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by Lisa Warn

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Researcher Contact Details

Name: Lisa Warn
Address: The Mackinnon Project, University of Melbourne, 250 Princes Hwy, Werribee 3030

Phone: 03 9731 2375
Fax: 03 9731 2388
Email: l.warn@ unimelb.edu.au

In submitting this report, the researcher has agreed to RIRDC publishing this material in its edited form.

RIRDC Contact Details

Rural Industries Research and Development Corporation
Level 2, 15 National Circuit
BARTON ACT 2600

PO Box 4776
KINGSTON ACT 2604

Phone: 02 6271 4100
Fax: 02 6271 4199
Email: rirdc@rirdc.gov.au.
Web: http://www.rirdc.gov.au

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Foreword

Rising costs of conventional fertilisers has led broadacre livestock producers (wool, lamb, beef) to seek alternative nutrient sources to fertilise pastures and crops. Spent litter from meat chicken sheds is a viable alternative, particularly when key inputs like phosphorus fertiliser prices are very high, or where a range of macro nutrients and trace elements are required

The project was therefore undertaken to produce information that will assist livestock producers to successfully utilise litter on pastures in a cost-effective manner. It was also intended that the project will serve to increase awareness of chicken litter as an alternative source of nutrients and an ameliorant for poor soils by improving soil organic matter and carbon. A method for valuing the organic matter in litter, in addition to the nutrients, was also developed in the course of the project, based on the increases in soil organic carbon measured in the field experiments undertaken.

The project has and will continue to benefit livestock producers by providing them with objective data, practical information and demonstrations on how to utilise litter as an alternative fertiliser and how to value the nutrients relative to conventional fertilisers. The chicken meat industry will also benefit from the project through increased awareness of the product amongst livestock producers across south-eastern Australia. This will drive further demand for litter and create a more steady market which will benefit chicken meat producers and shed clean-out/cartage/spreading contractors.

This project will impact on the way that chicken litter is used by livestock producers on pastures by ensuring that it is used effectively for optimum pasture and soil responses while minimising potential risks. Usage from year to year will always be influenced by the relative price of inorganic fertilisers so this will set a limit to what price can be put on litter.

Funding for this project was provided by RIRDC as part of its Chicken Meat Program. This report is an addition to RIRDC's diverse range of over 2000 research publications and it forms part of our Chicken Meat R&D program, which aims to improve efficiency of production.

Most of RIRDC's publications are available for viewing, free downloading or purchasing online at www.rirdc.gov.au. Purchases can also be made by phoning 1300 634 313.

Craig Burns
Managing Director
Rural Industries Research and Development Corporation

About the Author

Lisa Warn (BAgrSc, MAgrSc, Dip. Wine Tech.) is a Senior Research Fellow and Senior Agricultural Consultant with The Mackinnon Project based at The University of Melbourne at Werribee and a former president of the Grassland Society of Southern Australia. The Mackinnon Project is a sheep and cattle production and health consultancy service, which is involved with on-farm consulting, applied research, producer training and undergraduate and post-graduate training. Lisa works with sheep and cattle producers across south-eastern Australia and has expertise in pasture agronomy, grazing systems and farm management economics.

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Abbreviations

N - nitrogen

P - phosphorus

K - potassium

S - sulphur

C - carbon

CEC - cation exchange capacity

kg DM - kg dry matter

ME - metabolisable energy (MJ ME/ kg DM)

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Executive Summary

What the report is about

This report summarises the results of a three year project which evaluated and demonstrated the use of chicken litter as an alternative fertiliser for pastures and a method for increasing soil organic carbon.

The grazing industries are an important outlet for used litter from meat chicken sheds. The consequences of rising inorganic fertilise prices and years of drought is that sheep and cattle producers are looking for economic alternatives to conventional fertilisers to supply nutrients to pastures and ways to improve poor soils.

Forecast growth of the chicken meat industry may result in increased volumes of used litter being produced which has waste management and environmental ramifications. Increasing the demand of used litter by the grazing industries is a positive solution to achieve effective utilisation of litter.

Who is the report targeted at?

Target audiences include:

- Sheep and cattle producers - located close enough to meat chicken farms to make chicken litter an economic alternative to inorganic fertilisers. This group includes producers who are already aware of the value of chicken litter and are receptive to trialling the product but do not have detailed knowledge about composition, effect on production/soils, cost or application rates and techniques. It also includes producers who have not considered chicken litter due to a range of perceived problems such handling, storage, odour, reliability of supply or cost.
- Agronomists/advisors/consultants providing advice on pasture and soil management.
- Chicken litter suppliers – meat chicken growers and contractors involved in the supply and application of litter will find the information useful to promote the benefits of litter and provide objective information about using litter.

Where are the relevant industries located in Australia?

This work is relevant to all broad-acre livestock (sheep, cattle) producers in the temperate pasture zone of Australia, but in particular those that are in close proximity to the meat chicken farms. In Victoria, the chicken meat industry is located around Nagambie, Bendigo, Geelong, West Gippsland and the Mornington Peninsula. It is feasible to transport litter up to 100 km from the chicken farm, but transport costs usually increase significantly after that distance. In the other states, NSW, SA, WA and Queensland, the chicken industry is located in peri-urban areas or decentralised locations. New South Wales is the largest chicken meat producer in Australia at present, but the industry is expanding in SA and Queensland.

Background

Rising costs of conventional fertilisers has led broad-acre livestock producers (wool, lamb, beef) to seek alternative nutrient sources to fertilise pastures and crops. Spent litter from meat chicken farms is a viable alternative, particularly when key inputs like phosphorus fertiliser prices are very high, or where a range of macro nutrients and trace elements are required. There is the additional benefit of adding organic matter, although this benefit has not been quantified for pasture soils. The wider implication of increasing organic matter in soil is the potential for carbon sequestration and generation of carbon credits.

Market research undertaken as part of the National Poultry Litter program highlighted a range of barriers to greater adoption of poultry litter on broad-acre farms. Key barriers were: the need to demonstrate the value of litter to potential end users; difficulties associated with storing, handling and applying litter; and perceived lack of information about what is in litter and its performance benefits.

Aims/objectives

- To evaluate and demonstrate the use of chicken litter as an alternative source of nutrients (phosphorus in particular) for pastures.

- To promote and support adoption of the use of alternative fertilisers and practices that are cost effective and can improve soil organic carbon.

- To evaluate if the use of chicken litter, broadcast on the soil surface, can increase the rates at which total soil organic carbon and more stable forms of carbon (humus) are built up, in comparison to the use of inorganic fertilisers.

Methods used

Replicated field experiments were established at two sites in central Victoria with different soil types and limitations to evaluate and demonstrate the use of chicken litter as an alternative fertiliser for pastures compared with conventional, inorganic fertilisers. Fresh (non-composted), single batch litter, sourced from a meat chicken farm, was used at three different rates. Each batch of litter was analysed for composition to allow appropriate application rate to be determined. Litter and fertiliser products were applied each year from 2009-2012.

