final report

Project code: E.PDS.1412

Prepared by: Holbrook Landcare Network

Date published: November 2014

PUBLISHED BY
Meat & Livestock Australia Limited
PO BOX 1961
NORTH SYDNEY NSW 2059

Part 2: 2013-2014

Alternatives to Superphosphate -

"Carp, Kelp and Christmas Island: where to next for fertilisers?

Meat & Livestock Australia acknowledges the matching funds provided by the Australian Government to support the research and development detailed in this publication.

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Abstract

Increased costs of superphosphate prompted producers to consider alternative products to provide similar pasture growth responses. No statistically significant data could be produced in support of superphosphate alternatives regarding increased pasture growth response through soil nutrient content or biological activity.

The initial PDS demonstration site, established in 2009 to evaluate a selection of products against a NIL control and superphosphate, found no products improved pasture growth over three seasons. Additionally, the interpretation of trends in soil properties at the start and end of the demonstration were constrained by reliance on two data points that can fluctuate seasonally.

The extension of the demonstration by two additional growing seasons showed no cumulative effects on pasture growth for any treatment.

Soil sampling from 2013 and 2014 highlighted methodological challenges in the 2013 data due to changes in funding intervals and consequent storage conditions. However, the additional two years of data showed a net importation of nutrients onto the site via the grazing method used, and no further conclusions could be drawn about trends in the soil phosphorus concentrations.

In summary, there were no measured production or economic benefits gained from the application of alternative products to a typical Holbrook pasture and soil type for the six seasons of the demonstration.

Executive Summary

The purpose of this extension was to provide additional time for product treatments to express any cumulative effects beyond the first three years of the initial producer demonstration site (PDS). Secondly, the extension enabled soil phosphorus trends to be better monitored in the presence and absence of added fertiliser P, and for herbage to be analysed to check that no micro-nutrient deficiencies and/or elemental toxicities were constraining pasture growth across the site.

The original three-year PDS found that treatment effects (using products that included soil microbes, industrial by-products and compost) showed no statistically significant variances in pasture growth, composition or feed quality, relative to either single superphosphate or NIL control treatments.

New batches of the treatment products were sourced and applied in 2014 and their soluble nitrogen (N), phosphorus (P) and potassium (K) contents analysed. While there was little change in their P and K concentrations, compared with the 2009 batches, there were variations in the N concentrations of some treatment products. Following further annual applications of the treatments in 2013 and 2014, no statistically significant variances were recorded in pasture growth or quality, relative to the NIL control.

Tissue analyses of rapidly-growing pasture collected in spring 2013 showed all plant nutrients were within normal concentration ranges and that all potentially toxic elements were either below analytical detection limits or below toxic concentrations.

Based on soil samples taken in 2009, 2012, 2013 and 2014, overall soil P concentrations increased modestly across all treatments from 2009 to 2012 (Colwell P: +6 to +39, average = +16, Olsen P: +2 to +15, average = +5 and Total P: +2 to +100; average = +47) and strongly from 2012 to 2014, even where no fertiliser P had been added. The project team concluded that the crash-grazing method used to remove pasture growth over each growing season had contributed to the increased concentrations of soil P and other macro-nutrients across the site. Thus, no meaningful conclusions can be drawn about the seasonal trends in plant nutrient availabilities for the treatments in this demonstration.

The monitoring of soil microbial properties showed that no treatment had any statistically significant effects on microbial abundance and activity.

The conclusion drawn from this six year demonstration is that no statistically significant differences were observed in pasture growth or pasture quality when compared with single superphosphate or no added fertiliser.

This PDS was conducted on a limed, well-fertilised soil, as producers wanted information on the effects of alternative products on pasture growth on soils that were already well supplied with available P. They identified the need for an objective baseline to begin discussions on the economics of pasture production, fertiliser and nutrient management in high-rainfall, pastoral farming systems with high P soils.

The 2014 annual costs of treatments are reported but in the absence of any pasture growth responses, no comparative cost: benefit analyses can be made.

In assessing the impact and effectiveness of the producer demonstration process, community feedback recorded increased awareness and knowledge of useful and

relevant fertiliser information to landholders. However, the PDS has identified the need for ongoing support of landholders' evidence based decision-making processes to ensure appropriate nutrient management and pasture extension to enable practice change.

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Background

In 2008, large price increases in single superphosphate sparked producer's interest in 'alternatives to superphosphate'. Members of the Holbrook Landcare Network (HLN) Beef Committee established a MLA Producer Demonstration Site (PDS) in 2009 to assess potential production and economic benefits of selected alternative products against superphosphate in the '*Carp, Kelp and Christmas Island: where to next with fertilisers?*' project.

The PDS was established on a phalaris-based pasture which is representative of the high-rainfall, mixed-farming enterprises that are widespread in the Holbrook district. A range of treatments were applied annually. Products selected for the demonstration varied in their mode-of-action, nutrient/biological content and organic matter content.

Pasture growth was measured for three growing seasons (2009-2011) and all plots soil sampled in July 2012, three years after the pre-treatment soil sampling.

Following completion of the MLA 'Alternative Fertiliser' PDS in early 2013, external expert (Dr Lewis Kahn) reviewed the demonstration and recommended the Holbrook field demonstration continue for two additional seasons to allow sufficient time for the demonstration site to express any medium-term effects. Dr Kahn made some recommendations on the most appropriate soil microbiological measurements to be taken in the 2013 and 2014 growing seasons.

Holbrook Landcare Network then sought an additional two years of funding from MLA to continue to monitor soil nutrient levels, microbial populations and pasture growth responses.

Producer needs

Holbrook Landcare Network (HLN) is a landcare and producer group based in Holbrook, NSW, representing over 450 members. Their members represent an economically and socially resilient agricultural community with a strong environmental ethic. HLN facilitates and supports the rural community to achieve economic, environmental and social outcomes for the region by engaging with members in local and regionally relevant issues to enable evidence based decision making with a focus on the high rainfall zone, mixed farming system of southern NSW.

Holbrook Landcare Network would like to acknowledge Project Agronomist, Jeff Hirth for his dedication to the project over the 5 year period.

HLN would also like to acknowledge the role of the HLN Beef sub-committee, the Grasslands Society of Southern Australia Inc. and the Australian Government - Caring for Our Country (CFOC) support in the developmental stage of the PDS process.

The HLN Beef sub-committee is an initiative of landholders within the HLN membership focusing on specific issues relevant to beef producers in the high rainfall zone (HRZ). HLN beef producers involved directly in the demonstration include: Marcus Richardson, Table Top NSW; Ian Locke, Holbrook NSW; and Lucinda and Bryan Corrigan, Bowna and Culcairn, NSW. The key landholders directly manage approximately 5000 head of cattle, with the largest herd size around 3000 head and the smallest herd size around 950 head. The key landholders involved with the demonstration collectively manage 5,150 hectares of pastoral land with property sizes ranging from 900 hectares to 2450 hectares.

HLN members in the high-rainfall mixed farming zone identified the need for independent and objective information and extension advice, in order to make evidence-based land management decisions. HLN identified a research and extension gap in the emerging agricultural product market. Landholders were seeking independent research data to manage the fertility of their soils and the phosphorus nutrition of their pastures to manage the feed requirements of their livestock. HLN encourages land managers to reflect on their pasture growth objectives while considering their economic position and returns on investment in their grazing enterprises.

Expected benefits

The extension resulting from the Holbrook PDS aims to objectively compare the performance of selected products, based on sound and accepted scientific principles, by considering economic returns, fertiliser composition, dry matter (DM) yields, feed quality, and soil elemental and microbial levels.

Producers will benefit primarily from objective comparisons of the treatments, and secondly from extension activities based around the project, including group discussions on fertilisers available in the market place, objective measurement of pasture DM yields, economic discussions and a greater understanding of nutrient management principles.

Objective evaluation and effective communication of these results will provide producers with better information on which to make informed decisions on reducing their unit costs of production.

Project objectives

The objectives of the initial three-year project (B.PDS.0003) were to:

1. measure the effects of alternatives to, and supplements of, single superphosphate on the growth of a phalaris-sub clover pasture on a limed soil well-endowed with plant available phosphorus (Colwell P = 59 mg/kg),
2. measure the changes in 21 elemental and microbial properties of the treated soils prior to and three years after the application of all products,
3. use the differences in pasture growth and quality, together with changes in the measured soil properties, to rank the economic benefits of the fertiliser and soil ameliorant products.

The modified objectives for the continuation of the project as E.PDS.1412 over the 2013 and 2014 growing seasons were to:

1. establish annual variations in soil phosphorus concentrations to better define the longer term impact of the treatment products,
2. compare treatment effects on the abundance and activity of soil bacterial and fungal populations,
3. determine and assess the impact of treatments on the mineral content of fodder,
4. determine the impact of treatments on pasture production (kg DM/ha) at key seasonal times, and
5. conduct an economic analysis of the costs and benefits of each treatment.

Methodology

Trial Design

The trial design consisted of 10 treatments, replicated four times in a randomised block layout to give 40 plots 2 m wide and 10 m long. Products to be tested were selected from those available locally and were applied at the rates and manner recommended by their supplier/manufacturer. There were two control (no fertiliser or product applied) plots in each replicate block.

Application

All treatments, including the control; single superphosphate, were applied on 7 May 2013 and 8 April 2014 at the same rates and in the same manner as in the previous four years. The annual application rates were:

Product	Application Rate	Mode of Action
Single Superphosphate	123 kg/ha or 0.6 kg P/DSE	fertiliser
Bactivate Plus	75 kg/ha	microbial *
Biodiesel by-product	100 kg/ha,	industrial by-product
Calsap	20 L/ha,	soil ameliorant *
NutriSoil LS	5 L/ha in autumn & spring	liquid plant & soil microbial food *
Prolong®	491 kg/ha every fourth year	biologically-activated rock phosphate*
R.U.M.	5 L/ha	liquid plant & soil microbial food *
Compost	1000 kg/ha	soil ameliorant *

* purported to contain biologically active materials or microbial cultures
Bactivate Plus was applied with 2 L/ha of a commercial source of humic acids (Monty's Liquid Carbon)

Fresh batches of the above products were re-sourced and applied in 2014. The available phosphorus, potassium and nitrogen concentrations of all fresh products were analysed by a fertiliser laboratory in May 2014.

Soil Sampling

On 16 August 2013 and again on 22 August 2014 the 40 plots were soil sampled to 10 cm depth as follows; 30 soil cores were collected from each plot, mixed and subsampled for soil biological and chemical analyses. The samples for soil microbiological analyses were immediately packed in portable coolers and sent via overnight courier to the soil microbiological laboratory.

In 2013, soil samples were collected for soil chemical analysis (retained, air dried and stored at room temperature) until funds were available in May 2014. The 2013 soils were sent in their dry condition to the soil chemical laboratory at the end of May 2014. The 2014 samples were sent direct to the soil chemical laboratory in their field moist condition four days after soil sampling. The following analysis were carried out on all soil samples collected in 2009, 2012, 2013 and 2014: Colwell P, Olsen P, Colwell K, KCl_{40} extractable sulphur, ammonium N, nitrate N, pH (two extractants), EC, organic matter, exchangeable Ca, Mg, K, Na and Al, PBI, total P and total N.

Soil microbiology was analysed to determine any treatment effects on the abundance and activity of soil bacterial and fungal populations. Soil microbial biomass carbon levels were identified to derive microbial abundance relative to superphosphate, and, a fluorescein diacetate activity (FDA) assay was used to measure microbial activity to distinguish between active (living) and non-active (dead) soil bacteria and fungi.

