7	5.5
GFW (kg)	per head	7.1	6.4	7.1
Clean wool (kg)	per head	5.1	4.5	5.1
Micron	average	19.0	18.4	18.7
Wool Price (Dec 2020)	cents/kg clean	1450	1552	1500
Clean Wool (kg)	per ha	38.5	16.7	27.8
Wool income ($/HA):		557.58	258.41	417.69
Meat income				
Livestock value as of Feb'20				
Average Liveweight	kg	42.7	42.7	41.9
Purchase price	c/kg cwt	830.0	830.0	830.0
Livestock value/hd	$/hd	145.3	145.3	142.6
Livestock value/ha	$/ha	1095.6	537.6	778.5
Livestock value as of Dec '20				
Average liveweight off shears	kg	63.0	58.7	65.2
Mutton price	c/kg cwt	680	680	680
Livestock value/hd	$/hd	184.2	171.6	190.6
Livestock value/ha	$/ha	1389.0	635.1	1040.9
Meat income ($/HA):		293.34	97.42	262.40
TOTAL INCOME ($/HA)		850.92	355.83	680.09
Costs				
Variable Costs	$/ha			
Animal health ($3.50/hd)		26.39	12.95	19.11
Wool harvesting ($9.00/hd)		67.86	33.30	49.14
Selling costs (4% of wool income)		30.67	14.21	22.97
Fertiliser costs	$/ha	90.20	0	53.25
Feeding costs	$/ha			
TOTAL COSTS ($/ha)		215.12	60.46	144.47
PROFIT				
$/ha		635.80	295.37	535.62
Difference (to control)		340.43		240.25

Appendix 8: Fertiliser, lime and supplementary feeding costs

Fertiliser

Lime + Super	2015	2016	2017	2018	2019	2020	Ave
Price delivered ($/t)	344	344	344	344	335	370	347
Rate applied (kg/ha)	125	125	160	160	170	160	150
Fertiliser price ($/ha)	43	43	55	55	57	59	52
Spreading cost ($/ha)	7	7	7	7	7	7	7
Total cost ($/ha)	**50**	**50**	**62**	**62**	**66**	**66**	**59**

Super	2015	2016	2017	2018	2019	2020	Ave
Price delivered ($/t)	344	344	344	344	335	370	347
Rate applied (kg/ha)	125	125	160	160	170	125	144
Fertiliser price ($/ha)	43	43	55	55	57	46	50
Spreading cost ($/ha)	7	7	7	7	7	7	7
Total cost ($/ha)	**50**	**50**	**62**	**62**	**64**	**53**	**57**

Lime

Lime	
Price delivered ($/t)	45
Freight ($/t)	16
Spreading cost ($/t	19
Total cost ($/t)	80
Spreading rate (t/ha)	2.5
Total cost ($/ha)	**200**
Life of application (years)	10
Annual cost ($/ha/yr)	20
plus interest @ 6% ($/ha)	4
Total annual cost ($/ha)	**24**

Supplementary feeding costs:

Due to drought conditions all paddocks were destocked during winter in both 2018 and 2019. Wethers from all three treatments were mixed together and run as a separate mob in a nearby paddock. The table below shows the calculations used to attribute a feeding cost for these two periods.

	2018	**2019**
Date livestock removed	24-Jul	6 Jun
Stock back in	3-Oct	5 Aug
No. days removed	71	60
Cost of feeding 12.5 ME barley ($/tonne landed)	500	340
Daily 'as fed' amount	0.56	0.56
$/hd/day	0.28	0.19
Cost for period ($/hd)	**19.88**	**11.40**