Data was collected on the following parameters:

- pasture production (kg DM/ha);
- species composition;
- pasture feed quality;
- topsoil macro nutrient (N,P,K,S) levels, trace elements/heavy metals, pH, salt, cations;
- topsoil and subsoil carbon content, carbon stocks and carbon fractions;
- leaf tissue macro nutrient and trace elements levels; and
- soil microbial activity and microbial biomass organic carbon.

An extension program was conducted to extend research results to sheep and cattle producers, litter distributors/spreaders and meat chicken growers, and to create awareness about how to effectively use litter. The program involved field days and farm walks at the field sites, a major workshop, presentations to producer groups and conferences, and newsletter articles.

Results/key findings

- Broadcasting chicken litter onto pastures can give similar pasture growth responses to conventional fertilisers.
- In soils with adequate phosphorus levels, pasture responses were mainly due to nitrogen. In the short-term, it is more-cost effective to apply nitrogen (urea) alone rather than litter. Litter was as effective as conventional fertiliser at increasing soil fertility, when applied at similar rates of nutrients. Soil phosphorus levels, and plant tissue levels of potassium, increased with increasing rates of either product. Plant tissue levels of copper and molybdenum also increased with increased rates of litter. Trace elements/heavy metals were still at acceptable levels in soils and plant tissue where very high rates of litter were applied.
- Soil organic carbon increased by 0.5 - 0.9% in the topsoil at the two sites and Carbon stocks increased by 3-10 t/ha, over four years, where high rates of litter were applied relative to the

Control (nil fertiliser). Increases in soil carbon stocks could be worth an additional \$3.20 -5.20/m^3 on the price of litter, using a carbon price of \$15.00 -24.15/t CO_2 equivalents.
- Capital rates of litter and conventional fertiliser (NPKS blend) both increased pasture quality by 1-2 MJ ME/kg DM and protein by 3-8% in the winter following autumn application.
- Litter had a positive effect on pasture composition, promoting both clover and improved perennial grass content.

This project will impact on the way that chicken litter is used by livestock producers on pastures by ensuring that it is used effectively for optimum pasture and soil responses while minimising potential risks. Usage from year to year will always be influenced by the relative price of inorganic fertilisers so this will set a limit to what price can be put on litter. The cost of litter varies from \$16 - \$28/m^3 spread, from district to district, with the lower price representing good value for a single nutrient like phosphorus (on a \$/kg basis) compared to conventional fertilisers.

Implications for relevant stakeholders for:

Grazing industries (Wool, lamb and beef)
Chicken litter contains a range of valuable nutrients for pasture production and can be a cheaper alternative than conventional fertiliser. There was no additional pasture yield response to litter over and above that of the conventional fertilisers after four years of applications. In the short-term, increases in soil carbon and cations, from applying high rates of litter, did not translate into additional yield but may do so in the long term. Hence the cost-effectiveness will depend on the composition of the litter, what nutrients the soils require, and the price of litter relative to inorganic fertilisers. This work relates to single batch litter, but multi batch litter may have higher nutrient levels and may be cheaper on a \$/kg nutrient basis. High rates of litter can also be used to improve poor soils and degraded pastures. There is an opportunity for many producers located close to meat chicken farms to access litter as an alternative fertiliser.

Changes in soil carbon, from applying high rates of chicken litter, could provide opportunities for generating carbon credits if future Government Emission Reduction schemes include soil storage of carbon.

Chicken Meat industry
The grazing industries are an important outlet for used litter from meat chicken sheds. There may be opportunities to increase returns from litter, but the litter will still need to be competitively priced relative to conventional fertilisers. In addition to the nutrient value in litter, the value of carbon sequestration, from application of high rates of litter, could be worth a further \$3.20 - \$5.20/m^3 on the price of litter, based on a carbon price of \$15.00 -24.15/t.

Increased demand for litter could mean that litter may be carted direct from chicken shed to broad-acre farm. This will reduce the need for double handling/carting litter to and from stockpiles and could reduce costs for contractors.

The forecast growth of the chicken meat industry may result in increased volumes of used litter which would have waste management and environmental ramifications, subject to the extent of uptake of litter reuse on chicken farms. Increasing the demand of used litter by the grazing industries is a positive solution to achieve effective utilisation of increasing volumes of litter.

Communities
Greater demand for used litter from chicken farms will reduce environmental impacts associated with the stockpiling of litter.

Changes in soil carbon, from applying high rates of chicken litter, could provide opportunities for generating carbon credits if future Government Emission Reduction schemes include soil storage of carbon.

Recommendations

There is a need for a continued extension effort to promote the benefits of chicken litter to broad-acre livestock producers, and provide information and tools so they can utilise litter effectively on their farms. This will be important as the chicken meat industry grows and the amount of used litter increases.

Research results also need to be disseminated to Departments of Primary Industries, Catchment Management Authorities and Landcare groups who are interested in soil health and soil carbon aspects of using alternative fertiliser products that contain organic matter.

There is also a need to study the long-term impacts of regular applications of high rates of chicken litter on pastures and the impact on soil parameters such as total organic carbon and total cations. These soil properties affect nutrient retention, while carbon also affects the water holding capacity of soils. A preliminary attempt to value the organic matter and carbon in litter has been made in this report but this benefit could be higher in the long- term.

Introduction

The chicken meat industry produces around 2.7 million m^3 /year (1,216,00 t/yr) of used chicken litter annually (McGahan *et al.* 2013). This is equivalent to around 2.4 kg litter per chicken per year. Runge *et al.* (2007) estimated chicken litter incurs a cost of $10.07 million annually to chicken meat producers to remove from sheds, store and dispose. However this figure could now be double that, based on the increase in litter production estimated by McGahan *et al.* (2013). The Australian poultry industry and the community generally are concerned about the management of litter. There is potential to add value to chicken litter and increase returns to chicken growers.

There is a large potential market amongst broad-acre farmers (sheep/beef) who could use chicken litter as an alternative fertiliser. Rising prices for inorganic fertilisers have made chicken litter more cost competitive on a $/kg nutrient basis. There is the additional benefit of adding organic matter, although this benefit has not been quantified for pasture soils. The wider implication of increasing organic matter in soil is the potential for carbon sequestration and carbon trading.

Market research undertaken as part of the National Poultry Litter program highlighted a range of barriers to greater adoption of poultry litter on broad-acre farms. Key barriers were: the need to demonstrate the value of litter to potential end users, difficulties associated with storing, handling and applying litter, and perceived lack of information about what is in litter and its performance benefits (Dorahy, 2008). Runge *et al.* (2007) identified further issues associated with utilising litter to be uncertainty about application rates and composition, including heavy metals, and potential pathogen risks.

Research has been conducted on crop and soil responses to farmyard manure in comparison to conventional fertilisers in a number of long-term experiments conducted overseas (Edmeades, 2003). Most of the work involved crop rotations and the manure was usually incorporated or harrowed into the soil. Often the manure was from pigs or cattle, which had lower nutrient and organic matter contents than chicken litter, or the composition was not known. Most of the trials showed there was no significant difference between fertilisers and manures in their long-term effects on crop production. Previous work conducted as part of the National Litter Project investigated the value of chicken litter in broad-acre cropping in South Australia, but did not include work on pasture application (Craddock, 2012). That study highlighted the need for some conventional starter fertilisers (DAP at sowing) to be used in conjunction with chicken litter to achieve similar crop yields to using conventional fertiliser alone. There is limited data on soil and pasture responses to surface applied chicken litter. Hence, research was required to provide hard data for potential litter users.