In 2013, Dr Lewis Kahn concluded that the project continue to use the same soil microbiological analyses as before, namely soil microbial biomass carbon and the fluorescein diacetate activity (FDA) assay.

Microbial biomass carbon is a direct measure of the weight of carbon in soil microorganisms, while the fluorescein diacetate (FDA) hydrolysis assay measures the activity of extracellular microbial enzymes in soil and as such provides an indirect measure of microbial abundance in soil. For both measures, relative changes over time provide a relatively simple assessment of the effect(s) of management practices, such as the addition of fertilisers, on the abundance of soil microorganisms. However, interpretation of their absolute values is constrained by the absence of critical values for most soil types. Nevertheless, these two measures of soil microbial abundance are the most reliable available and do provide the best data possible.

Pasture Sampling

The pasture on the site was phalaris, rye grass and sub clover dominated with a smaller component of other common annual grasses such as barley grass.

Ten toe-grab samples of pasture were collected from each plot on 23 September 2013 The replicate samples from each treatment were bulked and stored at -18° C until funds became available for the analysis of their feed quality and elemental tissue concentrations. Ten frozen pasture samples were sent direct to the feed test laboratory on 19 May 2014.

Pasture dry matter yields of all 40 plots were measured on 30 October 2014 using a rising plate meter (see Figure 1). Photographs of all labelled treatment plots were also taken with an MLA-Pasture Ruler in each photograph (see Appendix 4).

An average of 36 rising plate height measurements were recorded for each plot and at the conclusion of plot height measurements, 14 calibration measurements were taken, representing the range of pasture heights across the site. All pasture herbage within each calibration quadrat was cut by hand to ground level, dried at 70° C for 48 hours and a calibration equation developed between dried pasture mass and plate height to calculate plot dry matter yields.

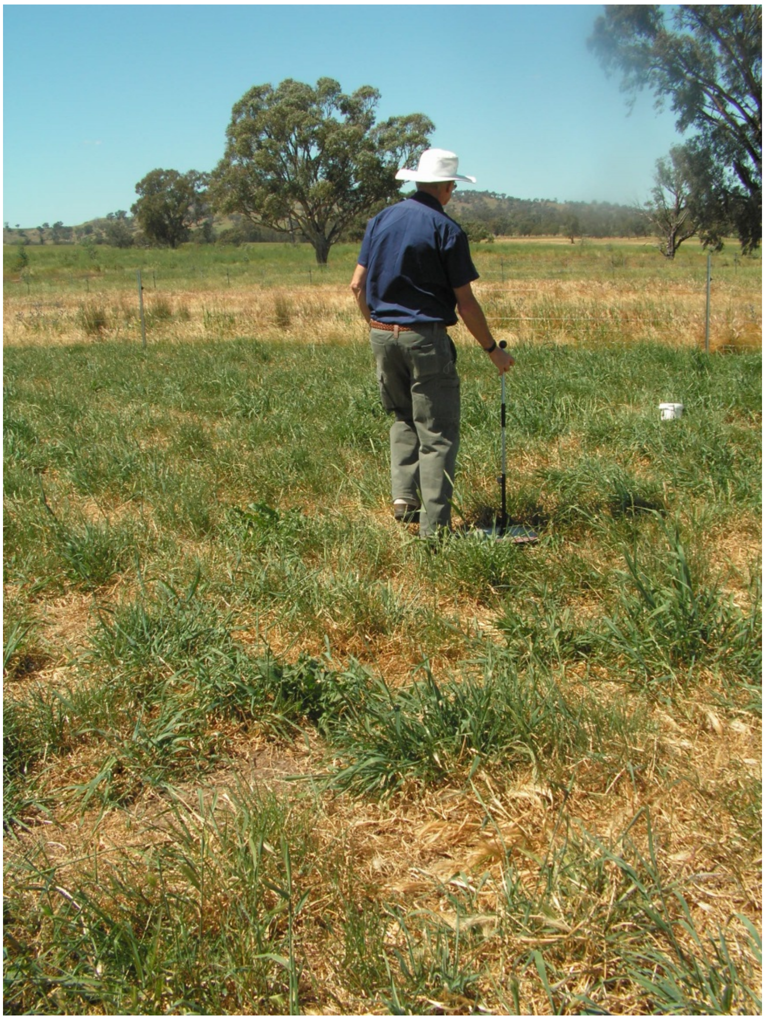


Figure 1. Project Agronomist, Jeff Hirth, using the rising plate meter to measure pasture growth as part of the Holbrook Landcare Network PDS.

All replicated data were statistically analysed by the Analysis of Variance general linear model of Minitab statistical software. Duncan's multiple range test was applied to significant treatment differences to increase robustness against false positive differences.

Pasture Monitoring

The property owner, Mr Ian Locke, continuously monitored the demonstration site, and once the estimated pasture dry matter yields exceeded 2.5 t/ha, Mr Locke visually assessed all plots for any observable growth differences between treatments. The site was then 'crashed-grazed, as in previous years, with at least 200 sheep for approximately 12 hours.

Results

Nutrient content of treatment products

The products first applied in 2009 were analysed for their soluble N, P and K concentrations in 2009 and were applied annually until 2013. The newly sourced products applied in 2014 were analysed for their soluble nitrogen (N), phosphorus (P) and potassium (K) concentrations (Table 1) to assess any changes to product composition and to ensure consistency in the rate of nutrient being applied. Bactivate Plus replaced the original Bactivate in 2010; where Bactivate Plus was applied in conjunction with Monty's Liquid Carbon (as per manufacturers/suppliers recommendation). Bactivate Plus replaced Bactivate which had been applied in 2009 with additional Blood & Bone. Bactivate Plus was first analysed in 2014. Johnson's Compost was first applied and analysed in 2010 and applied annually thereafter.

All treatment products contain negligible concentrations of soluble N (from <0.001 to 1.72 per cent) compared with commercial nitrogenous fertilisers like urea which contains 46 per cent N.
Analysis of the treatment products showed small variations in the soluble N contents between the 2009 and 2014 batches of some products, most notably Johnson's compost, which contained 0.4 per cent N in 2010 and 1.7 per cent N in 2014. In 2009, Calsap contained 0.2 per cent N but 0.8 per cent in 2014.

The soluble P concentrations of the 2014 batches of the treatment products were similar to those for the 2009 batches with three products below the detection limits in both years while another three contained less than 1.0 per cent soluble P. The 2009 batch of Prolong® was re-applied in 2014 and not re-analysed due to the product being discontinued.

Table 1. The soluble nitrogen (N), phosphorus (P) and potassium (K) concentrations (g/kg or mg/L) of the treatment products applied from 2009 to 2013 and in 2014.

	2009	**2014**	**2009**	**2014**	**2009**	**2014**
Product	**Soluble N**		**Soluble P**		**Soluble K**	
Particulates	***(g/kg)***		***(g/kg)***		***(g/kg)***	
Bactivate [A]	1.3		11.3		2.5	
Blood & bone [A]	0.2		49.1		9.6	
Bactivate Plus [B]		1.2		2.3		<0.5
Humic Acid [B]		<0.01		<0.1		<0.5
Biodiesel by-product	0.1	0.5	<0.1	<0.1	352	348
Johnson's compost [B]	0.4[C]	1.7	0.41	0.40	31	62
Prolong®	0.1	nm	131	nm	25	nm
Superphosphate	0.0	0.0	88	88	0	0
Liquids	***(mg/L)***		***(mg/L)***		***(mg/L)***	
CalSap	205	845	<0.1	<0.1	17	21
NutriSoil LS	127	112	<0.1	<0.1	<0.5	<0.5
R.U.M.	1643	1320	6.4	5.2	6	7

[A] Applied in only 2009; [B] Applied 2010 to 2014; [C] analyses done in 2010; nm =not measured.

For the soluble K concentrations a similar picture emerged. There were negligible changes between the 2014 and 2009 batches of the biodiesel by-product, NutriSoil LS and R.U.M. The soluble K concentrations of Johnson's compost increased from 0.3 per cent in 2010 to 0.6 per cent in 2014, while Calsap decreased from an albeit low (0.0174 per cent) concentration to extremely low (0.0021 per cent) concentration.

To put these concentrations into context, superphosphate supplied 10.8 kg of soluble P/ha annually, and Prolong 64.2 kg/ P/ha every fourth year. In contrast, Johnson's compost only supplied 0.4 kg soluble P/ha/year, the original Bactivate with blood and bone, and the replacement Bactivate Plus with humic acid 0.2 kg soluble P/ha annually and Biodiesel by-product, 0.1 kg/ha/year. No other products supplied any P.

Five products supplied no soluble N, while the remaining products supplied very low amounts compared with, for example, 100 kg/ha urea which provides 46 kg N/ha. The 2010 and 2014 batches of Johnson's compost provided 0.4 and 1.7 kg N/ha, respectively, while the Biodiesel by-product provided 0.3 kg N/ha annually. Prolong also supplied 0.1 kg N/ha in 2009 and 2014 from its fish meal component.

The Biodiesel by-product was the only product to provide adequate quantities of K at 35.2 kg/ha/annum, which is equivalent to 70 kg/ha of muriate of potash. Both batches of Johnson's compost provided 3.1 kg K/ha, while Calsap provided 0.4 kg K/ha per year. The original Bactivate with blood and bone supplied 1.8 kg K/ha, while the replacement Bactivate Plus with humic acid supplied negligible amounts of K.

Pasture growth responses

Over the 2013 and 2014 growing seasons, visual assessments of the amounts of pasture dry matter on the treatment plots were made by the site manager prior to each grazing and reports have shown no visual differences between treatments on any occasion.

The dry matter yields measured at the end of the 2014 growing season found there were no statistically significant ($P>0.05$) differences between any of the treatments (Table 2).

Table 2. Pasture dry matter yields of a range of treatment products on 30 October 2014, expressed as a percentage of the NIL control and single superphosphate treatments.

	NIL control	Single superphosphate
Actual DM yield (t/ha)	7.653	7.629
Percentage yields		
Bactivate	98.7%	99.0%
Biodiesel	100.7%	101.0%
CalSap	99.4%	99.7%
Johnson's compost	101.0%	101.4%
NutriSoil LS	99.0%	99.4%
Prolong®	98.2%	98.5%
R.U.M.	100.5%	100.8%
Single superphosphate	99.7%	-

At the time of this harvest on 30 October 2014, all the annual grasses and legumes had senesced and sampling across the trial site showed there was significant amounts of dead leaf litter in and around the base of the phalaris crowns, despite the phalaris plants remaining green and flowering. It was estimated that some 4-5 t/ha of senesced plant litter was present in the bottom 7-8 cm of the pasture canopy.
In the final year, the pasture was quite 'lumpy', and while this estimate applied to 80-85% of the pasture, there were patches (15-20%) with much less dry matter cover (1-2 t/ha DM).

The 2009, 2010 and 2011 pasture yields measured during mid-spring, when daily pasture growth rates are at their peak and treatment differences are likely to be a maximum are reported in Appendices 1-3.

Pasture quality

The feed test analyses of pasture samples collected in September 2013 were consistent with the results from the 2009, 2010 and 2011 samplings (Table 3). As each sample from the replicate plots were bulked in 2013, no statistical analyses were undertaken on these data. For the 2009 -2011 seasons, there were no statistically significant (P>0.05) differences between any treatments in any year.