Appendix 9: Wether production and financial data across years

	2015	2016	2017	2018	2019	2020	2021
Lime + Super							
Wethers/ha*	7.3	7.6	7.9	8.1	7.01	7.5	
GFW (ave kg/hd)	4.7	4.4	5.8	4.6	6.9	7.1	
Micron (ave)	18.0	18.0	17.8	17.0	18.9	19	
Wool cut (kg wool/ha, clean)	24.0	24.6	32.7	25.9	29.5	38.5	
Wool income ($/ha/yr)	395.71	394.68	690.95	633.50	524.05	557.58	
Meat income ($/ha/yr)	40.76	161.15	273.90	-65.26	664.96	293.34	
Total income ($/ha/yr)	400.47	555.83	964.85	568.24	1189.01	850.92	
Total costs ($/ha/yr)**	169.23	173.89	222.36	384.13	271.04	215.12	
Operating profit ($/ha/yr)	231.24	381.94	742.50	184.11	917.97	635.80	
Difference to control ($/ha profit/yr)	+58.32	+91.23	+298.01	-2.21	427.27	340.43	
Control							
Wethers/ha*	5.5	5.4	5.2	4.4	6.75	3.7	
GFW (ave kg/hd)	4.5	4.4	5.1	5.0	6.7	6.4	
Micron (ave)	18.4	18.3	17.3	17.2	18.7	18.4	
Wool cut (kg wool/ha, clean)	17.5	17.3	18.8	15.3	15.7	16.7	
Wool income ($/ha/yr)	257.09	292.38	426.92	371.52	288.86	258.41	
Meat income ($/ha/yr)	-12.96	187.32	105.57	-20.86	299.16	97.42	
Total income ($/ha/yr)	244.13	479.70	532.49	350.66	588.02	355.83	
Total costs ($/ha/yr)	71.20	71.20	88.01	164.34	97.32	60.46	
Operating profit ($/ha/yr)	172.93	408.49	444.48	186.31	490.70	295.37	
Super							
Wethers/ha*	8.8	7.9	7.0	6.6	6.1	5.5	
GFW (ave kg/hd)	4.4	3.9	5.7	4.9	6.6	7.1	
Micron (ave)	17.6	17.4	17.9	17.6	19.2	18.7	
Wool cut (kg wool/ha, clean)	26.7	23.5	28.2	22.2	22.9	27.8	
Wool income ($/ha/yr)	404.71	378.88	597.63	531.93	414.93	417.69	
Meat income ($/ha/yr)	-7.18	113.86	238.26	-76.33	444.99	262.40	
Total income ($/ha/yr)	397.52	492.74	835.89	455.60	859.91	680.09	
Total costs ($/ha/yr)	162.68	151.66	181.83	303.58	212.48	144.47	
Operating profit ($/ha/yr)	234.84	341.07	654.06	152.02	647.43	535.62	
Difference to control ($/ha profit/yr)	+61.92	+50.36	209.58	-34.30	156.74	240.25	

* Paddock areas were adjusted to take into account grazing area lost to bracken fern (i.e. some paddocks had more bracken fern than others. A handheld GPS unit was to map out the amount of bracken fern in all treatments.

** The cost of applying lime ($24/ha) is presented as an annualised cost. This cost is based on lime delivered at 'Carinya' plus spreading costs and interest (6% p.a.) over a 10 year period (all prices GST exclusive). The annualised cost of lime ($25/ha) is then added to the cost of single superphosphate.

Appendix 10: Results from the Bookham Grazing Demonstration

13 Year wether production data from the Grazing Demonstration at 'Kia-Ora', Bookham NSW.

SUPER	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	13 YEAR AVGE
Stocking Rate / ha	11.05	10.70	11.20	12.80	13.20	14.00	14.90	14.90	14.60	12.60	14.50	15.10	15.10	13.43
Total Clean Wool kg/ha	35.30	39.90	41.30	39.90	43.60	50.20	53.60	56.00	43.50	31.60	34.00	41.50	35.40	41.98
Total Wool Income $/ha	462.43	251.37	255.73	374.66	218.44	347.43	701.41	574.56	581.16	285.35	311.58	341.13	415.95	393.93
Total Cost $/ha	258.32	225.97	217.28	248.73	251.09	228.96	281.51	297.64	289.89	392.99	344.11	333.48	321.06	283.92
Profit $/ha	204.11	25.40	38.45	125.93	-7.33	136.01	419.90	276.92	291.27	-107.64	-32.53	7.65	94.89	113.31
Difference Super-No Super $/ha Profit	94.90	5.07	23.86	72.04	15.24	124.31	287.63	209.04	123.67	-41.65	-9.65	40.67	78.82	**78.76**
Cost of Production c/kg Clean	7.32	5.66	5.26	6.23	5.76	4.56	5.25	5.32	6.66	12.44	10.12	8.03	9.07	7.05

NO SUPER	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	13 YEAR AVGE
Stocking Rate / ha	6.30	6.30	6.30	6.30	6.30	6.30	6.10	6.10	6.30	6.10	5.80	5.30	5.80	6.10
Total Clean Wool kg/ha	19.50	22.90	22.20	19.50	19.50	23.80	22.90	22.50	22.10	15.60	15.60	15.50	14.10	19.67
Total Wool Income $/ha	253.50	151.83	138.46	191.30	116.22	149.94	288.08	225.00	333.05	158.50	151.32	122.76	178.08	189.08
Total Cost $/ha	144.29	131.50	123.87	137.41	138.79	138.24	155.81	157.12	165.45	224.49	174.20	155.78	162.01	154.53
Profit $/ha	109.21	20.33	14.59	53.89	-22.57	11.70	132.27	67.88	167.60	-65.99	-22.88	-33.02	16.07	34.54
Cost of Production c/kg Clean	7.40	5.74	5.58	7.05	7.12	5.81	6.80	6.98	7.49	14.39	11.16	10.05	11.49	8.23