This project addressed the barriers to adoption identified in the market research. Firstly, the project evaluated pasture and soil responses to different rates of fresh, broadcast chicken litter, in comparison to inorganic fertiliser, to provide hard data on cost/benefits for existing and potential litter users. Secondly, it provided information and training to broad-acre producers on: litter composition, how to calculate appropriate application rates, and how to safely store, handle and apply litter.

Objectives

The primary objectives of this research were:

- To evaluate and demonstrate the use of chicken litter as an alternative source of nutrients (phosphorus in particular) for pastures
- To promote and support adoption of the use of alternative fertilisers and practices that are cost effective and can improve soil organic carbon.

- To evaluate if the use of chicken litter, broadcast on the soil surface, can increase the rates at which total soil organic carbon and more stable forms of carbon (humus) are built up, in comparison to use of inorganic fertilisers.

Methodology

Research sites

A replicated field experiment was established at two sites in Victoria. Two different soil types were selected. The Glenaroua site was located 10 km west of Seymour on duplex soils (clay loam overlying clay) of sedimentary origin. The Pastoria site was located 10 km east of Kyneton on soils of granite origin, low in organic matter and prone to nutrient leaching (i.e. N,K,S) and erosion.

Glenaroua has a long-term average annual rainfall of 600mm while Pastoria has a long term average annual rainfall of 750mm. Glenaroua is warmer than Pastoria in winter due to its lower elevation (Figure 1) but has a shorter growing season.

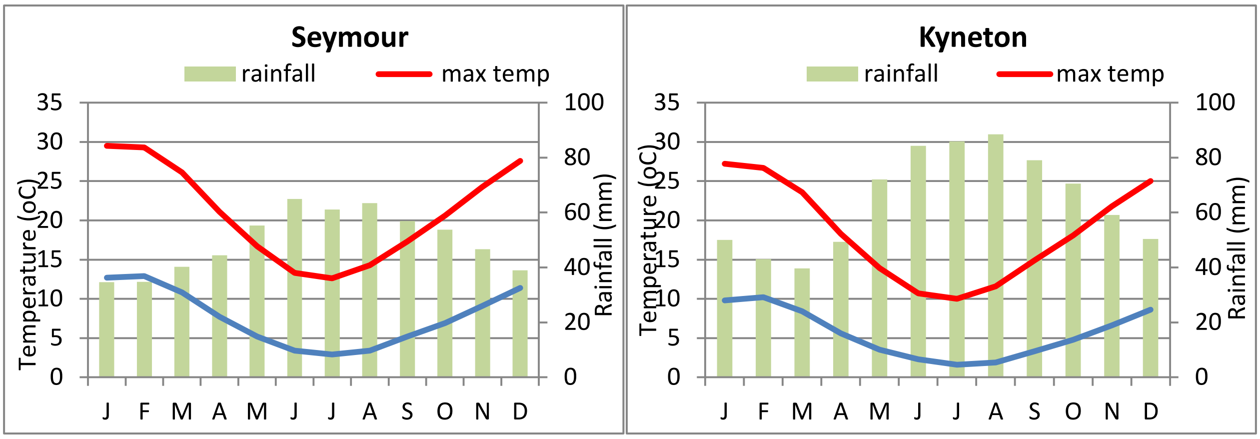


Figure 1. Long-term monthly temperature and rainfall for Seymour and Kyneton (B.O.M.)

The Glenaroua site had P and S levels around the target levels while K was above target levels (Table 1). So although not deficient at the start of the experiment, it was assumed that a control/ nil treatment would drop in fertility during the experiment to allow P responses from applied products to be detected. The Pastoria site had good P levels but was deficient in K and S. Both sites were strongly acidic and typical of soils in those districts. Producers who use chicken litter on pastures are using it as a substitute for their maintenance P,S fertiliser (superphosphate) on their improved pastures or as a capital application to boost PKS levels of highly deficient soils or improve poor soils with low organic matter. Hence, investigating responses of chicken litter on soils with relatively good Olsen P levels was relevant to users. The Pastoria site represented a poorer soil as it had a low level of organic carbon.

Table 1. Topsoil texture and initial fertility levels for the two sites (August 2009)

Site	**Soil type**	**pH ($CaCl_2$)**	**Organic Carbon (%)**	**Olsen P (mg/kg)**	**Colwell K (mg/kg)**	**KCl40 S (mg/kg)**
Glenaroua	clay loam	4.3	4.05	13.4	216.0	8.3
Pastoria	loam	4.3	2.01	16.2	71.0	4.3
Desirable range/target		4.5-5.2	3 - 5	12-15	150 (loam) 160 (clay loam)	8.0

At Glenaroua, the pasture consisted of phalaris and subterranean clover, some native grasses and volunteer annual (capeweed) and perennial weed species (onion grass). At Pastoria, the pasture was a degraded old perennial ryegrass/cocksfoot/sub clover pasture with annual (capeweed) and perennial (sorrel, flatweed, small patches of bent grass) weeds. Both sites had experienced a run of droughts/dry years in the past decade and pastures had been grazed very hard as a consequence. Producers at both sites were keen to see if chicken litter could improve drought damaged pastures.

The experiment commenced in spring 2009 after a decade of dry years. The 2010 season saw a return to better rainfall and pasture growth conditions. The spring-summer of 2010-11 was very wet at both sites (Figure 2 and 3) which resulted in above average growth. In 2012, both sites experienced a very dry spring and very poor spring growth.

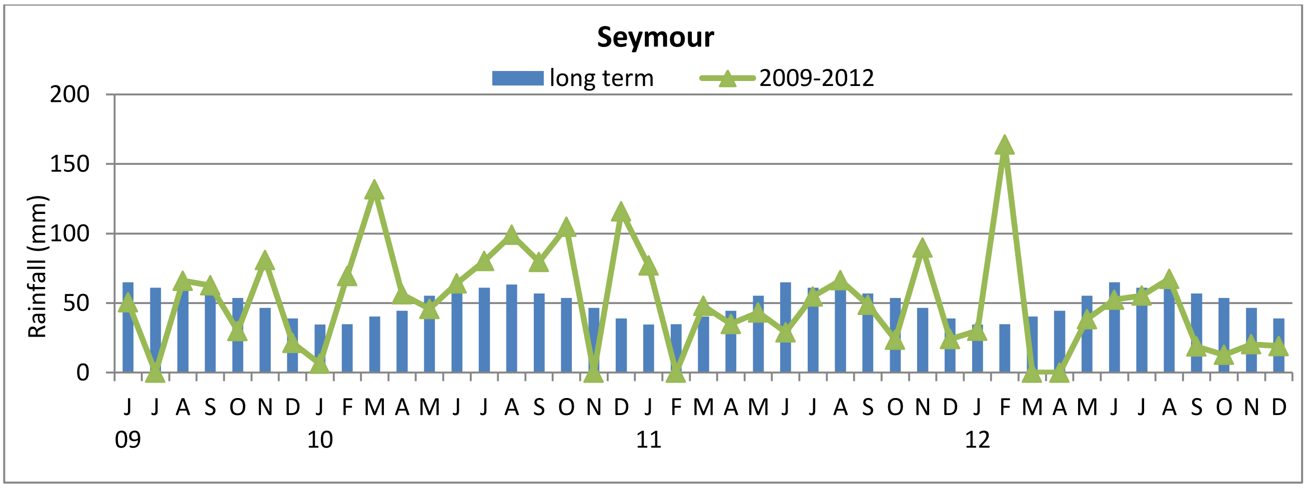


Figure 2. Monthly rainfall from June 2009 to December2012, for Seymour, compared with the long term average (Bureau of Meteorology)