Table 3. Mean dry matter digestibility (per cent), crude protein (per cent) and metabolisable energy (MJ/kg) of pasture from all fertiliser treatment plots in early-to-mid spring of 2009, 2010, 2011 and 2013.

Sample date	Dry matter digestibility (per cent)	Crude protein (per cent)	Metabolisable energy (MJ/kg)
8 October 2009	72.1	23.8	10.8
27 September 2010	76.1	23.9	11.5
18 October 2011	72.7	14.1	10.9
23 September 2013	80.9	28.9	12.3

Elemental content of pasture herbage

As the herbage samples from each treatment replicate were combined, only the means and ranges of the elemental concentrations of pasture herbage from the 10 fertiliser treatments are presented in Table 4.

These data show that the concentrations of the nutrient elements boron, calcium, copper, magnesium, manganese, phosphorus, sulphur and zinc were generally within the ‘adequate’ values for phalaris, with molybdenum well above the normal range for both phalaris and sub clover.

Table 4. Elemental concentrations (mean and range) of pasture tissue samples collected from the fertiliser treatment plots on 23 September 2013, together with concentrations from the scientific literature considered to be acceptable for phalaris and subterranean clover.

			Adequate range	
Element	**mean**	**range**	**phalaris**	**sub clover**
Aluminium (mg/kg)	37	29-50	?	?
Arsenic (mg/kg)	<5	<5		
Boron (mg/kg)	5.6	4.0-8.8	5-15	20-40
Calcium (%)	0.37	0.32-0.42	0.25-0.50	0.4-0.5
Cadmium (mg/kg)	<0.2	<0.2		
Cobalt (mg/kg)	<0.4	<0.4		>0.04
Chromium (mg/kg)	1.5	1.0-2.6	?	?
Copper (mg/kg)	5.3	5.0-5.7	4-10	>4
Iron (mg/kg)	138	120-160	?	50-60
Lead (mg/kg)	<2	<2		
Magnesium (%)	0.18	0.17-0.19	0.20-0.35	
Manganese (mg/kg)	200	180-220	60-200	
Molybdenum (mg/kg)	1.3	1.0-1.8	0.3-0.4	>0.15

Nickel (mg/kg)	0.94	1.30	0.76	
Phosphorus (%)	0.47	0.43-0.51	0.25-0.40	0.15-0.25
Potassium (%)	3.6	3.4-4.0	1.5-3.5	1.0-1.5
Selenium	mg/kg		<4	<4
Sodium (%)	0.16	0.14-0.18	?	?
Sulphur (%)	0.34	0.32-0.37	0.2-0.4	>0.25
Zinc (mg/kg)	32	30-35	15-50	>14

Changes in the abundance and activity of soil microbial populations

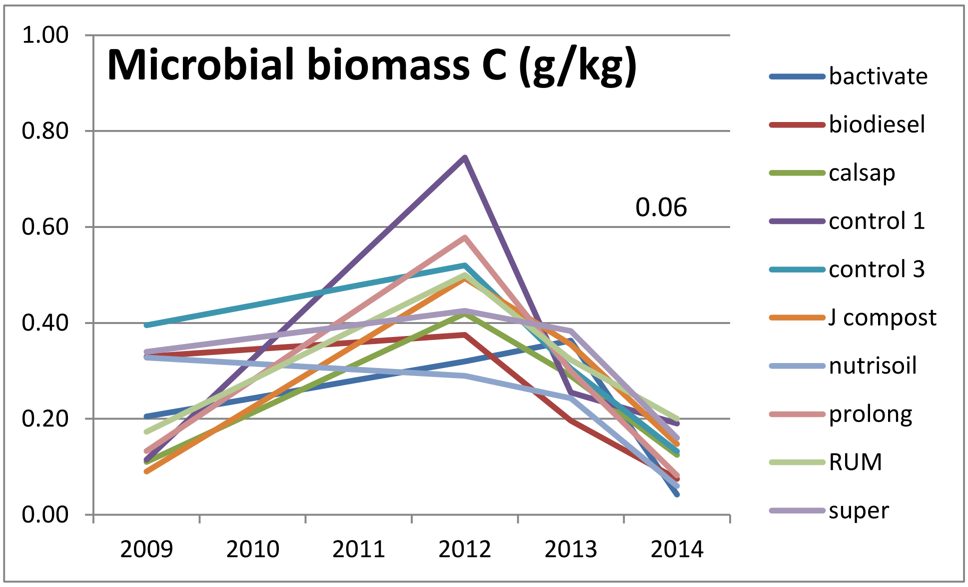
The two measures of microbial abundance in soil undertaken in this field demonstration were microbial biomass carbon and the fluorescein diacetate activity (FDA) assay.

Microbial biomass carbon is a measure of the weight of carbon in soil micro-organisms that include bacteria, fungi and archaea. While a single measure of microbial biomass carbon can be difficult to interpret, trends over time provide a relatively simple assessment of the effects of treatments on the abundance of soil micro-organisms.

There was a general increase in microbial biomass carbon concentrations between 2009 and 2012 for most treatments, with decreases for most treatments from 2012 to 2013, and decreases for all treatments from 2013 to 2014 (Figure 2). There were no statistical differences ($P>0.05$) between any of the treatments in 2009 (before the application of the treatments), 2012 and 2013.

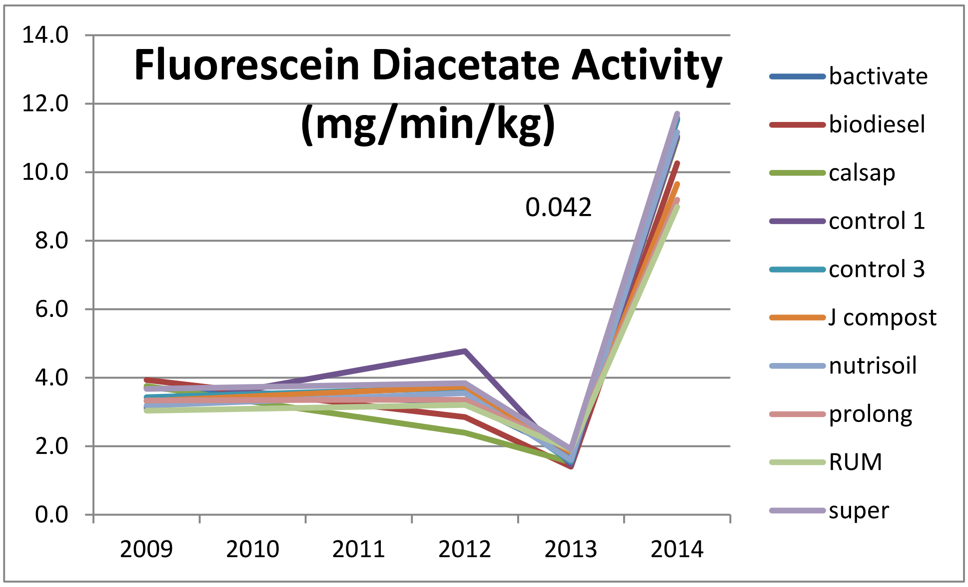
In 2014, when the differences between all treatments were smallest, the Bactivate Plus and NutriSoil LS treated soils contained significantly ($P<0.05$) less microbial biomass carbon than the untreated Control 1 and R.U.M. treated soils. Additionally, the Bactivate Plus treatment soil contained significantly ($P<0.05$) less microbial biomass carbon than the Johnson's Compost and single superphosphate treated soils.

Figure 2. Microbial biomass carbon concentrations (g/kg) of the 0-10 cm horizon of soils to which no fertiliser (control), single superphosphate and a range of treatment products have been applied annually since 2009.



The fluorescein diacetate activity (FDA) assay measures the enzyme activity of all active micro-organisms in soil. As such, it is a good measure of the total microbiological activity in soil and by default a good general measure of organic matter turnover rates in soils.

Figure 3. Fluorescein diacetate activity rates (mg/min/kg) in the 0-10 cm horizon of soils to which no fertiliser (control), single superphosphate and a range of treatment products have been applied annually since 2009.



The activity rates of microbial enzymes in the sampled treatment soils (Figure 3) show virtually no change between 2009 and 2012, with a relatively small decrease between 2012 and 2013. However, between 2013 and 2014, there was a sharp, many-fold increase in enzyme activity.

Statistical analyses showed that there were no statistical differences ($P>0.05$) between any of the treatments in 2009 (before the application of the treatments), 2012 and 2014. In 2013, when the differences between all treatments were least, microbial enzyme activity in the Biodiesel by-product treated soil and the untreated

Control 1 soil were significantly ($P<0.05$) less than in the Prolong®, single superphosphate and R.U.M. treated soils.

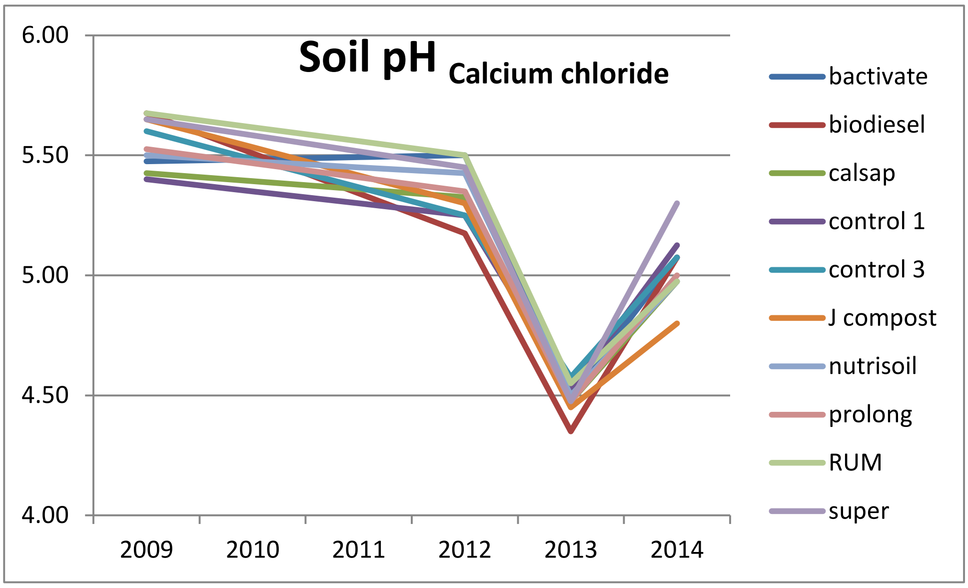
Seasonal changes in soil properties

The changes in soil pH (calcium chloride) from 2009 to 2014 are reported in Figure 4 for each treatment. These trends are based on data from the two soil samplings taken at the start and end of the initial three year project, together with data from the 2013 and 2014 samplings, as contracted in this project extension.

On the NIL control plots, the pH decreased by a mean 0.25 of a pH unit over the first three years (2009 to 2012), then decreased by a further 0.70 of a pH unit in the next 12 months (2012 to 2013, but increased by 0.55 of a pH unit in 2014. Over the six years from 2009 to 2014, the mean pH of the NIL control plots decreased by a total of 0.40 of a pH unit, which represented an annual average decrease of 0.08 pH units per year.

The marked decrease and then increase in soil pH between 2012 and 2014 appears to be an inconsistency associated with the storage conditions of the 2013 soil samples, the implications of which will be discussed in more detail in the Discussion section. When viewed against results for other soil indicators it is believed that the 2013 soil pH data were not representative of the actual soil values at the time of sampling.