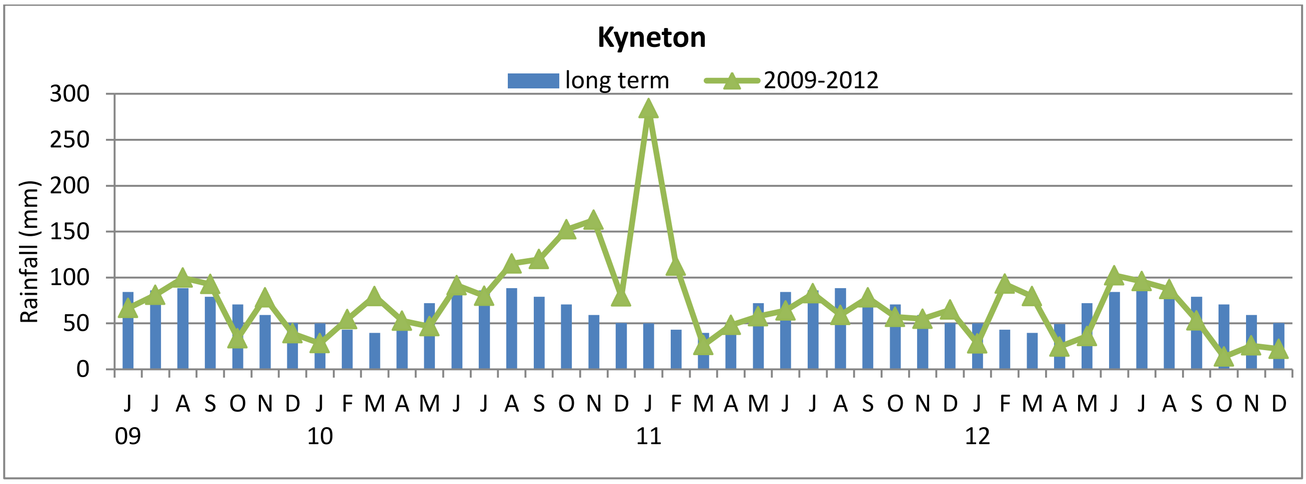


Figure 3. Monthly rainfall from June 2009 to December2012, for Kyneton, compared with the long term average (Bureau of Meteorology, 2013)

Treatments

Fresh (non-composted) chicken litter was used at both sites and the stockpile of litter was fenced off from stock prior to spreading on trial plots. The litter was sourced from the same meat chicken farm near Nagambie each year. On all occasions, the litter was from a single batch of chickens. Each batch of litter was analysed for composition to allow an appropriate application rate of macro nutrients (N,P,K,S) to be determined. All products were reapplied in autumn each year by broadcasting by hand.

The following treatments were applied:

a. Control A (Nil fertiliser)
b. Control B (Nil fertiliser)
c. Maintenance rate inorganic P,S fertiliser + Humic acid
d. Maintenance rate inorganic P,S fertiliser
e. Maintenance rate inorganic P,S fertiliser + N,K
f. Capital rate inorganic P,S fertiliser
g. Capital rate inorganic P,S fertiliser + N,K
h. Maintenance rate litter (ranged from 0.9 - 1.6 t/ha)
i. Capital rate litter (ranged from 1.8 - 3.2 t/ha)
j. High Carbon rate litter (5t /ha)

A randomised block design, using four replicates, was used. Each plot was 3 m x 10 m in size and separated with laneways (to which nothing was applied) to prevent nutrient run-off into neighbouring plots.

The actual rates of products applied each year varied as it was based on the nutrient analysis of the poultry litter. The maintenance rate of inorganic fertiliser (treatments c, d and e) was applied at a rate to supply 8.4 kg/ha of phosphorus (P) each year (equivalent to 95 kg/ha superphosphate). The capital rate of inorganic fertiliser (treatments f and g) was applied at a rate to supply 16.8 kg/ha P (equivalent to 190 kg/ha superphosphate). The maintenance and capital rates of litter were applied at rates to supply 8.4 and 16.8 kg/ha P respectively. The amount of N, K and S supplied in the two rates of litter was then calculated and the equivalent amount was applied to the inorganic fertiliser treatments (treatments e and g) as urea (N) and muriate of potash (K). As litter usually has a lower ratio of S to P than single superphosphate (8.8% P, 11%S), a mixture of single superphosphate and double super was used to achieve the same P and S levels as in the litter. The high carbon rate of litter (treatment j) was applied at 5t/ha of fresh weight each year, regardless of composition. A summary of actual nutrient (kg/ha) applied each year is shown in Table 2. The amount of carbon applied in the litter treatment is also shown.

Humic acid liquid was applied to treatment c in addition to the maintenance rate of inorganic fertiliser. Humic acid was sprayed on the plots, with a watering can, at the rate of 10 l/ha of actual humic acid (which was diluted in water), after the fertiliser was applied. The humic acid liquid used contained potassium humate (12%) and fulivc acid (2%). Humic and fulvic acids can be found in humus - the product that results from the decay of organic matter. Manufacturers of the humic acid liquid used in this experiment claim that it can be used as a fertiliser, plant growth promotant, soil life activator and soil conditioner. More specifically, they claim, the product detoxifies chemical and heavy metals, stabilises urea and other sources of N, chelates all cations, promotes and feeds beneficial fungi, improves soil structure, enhances root development and increases nutrient uptake. This product was included in the experiment in order to compare its effect on soil carbon, cations and soil biology with that of the organic matter in litter.

Table 2. Macro nutrient applied in fertiliser and litter each year in the 'maintenance' and 'high C' treatments*

Treatment	N kg/ha		P kg/ha		K kg/ha		S kg/ha		C (litter only) kg/ha	
	Maint	High	Maint	High	Maint	High	Maint	High	Maint	High
2009	47	145	8.4	26	26	81	7.3	23	565	1750
2010	36	117	8.4	27	18	56	5.8	17	570	1840
2011	35	183	8.4	44	14	73	4.1	22	351	1840
2012	32	187	8.4	49	15	86	3.6	21	240	1380

* 'capital' rate supplied double the amount of NPKS & C as the 'maintenance' rate

The timing of treatment application is shown in Table 3. First applications occurred in spring 2009, as soon as sites were established and fenced. Thereafter, fertiliser and litter were applied in autumn each year, as close to the autumn break as possible. Applications were later in 2012, but the autumn break was very late. In autumn 2011, treatment b (Control B) was altered at the Pastoria site only. This treatment was fertilised with the maintenance rates of PS inorganic fertiliser (superphosphate) plus K (potash) at the same rate as that applied in treatment e in autumn 2011 and 2012. This was done to be able to separate any potassium response in isolation of an N response as this site was deficient in K.

Table 3. Treatment application dates

Site	2009	2010	2011	2012
Glenaroua	20th September	23rd April	29th March	29th May
Pastoria	17th November	4th May	1st May	4th June

Monitoring

Litter composition

A sample of each batch of litter was taken and sent to Farmright Technical Service in Kyabram, for analysis. When the litter was dumped on site, ten samples were taken from different parts of the pile with a shovel and put into a bucket and mixed. From the bucket, a 1kg sub-sample was collected, put into plastic bag (double bagged) and sent for analysis.

Pasture production (kg DM/ha)

Pasture growth was measured by mowing a strip in each plot and weighing cut herbage. This usually occurred when there was at least 1,500-2,000 kg DM/ha of pasture available. Sub-samples of cut pasture were taken from each plot and weighed and dried back in the laboratory to determine dry matter content, and calculation of kg DM/ha. On several occasions, paddocks were too wet to drive onto, or the herbage was too thick or wet to mow, so a calibrated falling plate pasture meter was used instead, to assess the relative pasture production (Cayley and Bird, 1996). Plots were grazed off by sheep after each yield assessment to get all plots down to a similar pasture mass, ready for the next regrowth cycle. Sheep were locked into the plot area for 1-2 days to quickly eat pasture down and prevent selective grazing and uneven transfer of nutrients. Grazing was used rather than mowing off the whole plot area and discarding herbage as this would have removed nutrient at a faster rate than what would normally occur in grazed paddocks.

Botanical composition

Botanical composition was measured in each plot at each harvest using the dry weight ranking method (t'Mannetje and Haydock, 1963). The proportion of green and dead herbage present and the ground cover (%) was also assessed.

Pasture quality

Pasture quality was assessed at each harvest time in 2012 and in winter 2010 and 2011. Samples were collected from the herbage cut for yield assessments. The samples contained the mixed herbage and were not separated into green and dead. In winter and spring the material was primarily green herbage. Samples were sent to the FEEDTEST laboratory in Werribee, Victoria. Standard analysis was done using NIR, which included protein (%) and energy content (MJME/kg DM).

Soil nutrient analysis

Topsoil (0-10cm) samples were taken from each plot prior to the application of treatments in 2009 and then in spring each year. Samples were sent to Farmright Technical Service in Kyabram, Vic. Analyses undertaken included: macro nutrients (N,P,K,S), trace elements (Cu, Zn, Fe, Mn, Bo), pH, salt, total organic carbon and cations (Ca, Mg, K, Na).

Leaf analysis

Pasture samples were collected for nutrient analysis (macro and trace elements) in spring each year. Samples were collected at the same time plots were harvested for dry matter production. Samples were sent to Farmright Technical Service in Kyabram, Victoria. Leaf analysis is a more accurate method for detecting trace element deficiencies in pasture than soil testing.

Soil carbon

Topsoil (0-10 cm) and subsoil (10-30cm) samples were taken from each plot prior to the application of treatments in 2009 and at the end of the experiment in October 2012. These samples were collected for analysis of carbon fractions (particulate organic C, humic organic C/humus and resistant C) and calculation of total carbon (t C/ha) in the soil down to 30 cm. Additional samples were collected for determination of soil bulk density (g/cm^3) in order to adjust calculations of total carbon (metric t C/ha or Mg/ha). Carbon samples and bulk density samples were sent to the Department of Environment and Primary Industries laboratories at Werribee (2009) and Macleod (2012).

Testing for C % alone (as in a standard commercial soil analysis package) does not give a true indication of treatment effects on soil carbon as some treatments may alter soil bulk density. The National Soil Carbon Research Programme Australia (Sanderman *et al.,* 2011) outlines the standard method for assessing carbon stocks in soils which involves calculating (t C/ha or Mg/ha) for each depth of soil, along with the standard sampling depth of 0-30cm. Carbon % (Leco method) was multiplied by soil bulk density for each soil depth to derive figures for tonnes carbon per ha.

The type of carbon in soil is of importance and not just the total amount of carbon. Humic organic C is a more stable form of carbon than particulate organic C, which can readily be lost from the soil with management changes. Determination of carbon fractions was undertaken to investigate what impact the chicken litter and humic acid liquid might had on these fractions. Samples were sent to the DEPI Victoria laboratory at Macleod for analysis. This method involved the use of MIR to predict the amount of particulate organic carbon (POC), humic organic carbon (HOC) and resistant organic carbon (ROC). Predicted carbon fractions were measured mg C/g soil. Predicted values for carbon fractions were adjusted to add up to 100 % of the Leco carbon % measured.

Value of nutrients and carbon in chicken litter

The value of nutrients in chicken litter was calculated by comparison to the cost of supplying the same nutrients with inorganic fertilisers. This is the standard approach for looking at the comparing the value of litter against other options.

The organic matter (organic carbon) in litter has an inherent value but is difficult to assign an economic value to it. A method was established to put a price on the carbon in litter. Any additional carbon (t/ha, or Mg/ha) measured under chicken litter treatments relative to other treatments, could be assigned a dollar value.

As at 2013/14, there are two mechanisms for pricing carbon - the compliance market and the voluntary market. The Clean Energy Regulator administers the carbon pricing mechanisms in Australia and administers the Carbon Farming Initiative (CFI) (Clean Energy Regulator, 2014).

In the voluntary market, businesses can pay to offset their greenhouse gas emissions, and this is generally in the form of funding tree plantations to sequester carbon. Under the CFI, activities such as re-afforestation and reducing emissions are included, but soil storage of carbon is not at this stage. Farmers can generate carbon credits by participating in the CFI but involvement is voluntary.

In the compliance market, businesses can purchase Australian Carbon Credits Units (ACCUs) up until February 2015. One tonne of carbon dioxide equivalents (CO_2 e) abatement represents 1 ACCU. For the 2013/14 fiscal year, the price of a CO_2e in the compliance market is $24.15.

Although storage of soil carbon is not included in any of the schemes at present, the price of $24.15 for a CO_2e was used to value the carbon in the litter. Any additional carbon stored in the soil was multiplied by 3.66, to convert to CO_2e and then multiplied by the carbon price of $24.15.

From July 2015, the Clean Energy Regulator was to set the floor price for carbon of $15/t and then allow the price to be set by the market, as part of the transition to an Emissions Trading Scheme. However, under the current government, the Carbon Tax has been repealed and a Direct Action Plan is being developed which will build on the CFI and include an emission reduction fund.

The methodology used here to value the carbon in litter could be used regardless of what carbon pricing mechanism is in operation in the future.

Soil microbial activity

Soil samples (0-10 cm) were collected from each plot in winter and spring 2012 for analysis of soil microbial activity. Around 200-250 g of soil was collected from each plot and kept cool in a car refrigerator. Samples were put into foam boxes with ice bricks and were sent by courier to the Department of Trade and Investment NSW (formerly DPI NSW) laboratory at Wollongbar. Two sampling times were compared as soil biological activity is affected by soil temperature and moisture.