Figure 4. Soil pH (1:5 soil:0.01M calcium chloride) in the 0-10 cm horizon of soils to which no fertiliser (control), single superphosphate and a range of treatment products have been applied annually since 2009.



Seasonal variations in soil phosphorus concentrations

The seasonal (2009, 2012, 2013 and 2014) changes in the soil concentrations of available (Olsen P and Colwell P) and total phosphorus for the ten fertiliser treatments are reported in Figures 5, 6 and 7. Where there was a significant ($P<0.05$) treatment effect, the $LSD_{0.05}$ value is reported in the Figures as a numerical value in the year in which it occurred.

Only relatively small increases in available soil phosphorus concentrations were measured between 2009 and 2012 for all treatments, except for single superphosphate, which significantly (*P*<0.05) increased both Olsen P and Colwell P concentrations relative to all other treatments in 2012 (Figures 5 and 6).

Between 2012 and 2013, there were dramatic increases in available soil phosphorus concentrations in all treatments, including the NIL control plots.

Between 2013 and 2014, Olsen P concentrations either did not change, or they decreased, whereas Colwell P concentrations of most treatments continued to increase except the single superphosphate, Prolong® and Johnson's compost treatments, all of which decreased.

Figure 5. Available soil phosphorus (Olsen P) concentrations (mg P/kg) of the 0-10 cm horizon of soils to which no fertiliser (control), single superphosphate and a range of treatment products have been applied annually since 2009.

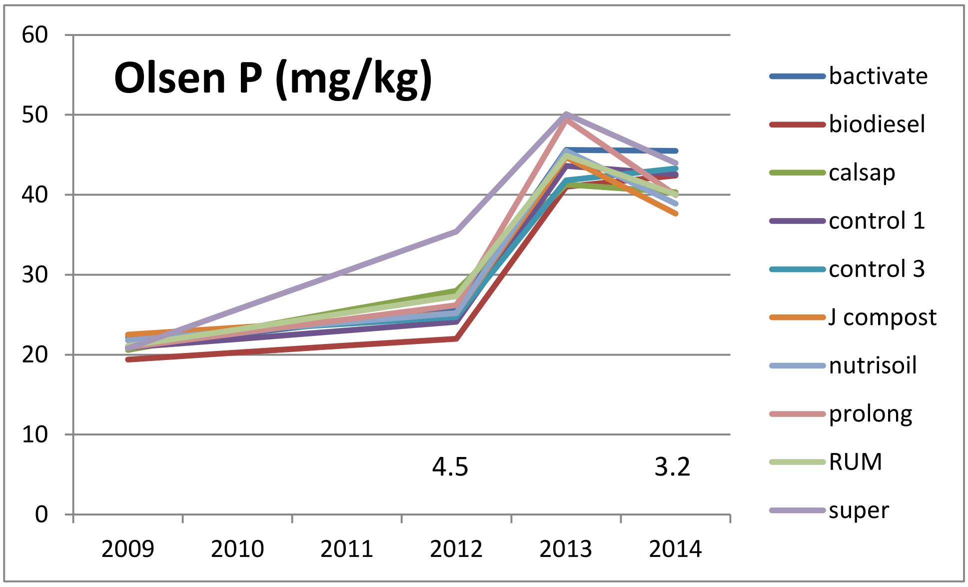


Figure 6. Available soil phosphorus (Colwell P) concentrations (mg P/kg) of the 0-10 cm horizon of soils to which no fertiliser (control), single superphosphate and a range of treatment products have been applied annually since 2009.

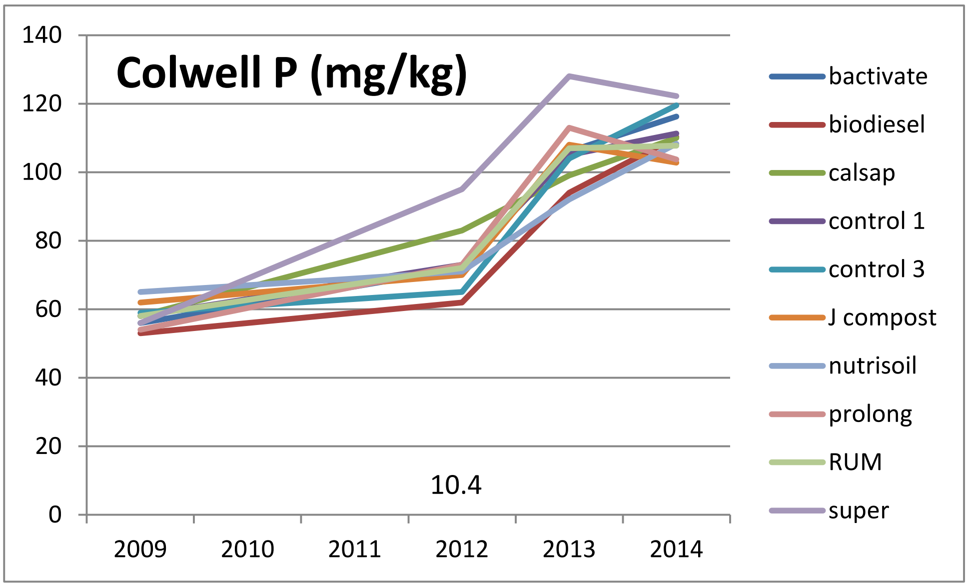
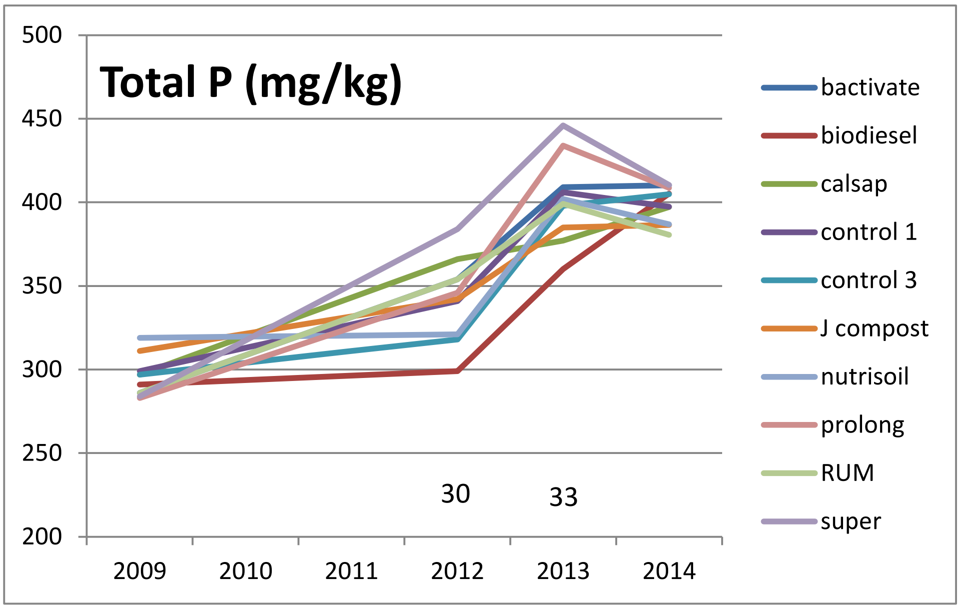


Figure 7 records the changes in the concentrations of total phosphorus in the surface 10 cm of soil for all treatments. From 2009 to 2012, there were modest increases in total P concentrations in the NIL control treatments (from 298 to 329 mg/kg) but strong increases for some other treatments that added negligible phosphorus (for example, Calsap which increased total P concentrations from 297 to 366 mg/kg). Single superphosphate, which 10.8 kg P/ha each year increased total P concentrations from 284 to 384 mg/kg.

Between 2012 and 2013, total soil P concentrations in all treatments increased strongly, with the NIL control treatment, for example, increasing from 329 to 402 mg P/kg. From 2013 to 2014, most treatments did not change except for single superphosphate and Calsap, which both declined and Biodiesel by-product which continued to increase (Figure 7).

Over the six years the treatments were applied, single superphosphate, Prolong® and Johnson's compost added a total of 67, 98 and 2 kg of P/ha respectively, with all other treatments adding negligible quantities of P to the treatment soils.

Figure 7. Total soil phosphorus concentrations (mg P/kg) of the 0-10 cm horizon of soils to which no fertiliser (control), single superphosphate and a range of treatment products have been applied annually since 2009.



Seasonal changes in other soil properties

The availability of other plant nutrients in the treatment soils showed similar trends to those described above for soil phosphorus. These included the soil concentrations of available potassium (Colwell K), available sulphur (KCl_{40}-extractable) and nitrate-nitrogen (Figures 8, 9 and 10).

Figure 8. Concentrations (mg/kg) of available soil potassium (Colwell K) of the 0-10 cm horizon of soils to which no fertiliser (control), single superphosphate and a range of treatment products have been applied annually since 2009.

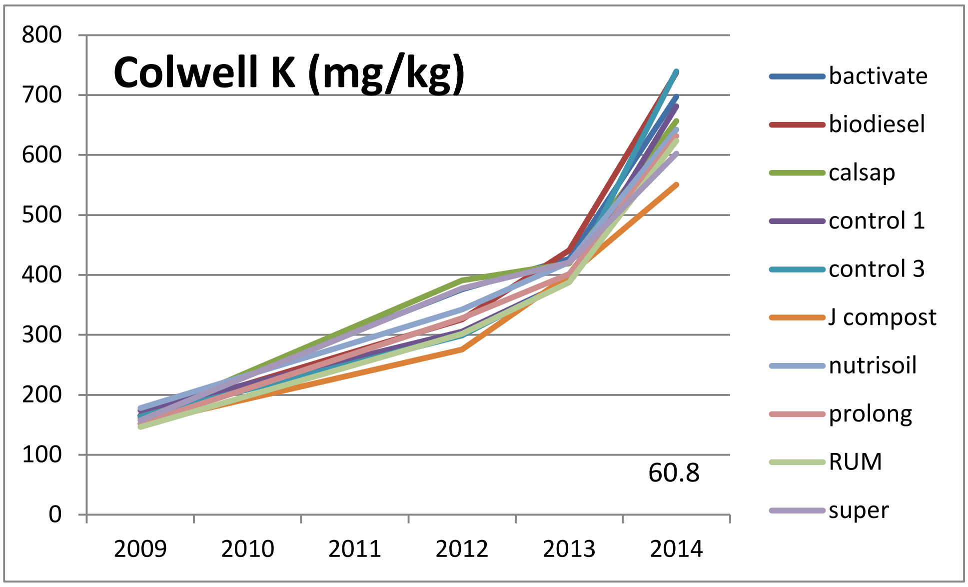
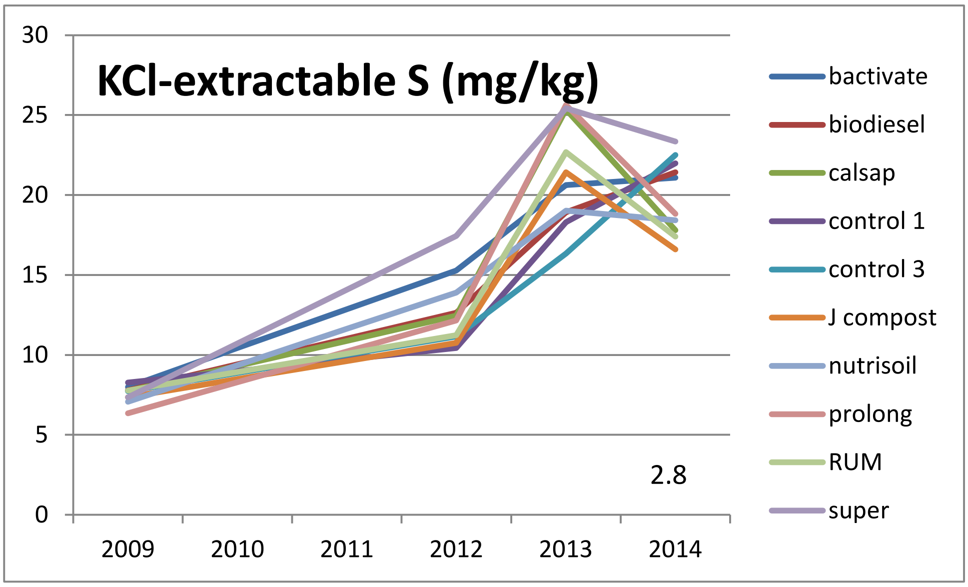


Figure 9. Concentrations (mg/kg) of available soil sulphur (KCl_{40}-extractable) of the 0-10 cm horizon of soils to which no fertiliser (control), single superphosphate and a range of treatment products have been applied annually since 2009.