Tests performed were the FDA (fluorescein diacetate) assay and microbial biomass organic carbon. FDA values are expressed as µg sodium fluorescein/gram dry soil/minute. Specific enzyme assays include phosphatase and urease, enzymes involved in phosphorous and nitrogen transformations. The FDA assay is relatively simple and is widely used to estimate general microbial activity (Reid and Cox, 2005).

Microbial biomass organic carbon (MBOC**)** uses a relatively simple microwave treatment to obtain a measure of the carbon bound in microbes. This test is an indirect measure of microbial activity. MBOC values are expressed as mg Biomass Carbon/gram dry-weight-equivalent soil**.**

Statistical Analysis

Data was analysed using a 2-way analysis of variance (ANOVA) to allow for the blocks, using the Analyse-it program. Least significant differences (LSD) were calculated where significant differences were identified between treatments in the ANOVA. LSD's are shown in the tabulated data where appropriate. Standard errors (SE) of the means were calculated and are shown in the figures where appropriate.

Extension & Communication

Numerous extension activities were conducted during the project to promote the research findings and train producers in how to objectively compare cost/benefits of alternatives like litter against conventional inorganic fertilisers and address other concerns like handling/application. A key milestone for the project was the delivery of a training workshop at the end of the project. The aim of the workshop was to improve the confidence, knowledge and skills of sheep/cattle producers and their advisors to achieve greater adoption of chicken litter as an alternative fertiliser.

Results

Litter composition and cost of nutrients

The litter used was single batch and sourced from the same chicken farm, near Nagambie, Victoria, each year. Fresh litter, straight form the shed, was used. From 2009 -2011 the litter contained wood-shavings as the bedding material. In 2012, the bedding material was rice hulls. The composition of each batch of litter is shown in Table 4. Dry matter and nutrient content varied markedly from batch to batch, with the rice hulls batch having the lowest carbon content and lowest C:N ratio.

Table 4. Chicken litter composition

Analysis	Units	Aug 2009	Mar 2010	Mar 2011	Apr 2012 (rice hulls)
pH	(1:5 water)	6.0	7.7	6.6	6.0
pH	(CaC12)	6.0	7.5	6.2	5.9
Salinity (EC)	(1:5 water)	10.50	5.93	5.63	12.75
Chloride	dS/m	4787	3145	2380	5118
Organic Matter	mg/kg	85.7	68.0	73.1	58.3
Total Carbon	%	49.8	39.5	43.0	33.9
Carbon / Nitrogen ratio		12 to 1	16 to 1	10 to 1	7 to 1
Dry Matter	%	71	90	85	81
TOTAL NUTRIENTS *					
Total Nitrogen	%	4.12	2.51	4.28	4.57
Phosphorus	%	0.74	0.58	1.03	1.20
Potassium	%	2.29	1.21	1.71	2.10
Sulphur	%	0.64	0.40	0.52	0.52
Calcium	%	1.22	1.25	2.22	2.25
Magnesium	%	0.60	0.44	0.51	0.64
Sodium	%	0.51	0.28	0.31	0.35
Copper	mg/kg	131.5	109.5	150.7	117.5
Zinc	mg/kg	411.6	264.4	398.8	469.3
Iron	mg/kg	2098.9	6770.8	1130.2	2795.0
Manganese	mg/kg	449.4	386.6	568.4	674.0
Boron	mg/kg	41.0	21.4	28.0	36.0
Molybdenum	mg/kg	-	2.6	4.4	3.6

** Total nutrients reported on a dry weight basis*

Litter was costed at \$20/m^3 delivered and \$28/m^3 spread. This is the local price and applies to delivery to farms within 100 km of the chicken farm. In other districts, the price can be lower. The cost of the macro nutrients (N,P,K,S) in the litter relative to conventional, inorganic fertilisers are shown Table 5. The cost of the litter varied from year depending on dry matter content and nutrient content. On an individual nutrient basis, the litter was always more expensive than the conventional fertilisers. Where more than one nutrient is required, however, litter can become cost-effective. Litter would have to be approximately $10/m^3 delivered (half the price) to supply a key nutrient like P at a similar cost to superphosphate (at $400/t). In some districts, litter is closer to this price.

Table 5. Cost of individual nutrients in litter relative to inorganic fertiliser (December 2011 prices)

Product	$/t spread (DM% basis)	$/kg nutrient N	P	K	S
Litter					
2009	$ 99	2.40	14.08	4.29	16.43
2010	$ 81	3.22	13.43	6.71	20.14
2011	$ 88	2.05	8.82	5.19	17.65
2012	$ 86	1.89	7.20	4.12	16.62
Single superphosphate (8.8%,11%S)	$ 400		4.55		3.64
Urea (46% N)	$ 600	1.30			
Potash (50% K)	$ 740			1.48	

Changes in soil fertility

Macro nutrients

Glenaroua

At the Glenaroua site, there were significant differences ($P \leq 0.05$) in available phosphorus (Olsen P) and total phosphorus between treatments by June 2013 (Table 6). Soil samples could not be taken in October/November 2012 due to very dry conditions and had to be delayed until June 2013. The Controls had Olsen P levels at the lower end of the target range of 12- 15 mg/kg. Maintenance rates of inorganic fertiliser increased P levels by 4-6 units compared with the Controls, whereas the Capital rates increased P levels by 7-9 units. The Maintenance and Capital rates of litter increased soil P levels by a similar magnitude as their equivalent rate of inorganic P fertiliser. The changes in total phosphorus levels across treatments followed a similar pattern to the available phosphorus.

There were no significant treatment differences in exchangeable potassium (Colwell K). However, there was a trend for the Capital and High rates of litter to have slightly higher soil K levels than other treatments. All treatments had Colwell K levels above the target of 160 mg/kg for this soil type (Table 6).

There were no significant differences in available sulphur (KCl40 S). There was a trend for the Capital rate of PS fertiliser to have slightly higher soil S levels than other treatments. All treatments had soil KCl40 S levels above the target of 8 mg/kg (Table 6).

Table 6. Macro nutrient status in the topsoil (0-10cm) at Glenaroua in June 2013

Treatment	Olsen P (mg/kg)	Total P (mg/kg)	Colwell K (mg/kg)	KCl40 S (mg/kg)
Control A (nil)	12.7	322.5	233.5	10.5
Control B (nil)	13.4	312.5	237.5	10.3
Maintenance PS	18.1	327.0	238.8	10.8
Maintenance PS + Humic acid	19.1	375.8	262.8	11.9
Capital PS	22.7	395.3	221.3	12.8
Maintenance NPKS	17.2	379.0	249.0	10.5
Capital NPKS	20.0	336.0	263.8	10.6
Maintenance Litter	16.7	348.5	226.8	10.3
Capital Litter	18.7	377.3	308.8	9.5
High C rate Litter	25.5	469.3	278.8	10.7
P value	*<0.0001*	*<0.0001*	*n.s*	*n.s*
L.S.D (P≤0.05)	*3.1*	*43.5*	*81.0*	*2.5*

n.s = not significant

Pastoria

At the Pastoria site, there were significant differences (P = 0.1) in available phosphorus (Olsen P), between treatments by October 2012 (Table 7). The High C treatment significantly increased Olsen P levels by 7 units relative to the Control. Capital rates of fertiliser and litter increased Olsen P levels by 1-4 units, but this was not significant at the 10% level. The Control still had an Olsen P levels at the upper end of the target range of 12- 15 mg/kg by the end of the experiment. The changes in total phosphorus levels across treatments followed a similar pattern to the available phosphorus, but there was no significant treatment effect.