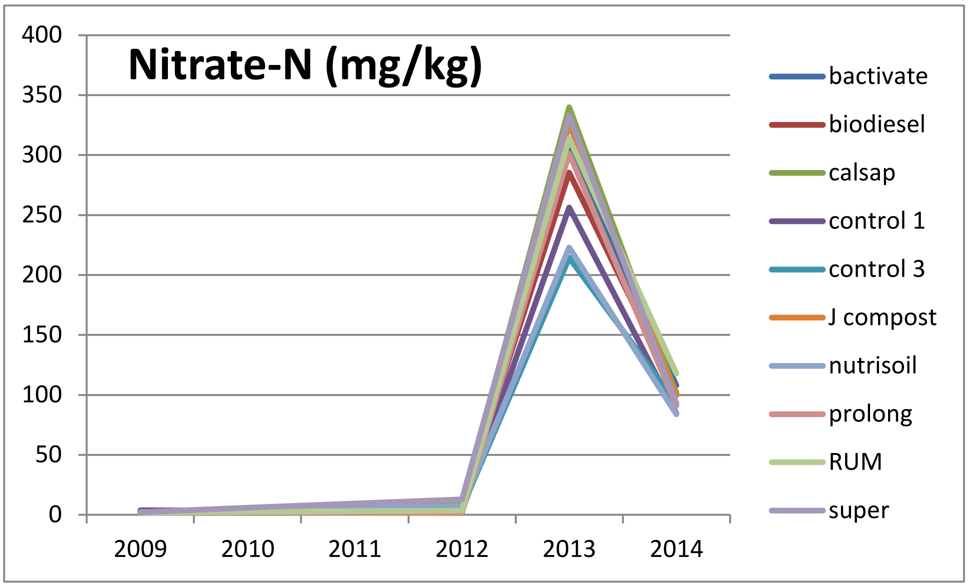


In the available potassium (Colwell K) data (Figure 8), there were no statistically significant (P>0.05) treatment differences in the 2009, 2012 and 2013 data, but in the 2014 data, there were a number of statistically significant (P<0.05) treatment differences. The most notable included the Johnson's compost treatment which contained significantly (P<0.05) less Colwell K than the two untreated Control soils and the soils treated with Bactivate Plus and the Biodiesel by-product. Additionally, the soils treated with R.U.M. and Prolong® contained significantly (P<0.05) less Colwell K than the untreated Control 3 soil and the soil treated with the Biodiesel by-product.

Figure 9 shows there were no statistically significant (P>0.05) treatment differences in available sulphur concentrations in the 2009, 2012 and 2013 data, but that in 2014, the soil treated with superphosphate contained statistically (P<0.05) more available sulphur than the soils treated with Johnson's compost, R.U.M., Calsap, NutriSoil LS and Prolong®.

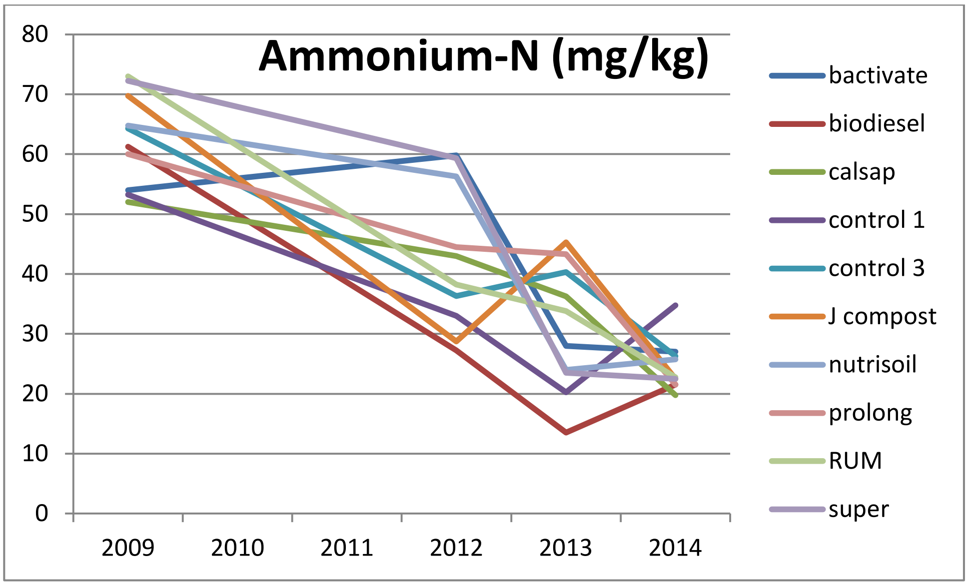
Figure 10 shows the concentrations of nitrate-nitrogen in the treatment soils were extremely low in 2009 (site mean = 2.3 mg/kg) and 2012 (site mean = 6.4 mg/kg), with a dramatic increase in 2013 (site mean = 290 mg/kg), before the concentrations decreased to an intermediate concentration in 2014 (site mean = 97.3 mg/kg). There were no statistically significant (P>0.05) treatment differences at any sampling.

Figure 10. Concentrations (mg /kg) of nitrate nitrogen in the 0-10 cm horizon of soils to which no fertiliser (control), single superphosphate and a range of treatment products have been applied annually since 2009.



In contrast, the ammonium-nitrogen concentrations (Figure 11) generally showed downward trends from 2009 to 2013 for all treatments with both increases and decreases between 2013 and 2014. Like the nitrate-nitrogen concentrations, there were no statistically significant (P>0.05) treatment differences at any sampling.

Figure 11. Concentrations (mg /kg) of ammonium-nitrogen in the 0-10 cm horizon of soils to which no fertiliser (control), single superphosphate and a range of treatment products have been applied annually since 2009.



Other soils properties that were measured in 2009, 2012, 2013 and 2014 for all treatments included soil pH (water), electrical conductivity, organic and total carbon, exchangeable cations (Ca^{2+}, Mg^{2+}, K^+ and Na^+) and phosphorus buffering index. Exchangeable aluminium (Al^{3+}) was measured in 2012 and 2014. For these 11 soil properties, there were no statistically significant (P>0.05) treatment differences for all sampling dates, although some soil properties showed temporal trends.

Other properties such as exchangeable cations and organic carbon concentrations remained relatively stable over the six years of the study (Figures 12 and 13).

Figure 12. Soil organic carbon concentrations (g/kg) in the 0-10 cm horizon of soils to which no fertiliser (control), single superphosphate and a range of treatment products have been applied annually since 2009.

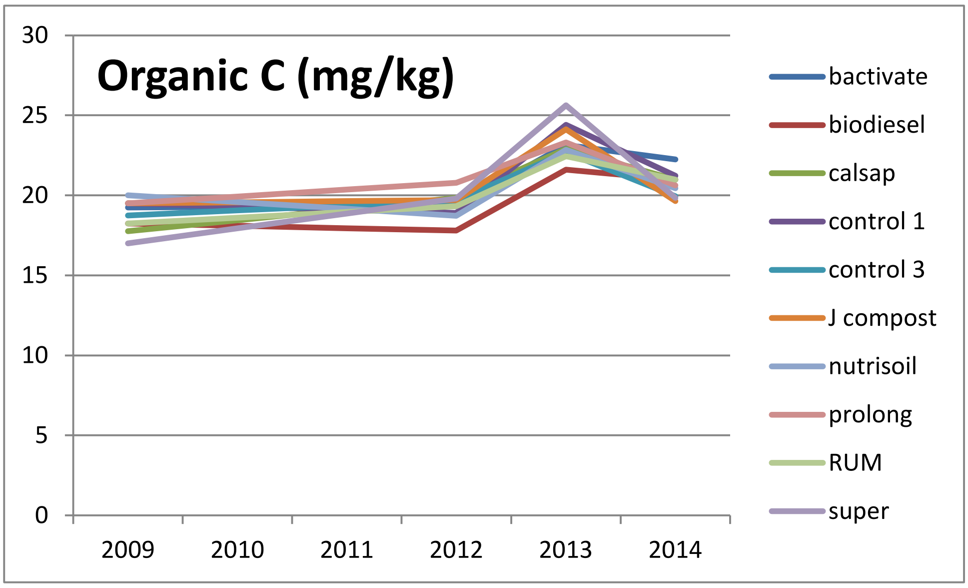
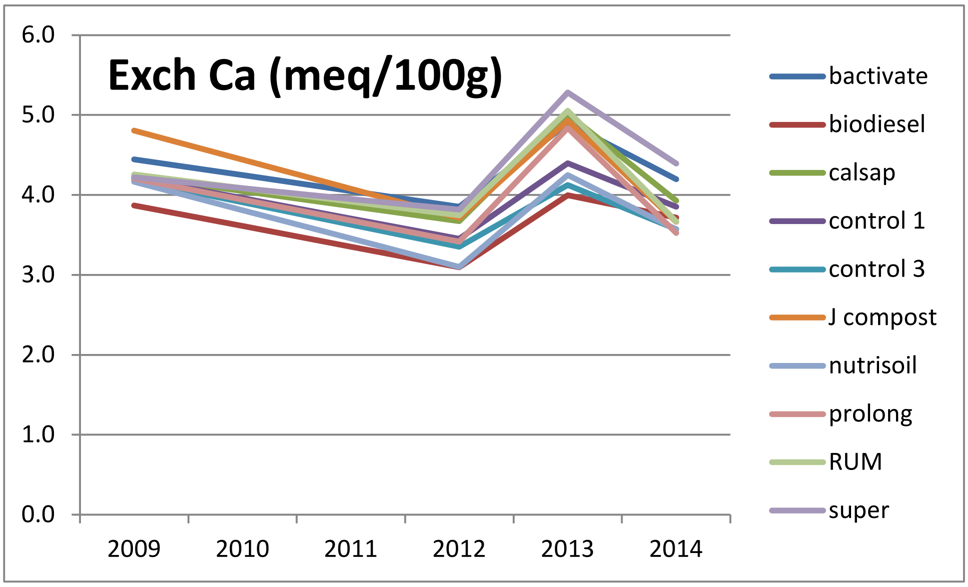


Figure 13. Exchangeable calcium concentrations (meq/100g) in the 0-10 cm horizon of soils to which no fertiliser (control), single superphosphate and a range of treatment products have been applied annually since 2009.



Discussion

Objective 1. Establish variation in soil phosphorus between growing seasons to determine longer-term impacts of treatment.

The commitment in this extension to measure soil chemical properties in both the 2013 and 2014 growing seasons in effect doubled the number of available data points to better define any trends in soil properties over time under each of the treatments.

Quality of Soil Data

There has been an impact on the quality of the 2013 soil chemical data due to a deviation in the soil storage conditions. Soil samples were stored by HLN to minimise financial risk whilst awaiting funding to continue the extension of the demonstration. The 2013 delay in analysis meant soil samples were air dried and stored in a facility that was subject to daily variations in temperature for nine months. By contrast, the soil samples collected in 2009, 2012 and 2014 were sent direct to the laboratory in a field-moist condition within days of sample collection at a cool time (July-August) of the year.

When soils are stored in air-dry condition for more than one to two months, reports in the scientific literature suggest that there can be marked changes in some soil properties including soil pH and the availability of some plant nutrients.

As N is highly labile in soils it is suspected that the sudden increase from 2012 to 2013 is associated more with the sample storage conditions of the 2013 soils than anything else like seasonal conditions.

An examination of the soil pH data collected in this project (Figure 4) shows a decrease of 0.70 of a pH unit in the NIL control plots over the 12 months between 2012 and 2013 and an increase of 0.55 pH unit in the same soil over the following 12 months. Given the change in soil pH on the NIL control plots between 2009 and 2012 was 0.25 of a unit (from 5.50 to 5.25), and between the 2012 and 2014 was 0.15 of a pH unit (from 5.25 to 5.10), the annual decreases in pH for these two periods are identical at 0.08 units/annum each.

This finding strongly supports the contention that the 2013 soil pH data were not representative of the actual soil values at the time of sampling.

Additionally, given that soil pH is a logarithmic scale, a decrease from 5.25 to 4.45 pH units represents a five-fold increase in the concentration of hydrogen ions (H^+) in solution, such that this change appears to be strongly associated with the soil sample storage conditions than any seasonal effects on soil pH between 2012 and 2013.

Email discussions with Dr Richard Simpson from CSIRO Canberra came to the same conclusion; that soil pH is a ‘very stable soil test value for $\log_{10}$ reasons and does not change very quickly at all, unless a lot of soluble alkali is applied to the soil’.

Thus all 2013 soil chemical data must be viewed with caution as the measured values may not represent those of the field moist soil at the time when the samples were collected in August 2013.

Seasonal trends in soil phosphorus concentrations

Relative to the variation in soil phosphorus concentrations, Dr Richard Simpson commented that there can be marked seasonal variations in available phosphorus concentrations in soils that receive both regular and nil applications of phosphatic fertilisers, and that soil phosphorus concentrations need to be measured annually for three to five years to confidently establish trends in soil phosphorus.

On a soil already well supplied with phosphorus, none of the treatments displayed any statistically significant differences in soil properties sampled at the start (July 2009) and in the fourth (August 2012) and sixth (August 2014) years. Single superphosphate was the only treatment to increase the plant-available and total concentrations of soil phosphorus between 2009 and 2012, as well as the plant-available concentrations of soil sulphur in 2014 when compared with some but not all other treatments.

If the total phosphorus content of single superphosphate is assumed to be 9.1 per cent, which includes 0.3 per cent of citrate-insoluble phosphorus, over six years superphosphate was added to the site, annual applications of 123 kg/ha would have added a total of 67 kg/ha of phosphorus. If the bulk density of the top 10 cm of soil at the demonstration site is assumed to be 1.3 g/cm^3, and assuming that all of the added phosphorus is retained in the surface 10 cm of soil, the addition of 67 kg P/ha would increase the total phosphorus content of the top 10 cm of soil by 52 mg/kg.

Between 2009 and 2014, the total phosphorus concentrations of the single superphosphate plots increased from 284 to 410 mg /kg, an increase of 126 mg /kg, which leaves 74 mg/kg of total phosphorus that is not accounted for by the phosphorus applied in the superphosphate. However, for the six treatments that added negligible amounts of phosphorus (Biodiesel by-product, Calsap, Control 1, Control 3, NutriSoil LS and R.U.M.) the average increase in total soil phosphorus was 97 mg/kg.

Even with the exclusion of the 2013 soil chemical data, there is strong evidence of unexplained increases in total and available soil phosphorus concentrations. These increases cause distraction from the key tenet of the demonstration; that is to identify annual trends in available soil phosphorus concentrations where fertiliser phosphorus was both added and not added.

In response to these unexplained increases in total and available soil phosphorus, as well as the marked increases in the availability of other plant nutrients not discussed in this report, there was much discussion among the project team and with experienced researchers and advisors about whether the grazing method employed on this demonstration site had created a 'sheep camp' effect as described by Hilder and Mottershead (Hilder EJ, Mottershead BE 1963. The redistribution of plant nutrients through free-grazing sheep. *Australian Journal of Science* 26, 88–89).

The 'sheep camp' effect may explain the increase as stock used to graze the site came from a high P pasture with full bellies, and over their first few hours on the site, deposited almost all of that nutrient in their faeces.

Thereafter, the stock effectively recycled the nutrient within the site area. The assumption of net nutrient import was also supported by the landholder's observations that stock had stopped eating before they were removed from the site, and so removed less phosphorus than they brought in.

The extent of the 'sheep camp' effect can vary significantly depending on factors such as the pasture composition the stock have come from and the length of time, if any, they have had to empty out prior to entering the demonstration site. The effect can be cumulative over the life of the project but could also explain a sharp increase in any given year if conditions were suitable.

If we assume each sheep ate 1-2 kg DM containing 0.3 per cent P before entering the site and retained none of this P, as mature animals do, the amount of P imported onto the site can be calculated as follows.

For the year July 13 – August 14, there were at least 5100 sheep entries onto the plot area of 0.32 ha. The amount of imported P equals 1.0 kg DM x 0.003 kg P/kg DM x 5100/0.32 ha = 47.8 kg P/ha for a 1 kg DM intake, and potentially up to 96 kg P/ha if they ate 2 kg DM/day.

Objective 2. Compare treatment effects on the abundance and variation of soil bacterial and fungal populations.

The purpose of this objective was to establish temporal trends in microbial populations by comparing microbial abundance and activity in soils treated with alternative products.

In this study, two surrogates of the direct measurement of populations of soil micro-organisms were used, as recommended in the initial project review by Dr Lewis Kahn. These two surrogate measures were soil microbial biomass carbon concentrations and the fluorescein diacetate activity (FDA) assay to measure the activity rates of soil microbial enzymes.

Soil microbial biomass carbon concentrations (Figure 2) tended to reflect the soil organic carbon concentrations (Figure 12) although the former can vary more widely than the latter because of temporal variations in soil water contents and soil temperatures at the time of sampling. Even so, the three products that were expected to influence populations of soil micro-organisms (Bactivate Plus, NutriSoil LS and R.U.M.) had no statistically significant ($P>0.05$) effects on microbial biomass carbon concentrations when compared with all other treatments including single superphosphate and the untreated NIL control soils.

Likewise with the assay of the activity rates of soil microbial enzymes (FDA), there were no statistically significantly ($P>0.05$) differences between any treatments at any sampling date, even though there was an overall marked increase in enzyme activity from 2013 to 2014, which presumably reflected more favourable soil water and soil temperature conditions at the time of the 2014 sampling.

Objective 3. Determine and assess the impact of treatments on the mineral content of fodder.

The purpose of the third objective was to assess the adequacy of the concentrations of the essential plant nutrients and to identify any potentially toxic non-essential elements in rapidly-growing pasture herbage collected from the treatment soils.

The results of elemental analyses of herbage collected in September 2013 are reported in Table 4 on page 11.

The tissue concentrations of the nutrients boron, calcium, copper, magnesium, manganese, nickel, phosphorus, sulphur and zinc were all deemed to be within ‘adequate’ ranges for phalaris, which is the sown and preferred perennial grass at the site. The concentrations of molybdenum were however, well above the adequate range for both phalaris and sub clover.

The plant tissue concentrations of Mo varied between treatments from 1.0 to 1.8 mg/kg. One set of control plots had the equal highest concentration of 1.8 mg/kg (the other 1.3), indicative that all Mo has come from soil sources, the availability of which would have increased when the paddock was limed prior to sowing down the phalaris pasture.

For cobalt, no assessment of the adequacy of herbage concentrations could be made as the detection limit of the analytical method (<0.4 mg/kg) was well above the cobalt concentrations deemed adequate for sub clover (>0.15 mg/kg).

The following non-essential elements that can be potentially toxic to plant growth were measured; aluminium, arsenic, cadmium, chromium, iron and lead.

The concentrations of arsenic, cadmium and lead were below the detection limits of the analytical method, while the aluminium concentrations were below those suggested in the literature to be toxic for pasture growth (100-150 mg/kg).

No information could be found in the scientific literature about the tissue concentrations of chromium and iron that are toxic to plant growth. New Zealand data (Cornforth IS, Sinclair AG. 1982. Fertilizer and Lime Recommendations for Pastures and Crops in New Zealand. Ministry of Agriculture and Fisheries, Wellington N.Z.) suggests that iron concentrations of >65 mg/kg in white clover herbage were considered high but the authors did not define a toxic concentration. Iron concentrations in herbage can, however, be problematic because of soil contamination and metal contamination if herbage samples are mechanically ground before analysis.

Two elements measured in the pasture herbage are considered essential for livestock health. Firstly, sodium concentrations were above the minimum 0.10 mg/kg considered necessary for animal growth and health (Towers NR, Smith GS 1983. Sodium *in* 'The mineral requirements of grazing ruminants'. *NZ Society of Animal Production Occasional Publication No. 9,* pp. 115-124.) The values measured in this demonstration ranged from 1400 to 1800 mg/kg, which is well above the livestock minimum and reflective of the age and amount of salt that has accumulated in the Australian landscape over eons.

Secondly, while the selenium concentrations of the pastures were below the detection limits of 4 mg/kg, no comment can be made about whether the selenium contents of the sampled pasture meets the requirements of mixed pastures to contain from 0.1-1.0 mg Se/kg to protect against white muscle disease in livestock.

Objective 4. Determine the impact of treatments on pasture production (kg DM/ha) at key seasonal times.

The fourth purpose of this extension project was to give the products additional time to express their cumulative effects on pasture growth. All products were first applied in July 2009. In the fifth (2013) and sixth (2014) years after the initial applications and with subsequent annual applications in every year since 2009, there were still no statistically significantly (P>0.05) differences in the cumulative effects of the treatments on pasture growth (Table 2) on a very fertile soil.

Objective 5. Conduct an economic analysis of the costs and benefits of each treatment.

A key discussion point for producers in demonstrating the economic value of commercial products to their business enterprise(s) is evaluating their cost/benefit ratios and validating the use of these products in the context of individual farming systems. At the inception of the project, the input costs of single superphosphate were a significant concern and this drove the aspiration to evaluate locally available, alternative sources of phosphorus.

The project team acknowledges that the immediate economic advantages of cheaper, soluble sources of phosphorus can be complex to articulate and may include ‘perceived’ and/or ‘real’ advantages. Additionally, producers may be willing to endure shorter term losses for perceived longer term gains from ameliorating their soils, thus enabling them to decrease and perhaps ever forgo annual phosphorus applications.