There were no significant treatment differences in exchangeable potassium (Colwell K). However, there was a trend for the Capital NPKS and High C litter treatments to have slightly higher soil K levels than other treatments. All treatments, except Capital NPKS, had Colwell K levels slightly below the target of 140 mg/kg for this soil type (Table 7). Despite the addition of 300 kg K/ha over the four years, the High C litter treatment soil K levels were not high.

There were no significant treatment differences in available sulphur (KCl40 S). All treatments, except Capital PS, Maintenance PKS and Capital NPKS, had soil KCl40 S levels below the target of 8 mg/kg (Table 7).

Table 7. Macro nutrient status in the topsoil (0-10cm) at Pastoria in October 2012

Treatment	Olsen P (mg/kg)	Total P (mg/kg)	Colwell K (mg/kg)	KCl40 S (mg/kg)
Control A (nil)	16.3	235.0	125.0	4.7
Maintenance PS	15.9	245.8	112.5	5.2
Maintenance PS + Humic acid	15.4	239.3	112.0	5.0
Capital PS	18.6	239.3	119.0	8.1
Maintenance PKS	16.9	237.8	122.3	8.7
Maintenance NPKS	16.7	251.8	126.5	5.8
Capital NPKS	20.3	256.3	153.3	7.7
Maintenance litter	15.7	247.3	125.0	4.8
Capital litter	17.0	252.8	114.5	4.4
High C litter	23.6	281.0	133.5	6.4
P value	*0.10*	*n.s*	*n.s*	*n.s*
L.S.D (5%)	*5.5*	*44.1*	*35.5*	*3.5*

n.s = not significant

Heavy metals/trace elements

Glenaroua

At the Glenaroua site, there were significant treatment differences ($P \leq 0.05$) in copper, zinc and boron levels in soil by June 2013 (Table 8). The three chicken litter treatments had significantly higher soil copper levels than most other treatments. Marginal levels of soil copper, for pasture requirements, are in the range of 0.35-0.60 mg/kg. Soil copper levels for the chicken litter treatments ranged from 0.56-0.86 mg/kg, indicating adequate levels for plants.

The three chicken litter treatments had significantly higher levels of zinc than all other treatments, and a rate response was evident (Table 8). Marginal levels of soil zinc, for pasture plants, are in the range of 0.40-0.80 mg/kg and all treatments were above this range indicating adequate levels.

There were no significant differences in soil manganese levels between treatments; however there was a trend for the Capital and High C rates of litter to have higher levels (Table 8). Marginal levels of soil manganese, for pasture plants, are in the range of 1.0 - 3.0 mg/kg and all treatments were above this range.

There were no significant differences in soil iron levels between treatments (Table 8). The soil test for iron is not recommended for predicting iron deficiency in plants so there are no guidelines for a target range.

There were significant differences in soil boron levels between treatments. The two Controls and the two Maintenance P treatments had lower soil boron levels than the other treatments. The High C litter treatment had the highest soil boron level (Table 8). Marginal levels of soil boron, for pasture plants, are in the range of 0.4-0.8 mg/kg, so all treatments were potentially responsive to boron but this is usually confirmed with a leaf analysis.

Table 8. Trace element/heavy metal status in the topsoil (0-10cm) at Glenaroua in June 2013

Treatment	**Copper (DTPA) (mg/kg)**	**Zinc (DTPA) (mg/kg)**	**Manganese (DTPA) (mg/kg)**	**Iron (DTPA) (mg/kg)**	**Boron (HWS) (mg/kg)**
Control A (nil)	0.30	0.86	8.9	529.1	0.3
Control B (nil)	0.42	0.90	10.9	538.2	0.3
Maintenance PS	0.33	0.82	10.2	518.0	0.3
Maintenance PS + Humic acid	0.47	1.01	10.9	532.7	0.3
Capital PS	0.28	0.86	10.8	566.3	0.4
Maintenance NPKS	0.37	0.79	9.6	541.1	0.4
Capital NPKS	0.30	0.87	11.8	470.6	0.4
Maintenance litter	0.61	1.69	11.1	499.6	0.4
Capital litter	0.56	2.62	14.5	439.5	0.4
High C litter	0.86	5.48	15.3	517.5	0.5
P value	*<0.0001*	*<0.0001*	*n.s*	*n.s*	*0.01*
L.S.D (5%)	*0.20*	*0.60*	*4.4*	*88.5*	*0.1*
Marginal range for pastures	*0.35-0.60*	*0.4-0.8*	*1.0-3.0*	*	*0.4-0.8*

n.s = not significant * no guidelines exist

Pastoria

At the Pastoria site, there were significant treatment differences ($P \leq 0.05$) in copper and zinc levels by October 2012 (Table 9). The Maintenance and High C rates of litter had significantly higher copper levels than the Controls and Maintenance inorganic fertiliser treatments. The Capital rate of litter also had higher copper levels but this was not significant at the 5% level. All treatments were potentially responsive to copper but this is usually confirmed with a leaf tissue analysis.

The three rates of chicken litter application had significantly higher levels of zinc than all other treatments, with the High C rate having the highest level (Table 9). All treatments had adequate zinc for plant growth.

There were no significant treatment differences in soil manganese, iron or boron levels (Table 9). All treatments had adequate manganese for plant growth. All treatments were potentially responsive to boron but this is usually confirmed with a leaf tissue analysis.

Table 9. Trace element/heavy metal status in the topsoil (0-10cm) at Pastoria in October 2012

Treatment	Copper (DTPA) (mg/kg)	Zinc (DTPA) (mg/kg)	Manganese (DTPA) (mg/kg)	Iron (DTPA) (mg/kg)	Boron (HWS) (mg/kg)
Control A (nil)	0.34	0.87	13.9	231.5	0.3
Maintenance PS	0.32	0.82	12.8	209.1	0.3
Maintenance PS + Humic acid	0.31	0.78	13.0	218.4	0.3
Capital PS	0.34	0.85	11.5	205.7	0.4
Maintenance PKS	0.39	1.01	17.2	203.4	0.3
Maintenance NPKS	0.38	0.97	15.1	201.1	0.3
Capital NPKS	0.40	1.06	17.3	192.8	0.3
Maintenance Litter	0.50	1.41	14.6	206.1	0.4
Capital Litter	0.45	1.43	13.2	241.9	0.4
High C rate Litter	0.54	2.51	13.9	243.7	0.4
P value	*0.05*	*0.0001*	*n.s*	*n.s*	*n.s*
L.S.D (5%)	*0.15*	*0.42*	*5.4*	*115.1*	*0.1*
Marginal range for pastures	*0.35-0.60*	*0.4-0.8*	*1.0-3.0*	*	*0.4-0.8*

n.s = not significant * no guidelines exist

Total cations / cation exchange capacity

There were significant ($P \leq 0.05$) treatment effects on soil cation exchange capacity (CEC) at Glenaroua but not at Pastoria (Table 10). At Glenaroua, the High C rate litter treatment had a significantly higher CEC than all other treatments. At Pastoria, there was a clear trend for total cations/CEC to increase with increasing rates of litter. The increase in cations was mainly due to increasing calcium levels, which were supplied in the litter. Superphosphate contains 19 % calcium and the litter contained 1.2-2.3 % calcium. The Maintenance and Capital rates of fertiliser supplied 18 and 36 kg Ca/ha each year, respectively. The Maintenance and Capital rates of litter supplied 20 and 40 kg Ca/ha each year, respectively. The High C rate of litter supplied 60-110 kg Ca/ha each year.