Additionally, producer group discussions (field days, feedback and event evaluation) have recognised that the impact of alternative products may include additional benefits beyond the immediate economic advantage such as reuse of waste products or adoption of products perceived to have a reduced environmental footprint compared to Superphosphate or other traditional products. However, the scope of this producer demonstration cannot measure and hence cannot calculate additional economic advantages beyond the fundamental comparative analysis provided in Table 5.

Table 5. Estimated annual costs ($/ha) of treatment products based on the rates used in the Holbrook Landcare Network - Producer Demonstration Site (PDS) when sourced and transported in bulk quantities to Holbrook.

	Application Rate	Bulk cost[1]	Freight cost[2]	Application cost	Product Unit cost[1]	**Total On-farm Applied Cost [6]**
	(kg/ha) (L/ha)	($/tonne) ($/1000L)	($/tonne) ($/1000L)	($/ha)	($/ha)	**($/ha/annum)**
Treatment						
Control						**0.00**
Superphosphate	123	353.00	0.00	6.00	43.42	**49.42**
Bactivate[3]	150	1650.00	220.00	6.00	330.00	**380.00**
Bio Boost Plus	2	12,745.00	220.00	15.50	25.49	**41.30**
Bactivate Plus[4]	77	14,395.00	440.00	21.50	355.49	**674.24**
Biodiesel	100	600.00	132.00	6.00	60.00	**79.20**
CalSap	20	1,950.00	110.00	15.50	39.00	**56.70**
J compost	1000	81.00	132.00	6.00	81.00	**219.00**
NutriSoil LS	10	4,500.00	0.00	31.00	45.00	**76.00**
Prolong®	491[5]			discontinued		N/A
R.U.M.	5	4,680.00	132.00	15.50	23.40	**39.56**

[1] 2014 prices, ex-GST and ex-freight, calculated on unit size closest to 1000kg/1000L.
[2] Freight cost to Holbrook NSW.
[3] Applied in 2009 only.
[4] Applied 2010 onwards requires the application of two separate products (2 L/ha Monty’s Liquid Carbon, now known as Bio Boost Plus and 75 kg Bactivate).
[5] Applied every fourth year, product discontinued.

Producer Feedback

Engagement and extension activities

Through the '*Carp, Kelp and Christmas Island; Where to next for fertiliser?*' and related nutrient management projects, HLN sought to encourage land managers and producers to understand:

- the benefits and limitations of available fertilisers and soil ameliorants in terms of production objectives, economic capacity, farming systems and soil types;
- the importance of soil testing and the application of soil health knowledge to decision-making regarding the use of fertilisers and soil ameliorants;
- the need for robust and objective scientific information on the potential benefits of alternative fertilisers and soil ameliorants;
- the importance of producer education about the perceived versus the actual benefits of soil ameliorants,
- the importance of maintaining objectivity through the adoption of rigorous scientific principles when setting up on-farm demonstrations.

HLN designed field days where extension material and presentations reflected the above messages:

- Field Day 24th September 2010

Approximately 60 people attended including guest speakers Jim Virgona (Senior Lecturer (Agronomy), School of Agricultural and Wine Sciences, Charles Sturt University), Lisa Warn (Agricultural Consultant, The Mackinnon Project,The University of Melbourne) and Phil Graham (Technical Specialist Grazing Systems, NSW DPI),

- Field Day 23rd September 2011

Approximately 39 people attended including guest speaker Nigel Philips (Technical Specialist Pastures, NSW DPI) and Ian Locke (producer insights from hosting the demonstration),

- Field Day 9th December 2011

Approximately 42 people including project notes/summary and 'Understanding P' soil testing program feedback,

- Final Field Day 23rd October 2014

Approximately 40 people attended including guest speaker Lewis Kahn (consulting agronomist for MLA Alternative Fertiliser PDS series) plus fact sheets and a landholder summary.

Specific attention was given to public information, reports and factsheets to reflect these key messages in a simple manner. HLN with project agronomist, Jeff Hirth, developed a Fact Sheet for landholders who may wish to trial/demonstrate products on farm highlighting the importance of scientific rigour including the need for controls, restricting the number of variables under evaluation, clearly identifying production and demonstration objectives, and a realistic understanding of the impacts of demonstration findings relevant to their farming systems, soil types, budgets, etc.

General insights gained from this demonstration could be incorporated by other similar producer groups, extension providers, consultants and suppliers on the topics of fertiliser decision-making and whole farm planning. To enable producers to adopt evidence based decision making frameworks and to maximise learnings from this program the following skills and tools should be considered:

1. training in the area of soil health, plant nutrient requirements and interpreting soil test data,
2. training in the area of scientific method, how to establish scientific trials, understanding statistical differences,

3. awareness of emerging scientific research and the implications for soil/pasture ecology,
4. decision support tools around calculating fertiliser requirements, assessing potential sources of nutrients, and calculating applications rates,
5. training and capacity development around whole farm planning, business planning, record keeping, monitoring and budgeting, and
6. training/skills development in the area of developing pasture growth objectives and matching fertiliser planning to production objectives.

In summary, further advisory and extension activities around the use of superphosphate substitutes and supplements will be needed to emphasise the importance of education and training to increase landholder awareness of critical nutrient levels contextualised for their production system. Secondly, a greater understanding of the benefits and limitations of fertilisers and soil ameliorants is required to assist landholders to apply independent, evidence-based decision making relevant to their production systems, soil types and rainfall zones.

Key Learnings

HLN collected written and verbal feedback from producers who attended the final field day of the project '*Carp, Kelp and Christmas Island; Where to next for fertiliser?*' Evaluation of producer feedback can provide insight for producer groups, extension staff, researchers and industry on the effectiveness and impact of programs such as this PDS.

Key learnings identified a range of producer needs and a range of reasons why producers make conclusions/decisions around practice change; such as adopting sound nutrient management plans.

Practice change arising from the research and extension provided by this PDS is limited by the knowledge and capacity of producers to translate detailed generic information to specific individual farming systems.

HLN can report producer learnings ranging from:
- continuing to see value in phosphatic fertilisers;
- understanding the limitations of fertilisers/ameliorants;
- the importance of extensive soil testing;
- the importance of analysing the nutrient content of alternative fertilisers and soil ameliorants.
- the importance of obtaining and using evidence and analysis as the basis for the application of soil nutrients.

HLN can report producer practice change outcomes ranging from:
- increased frequency and quality of soil testing
- increased focus on pasture composition (sub-clover) in terms of soil structure, carbon and nitrogen response,
- increased paddock monitoring of soil pH,
- increased time spent on researching fertiliser options,
- improved fertiliser budgeting to meet pasture needs and hence create efficiency gains.

Further exploration of these key learning themes with producers who were directly involved in the PDS have reiterated these themes. When asked about the benefits of being involved with HLN's PDS producers cited that they have "benefitted greatly from improving the discipline of our thinking", they "require more rigour" in information used to make large scale operational decisions, they "have a better understanding of the value of good trial data" and "a better understanding of soil P".

Other key learnings highlight producer's views on the treatment effect, or lack of; where one producer concluded "*if P is not limiting, such as at the demonstration site, there was little scope for any treatment products to show any advantages"* (in relation to expected P responses). Similarly *"demonstration data can result in more questions being raised than those that were being answered*".

Producers also referenced challenges in trial design, site selection, treatment selection and maintaining producer engagement across the lifetime of the project. In hindsight, producers would review:

- the process of selecting alternative products for testing,
- the selection of a high P site, and
- elements of trial design.

Despite the limitations of the PDS, producers found the process to be stimulating and it has illustrated future opportunities and identified research gaps for future projects.

Such research/information gaps identified by landholders in the evaluation of this PDS include:

- benchmarking soil biology species/abundance/diversity of high rainfall pastoral systems,
- ecological interactions of soil ecology and different pasture species (improved and native pastures),
- further investigation and comprehensive research trials of alternative sources of phosphorus,
- further investigation into the phosphorus cycle in fertile (high P) soil types in high rainfall farming systems,
- impacts of whole farm planning (rotational grazing and pasture management) on soil structure.

Overall the PDS has benefited producer's knowledge base as well as their bottom line. Producers involved in the PDS are reporting financial benefit resulting from:

- greater scrutiny of cost: benefit regarding new/emerging products,
- greater understanding of fertiliser budgeting, plant nutrient requirements and nutrient cycling resulting in more efficient expenditure on pasture fertilisers/inputs.

Key Messages

Producers, extension providers and researchers and consultants may consider the following key messages as a result of the PDS.

On the Holbrook soil which was already well supplied with phosphorus, no statistically significant differences in pasture growth were observed over six years. Based on this finding, producers need to:
a) know the critical/minimal values for plant-available phosphorus in their soil types and for their pastoral enterprises, and
b) use this knowledge to manage the production potential/risk of applying too much or too little fertiliser phosphorus.

Products expected to influence populations of soil microorganisms (Bactivate Plus, NutriSoil LS and R.U.M.) had no statistically significant ($P>0.05$) effects on both measures of microbial abundance after three, four and five years, relative to all other treatments, single superphosphate and the untreated NIL control soils.

The increased concentrations of total soil phosphorus over the life of the demonstration on all treatments, including the untreated NIL control soils, demonstrate a net importation of phosphorus onto the site, presumably in sheep dung. This outcome annuls any conclusions being drawn about the annual trends in available soil phosphorus concentrations for the treatment products, which was an objective of the project extension.

HLN encourages land managers to reflect on their pasture growth objectives while considering their economic position and returns on investment in their grazing enterprises. These objectives include:

1. Have clearly defined goals/objectives/purposes for your fertiliser and soil amelioration program(s).
2. Know and measure what is in your soils.
3. Know the minimum/critical values of the soil properties of interest to you.
4. Know the nutrient / organic matter / microbial / water contents of the fertilisers/soil amendments/products you are considering.
5. Set up your fertiliser paddock evaluations as detailed in Appendix 5:
6. Know how to read your pasture responses.

Appendices

Appendix 1. Spring pasture dry matter yields for a range of treatment products measured on 8 October 2009, expressed as a percentage of the NIL control and single superphosphate treatments.

	NIL control	Single superphosphate
Actual DM yield (t/ha)	4.197	3.750
Percentage yields		
Bactivate	98.4%	110.1%
Biodiesel	93.2%	104.3%
CalSap	93.2%	104.3%
NutriSoil LS	94.8%	106.1%
Prolong®	88.6%	99.2%
R.U.M.	99.8%	111.7%
Single superphosphate	89.4%	-

Appendix 2. Spring pasture dry matter yields for a range of treatment products measured on 27 September 2010, expressed as a percentage of the NIL control and single superphosphate treatments.

	NIL control	Single superphosphate
Actual DM yield (t/ha)	4.253	4.395
Percentage yields		
Bactivate	95.5%	92.4%
Biodiesel	106.4%	103.0%
CalSap	110.6%	107.0%
Johnson’s compost	96.2%	93.1%
NutriSoil LS	97.4%	94.3%
Prolong®	100.6%	97.3%
R.U.M.	97.2%	94.0%
Single superphosphate	103.4%	-

Appendix 3. Spring pasture dry matter yields for a range of treatment products measured on 20 October 2011, expressed as a percentage of the NIL control and single superphosphate treatments.

	NIL control	Single superphosphate
Actual DM yield (t/ha)	5.660	5.625
Percentage yields		
Bactivate	105.7%	106.3%
Biodiesel	105.9%	106.6%
CalSap	100.7%	101.3%
Johnson's compost	106.5%	107.2%
NutriSoil LS	90.1%	90.7%
Prolong®	103.5%	104.2%
R.U.M.	95.3%	95.9%
Single superphosphate	99.4%	-

Appendix 4. Photographs of demonstration plots using MLA Pasture Ruler to aid visual pasture growth comparisons.

Treatment	Photographs taken October 2014
Nil	

Single Superphosphate	
Bactivate Plus	

Biodiesel by-product	
CalSap	

NutriSoil LS	
Prolong®	

R.U.M.	
Compost	

Appendix 5 Supplementary Extension Materials:

5.1 Fact Sheet

Considerations for Demonstrating Products on Your Farm

Key Steps

1. Have clearly defined **goals/objectives/purposes** for your fertiliser and soil amelioration program(s).

   a. All producers want to grow sufficient pasture to match their livestock's seasonal demands for energy, protein and nutrients.

   b. Additionally, some producers may want to improve other aspects of their soil condition, such as the levels of soil biological activity, for example.

2. **Know** and **measure** what is in your soils.

   a. Soil test your paddocks regularly (every second or third year) for those soil properties that are critical to achieving your fertiliser/soil amendment goals.

   b. Look for trends (decreasing or increasing values) in those critical soil properties over time; i.e. between sampling dates.

3. **Know** the **minimum/critical values** of the soil properties of interest to you.

   a. Likewise, the most appropriate soil pH values for most pasture plants are well known.

   b. Use general rules of thumb for micro-nutrients – their availability can be strongly pH dependent (e.g. molybdenum, zinc, etc.) and deficiencies may be more common on particular soil types.

4. **Know** the **nutrient / organic matter / microbial / water contents** of the fertilisers/soil amendments you are considering.

   a. Products registered as solid or liquid fertilisers must state their N-P-K-S contents to the nearest whole number percentage.

   b. Products of variable organic content (e.g. manures and composts) need to be analysed for their N-P-K-S and water contents on a batch basis.

   c. Use their nutrient contents / organic matter contents, etc., on a dry basis / to calculate appropriate application rates to achieve your particular fertiliser / amelioration goals.

5. **Set up** your **fertiliser paddock evaluations** as follows:

   a. Select a uniform part of the paddock with a good coverage of pasture species that are likely to respond.

   b. Follow the same rules as for soil sampling; avoid fence lines, sheep camps, drainage lines, etc., etc., when you select your evaluation area.

   c. Make sure there are no underlying nutrient deficiencies in the selected area other than the nutrients to be tested in the evaluation.

   d. OPTION 1: apply 3-5 runs of the fertiliser spreader down the middle of the selected area and leave the rest of the selected area and the rest of the paddock unfertilized.

      OPTION 2: create a 'window' within the selected area where no fertiliser is to be applied, and apply fertiliser to the rest of the paddock. The unfertilised window must occupy the middle 25% of the selected area.

   e. Draw a sketch map of the paddock in your farm diary that clearly shows the areas where the fertiliser has and has not been applied, with clear labels and an application date.

   f. Test strips (Option 1) or window plots (Option 2) can be a useful way to evaluate an alternative fertiliser against a conventional fertiliser. The alternative fertiliser is applied to the selected test strip/window plot area and the rest of the paddock treated with the conventional fertiliser.

6. **Reading** your **pasture responses**

   a. If a visual response in the growth and/or colour of your pasture can be seen, this strongly suggests the whole paddock would benefit from an application of the test fertiliser.

   b. Remember it is only possible to see a 20 per cent and/or 0.25 t/ha increase in pasture growth with the naked eye. Smaller increases will need to be measured.

   c. Assess your fertiliser evaluation areas for three to four years at the time of the year when pasture growth rates are at or near their peak (typically early to mid-October). Use the same group of assessors (yourself, yourself plus members of your pasture group, farm group, neighbours, etc.) each year

   d. Remember that responses may vary from season to season, depending on seasonal conditions, and may not be immediately apparent in the year of application.

5.2 Producer Demonstration Summary: "Alternatives to Superphosphate" Carp, Kelp & Christmas Island: Where to next for fertiliser?

This summary outlines results from Holbrook Landcare Network's producer-led demonstration "*Carp, Kelp and Christmas Island; where to next for fertilisers?*" funded by Meat & Livestock Australia (MLA) from 2009 - 2014.

Grower Questions:

Members of the Holbrook Landcare Network – Beef Group initiated the project after sharp increases in single superphosphate prices in 2008. Growers questioned whether "locally-available, alternative fertiliser products could give the same pasture growth responses as single superphosphate?"

Site Selection:

- HLN beef group members worked to identify soils that represented typical Holbrook pastoral systems. Soil test results were collated in 2009 and all were found to be above the critical P levels for optimal pasture growth.
- A four-year-old, well-fertilised and limed phalaris-sub clover pasture soil was chosen as the site for this Producer Demonstration.

Products Selection: This demonstration has two control treatments:

- an ABSOLUTE NIL (no added product), and
- a RELATIVE CONTROL (annual maintenance rate of superphosphate @ 0.6 kg P/DSE or 123 kg/ha).

Seven treatments (products) were selected:

- Bactivate – microbial soil conditioner @ 150 kg/ha + 150 kg/ha blood & bone (2009 only). From 2010 onwards, Bactivate Plus was applied @ 75 kg/ha with 2 L/ha humic acid solution,
- Biodiesel by-product – high K and S product @ 100 kg/ha,
- CalSap – soluble calcium liquid @ 20 L/ha,
- NutriSoil LM – vermicomposted liquid plant food @ 5 L/ha to actively-growing plants in autumn and spring,
- Prolong – biologically-activated rock phosphate @ 491 kg/ha every fourth year,
- R.U.M. – liquid plant food @ 5 L/ha,
- Johnson's compost – first applied in 2010 @ 1.0 t/ha to a third set of Absolute NIL plots.

Each product was applied once, across four replicate plots each April, as indicated in the methods below.

Pasture growth:

In the first three growing seasons (2009-2011), pasture growth was measured before each grazing. For the second three years (2012-2014), pasture growth was visually assessed for differences between treatments before each grazing.

The following table shows the average pasture growth (t/ha) yields below (for the 12 harvests taken over the 2009-2011 growing seasons). The table shows no significant differences in growth between any treatments.
Visual assessments of pasture growth (for the 2012 to 2014 growing seasons) showed no consistent differences between any plots or treatments.

Average Pasture Dry Matter Yields (t/ha)

Products in the upper part of the table showed some nutrient contribution relative to Controls (Absolute NIL and Relative Nil – superphosphate). Products in the lower part of the table showed no nutrient contribution relative to Controls (Absolute NIL and Relative Nil – superphosphate).

	Absolute NIL	Super	Biodiesel	CalSap	J compost	Prolong.
Mean – all 2009-2011 harvests						
	3.24	3.28	3.27	3.37	3.16	3.23
Change relative to NIL		+0.04	+0.03	+0.13	-0.08	-0.01
Change relative to super			-0.01	+0.09	-0.12	-0.05
			Bactivate	NutriSoil	R.U.M.	
Mean – all 2009-2011 harvests						
			3.25	3.20	3.11	
Change relative to NIL			+0.01	-0.04	-0.13	
Change relative to super			-0.03	-0.08	-0.17	

Pasture Quality Results:

No significant differences were recorded between treatments on pasture feed quality in any season.
In all seasons, the pasture was:

- highly digestible (72-81%),
- contained excellent levels of protein (14-29%[1]), and
- sufficient energy (10.8-12.3 MJ/kg) for rapidly-growing stock.

Were there nutrient deficiencies/elemental toxicities effecting pasture growth?

The tissue concentrations of all nutrients, as well other potentially toxic elements, were measured in pasture foliage collected in September 2013.
The tissue concentrations of all plant nutrients were:

- within acceptable ranges for growth,
- aluminium, chromium, iron and nickel were not at toxic levels,
- arsenic, cadmium, cobalt, lead and selenium were below detection limits.

Soil Properties:

[1] The variation in protein percentages is due to different sampling dates and seasonal conditions.

Soil strength was measured on all plots with a manual penetrometer in June 2011 when the soil was at field capacity. A penetrometer was used to record the depth at which penetrometer resistance reached 2, 3 & 4 MPa respectively. At soil strengths greater than 2 MPa the growth of grass roots are seriously impeded. It must be noted that manual penetrometer readings are highly variable and do not necessarily provide accurate readings. Results show the range of values across all treatment and control plots at which the penetrometer reached 2Mpa was 7 – 48 cms depth; with an average depth of 17cms. No differences were recorded between treatments at a depth (60 cms) at which penetrometer resistance reached 2.0 MPa.

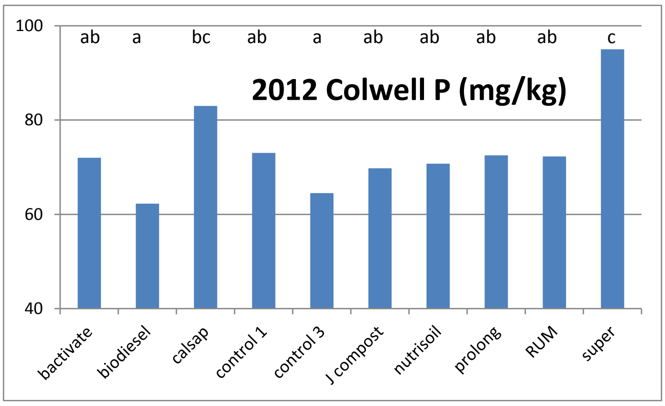
Soil Nutrient & Biological Properties:

Treatments that significantly ($P<0.05$) changed key soil chemical or biological properties, relative to the ABSOLUTE NIL, are identified below with a tick (**√**).

	2012	**2014**
Olsen P	**√**	**√**
Colwell P	**√**	-
Colwell K	-	**√**
Available S (KCl_{40})	**√**	**√**
pH (calcium chloride)	-	-
Organic C	-	-
Microbial biomass C	-	**√**
Total C	-	-
Microbial enzyme activity	-	-

Example:

Colwell P values below show that in 2012 single superphosphate increased available P levels relative to all other treatments except CalSap.



Summary:

Given the project objective was “to explore pasture growth efficiencies on a soil already well-supplied with available P”, no product increased pasture growth over and above the control (i.e. absolute NIL or relative NIL (superphosphate) measures.

Appendix 6: Rainfall (mm) at 'Spring Valley' Holbrook

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
2008	74.50	79.00	52.25	18.75	31.00	40.75	95.25	69.25	25.75	25.00	71.25	64.25	**647.00**
2009	9.00	1.75	8.50	58.00	12.00	79.25	57.00	60.25	53.75	44.50	36.75	33.75	**454.50**
2010	7.00	74.50	81.50	34.75	74.25	45.00	56.25	104.75	79.50	230.25	93.25	129.00	**1,010.00**
2011	103.75	284.00	128.75	31.25	36.50	31.00	51.75	79.00	65.75	29.50	106.50	58.50	**1,006.25**
2012	76.25	87.75	226.00	24.50	75.50	32.50	67.50	63.00	23.25	34.00	74.25	30.25	**814.75**
2013	20.50	93.25	48.75	12.75	81.00	127.75	67.75	68.25	60.75	24.75	15.25	43.50	**664.25**
2014	22.75	39.25	65.50	81.50	61.25	72.00	41.25	15.25	47.75	30.25	51.00	56.00	**583.75**