The clay loam soil at Glenaroua had a naturally higher CEC than the lighter soil at Pastoria, due to the higher clay content. Cation exchange capacity is a soil property which is not easily changed in the short-term, but the higher rates of litter can clearly have some impact.

Table 10. Cation exchange capacity (meq/100g soil) in the topsoil at Glenaroua and Pastoria

Treatment	**Glenaroua (June 2013)**	**Pastoria (Nov 2012)**
Control A (nil)	5.72	3.65
Control B (nil)	6.33	-
Maintenance PS	6.16	3.55
Maintenance PS + Humic acid	6.23	3.74
Capital PS	6.50	3.74
Maintenance PKS	-	3.65
Maintenance NPKS	5.95	3.83
Capital NPKS	5.90	3.79
Maintenance Litter	6.73	3.74
Capital Litter	6.54	4.00
High C rate Litter	8.01	4.22
P value	*0.01*	*n.s*
L.S.D (5%)	*1.20*	*0.91*

Pasture responses

Leaf nutrient content

Glenaroua

There were significant ($P \leq 0.05$) treatment effects on macro nutrient (P, K) and trace element (Cu, Mo) concentrations in pasture tissue at Glenaroua (Table 11).

Pasture tissue had higher K levels where NPKS fertiliser mix or litter was applied, with levels in the herbage increasing as the amount of applied K increased. Potassium levels were in the acceptable range, for all treatments, with respect to plant and animal nutrition (Table 11).

Pastures that received Capital rates of fertiliser and litter or the High C rate of litter had significantly ($P \leq 0.05$) more phosphorus in the herbage than the Controls (data not shown). There were no significant differences in the level of N or S in the herbage between treatments (data not shown). However, there was a trend for the three litter treatments to have higher N contents in the herbage than all other treatments.

Chicken litter significantly ($P \leq 0.05$) increased the amount of copper in the pasture tissue compared with the fertiliser treatments (Table 11). There was no effect of the rate of litter applied on copper content of pasture. Copper levels were in the acceptable range, for all treatments, with respect to plant and animal nutrition.

Chicken litter significantly ($P \leq 0.05$) increased the amount of molybdenum in the pasture tissue compared with the fertiliser treatments (Table 11). The level of molybdenum in the pasture increased with increasing rates of litter. Molybdenum levels, in all treatments, were in the acceptable range for animal nutrition but were marginal for sub clover in all treatments except for the Capital and High C rate of litter.

There were no significant treatment differences in Zinc, Iron or Boron content in herbage. However, there was a trend for the level of zinc to increase as the rate of litter increased (Table 11). All treatments had acceptable levels of zinc and iron in the herbage. Boron was potentially deficient, for sub clover requirements, in all treatments.

Table 11. Macro and trace element concentrations in pasture tissue at Glenaroua in Oct 2012

Treatment	Potassium (%)	Copper (mg/kg)	Zinc (mg/kg)	Iron (mg/kg)	Boron (mg/kg)	Molybdenum (mg/kg)
Control A (nil)	1.94	6.1	24.0	236.8	8.9	0.24
Control B (nil)	1.98	5.7	26.8	529.6	9.4	0.24
Maintenance PS	1.97	5.5	25.9	274.5	9.3	0.27
Maintenance PS + Humic acid	2.04	5.6	31.7	448.1	11.2	0.27
Capital PS	1.94	5.5	26.9	347.3	10.6	0.27
Maintenance NPKS	2.22	5.1	28.6	231.0	8.0	0.28
Capital NPKS	2.58	5.1	28.9	183.2	8.9	0.30
Maintenance litter	2.35	7.1	33.7	234.4	12.0	0.34
Capital litter	2.43	6.7	36.1	213.8	10.5	0.50
High C litter	2.71	6.7	39.8	181.8	10.2	0.91
P value	*0.0002*	*0.005*	*n.s*	*n.s*	*n.s*	*0.0001*
L.S.D (5%)	*0.39*	*1.1*	*11.3*	*322.8*	*3.6*	*0.15*
Desired level for sub clover**	*1.50-3.00*	*5-30*	*15-50*	*50-400*	*20-100*	*>0.40*
Desired level for ryegrass**	*2.00-4.50*	*6-20*	*15-50*	*50-400*	*10-25*	*>0.25*
Minimum DM nutrient content for sheep**	*0.45*	*5.0*	*20.0*	*40.0*	*	*0.10*

n.s = not significant * no interpretation guidelines ** Hosking *et al.* (1986)

Pastoria

There were significant (P ≤0.05) treatment effects on macro nutrient (P, S) and trace element (Cu, Zn, Mo) concentrations in pasture tissue at Pastoria (Table 12).

All fertiliser and litter treatments had significantly (P ≤0.05) more phosphorus and sulphur in the herbage than the Control (data not shown). The High C rate of litter had a significantly higher P content in herbage than the two lower rates of litter.

There were no significant treatment differences in the level of N (data not shown) or K in the herbage. However, the High C rate of litter had a higher K content than the Control (Table 12).

Chicken litter significantly (P ≤0.05) increased the amount of copper and zinc in the pasture compared with all other treatments but only when applied at the High C rate (Table 12). Copper and zinc levels were in the acceptable range, for all treatments, with respect to plant and animal nutrition.

Chicken litter significantly (P ≤0.05) increased the amount of molybdenum in the pasture tissue compared with most of the other the fertiliser treatments (Table 12). There was a trend for the level of molybdenum in the pasture to increase with increasing rates of litter although this was not significant at the 5% level. Molybdenum levels, across all treatments, were in the acceptable range with respect to plant and animal nutrition.

There were no significant treatment differences in iron or boron content in herbage (Table 12). All treatments had acceptable levels of iron in the herbage. Boron was potentially deficient, for sub clover, across all treatments.

Table 12. Macro and trace element concentrations in pasture tissue at Pastoria in October 2012

Treatment	**Potassium (%)**	**Copper (mg/kg)**	**Zinc (mg/kg)**	**Iron (mg/kg)**	**Boron (mg/kg)**	**Molybdenum (mg/kg)**
Control A (nil)	2.65	7.1	28.2	184.9	7.1	1.04
Maintenance PS	2.87	8.5	32.4	190.6	8.6	1.06
Maintenance PS + Humic acid	2.67	8.0	31.1	172.8	8.1	0.95
Capital PS	2.83	7.2	30.3	188.1	8.4	1.01
Maintenance PKS	2.87	7.3	30.5	180.5	7.9	0.86
Maintenance NPKS	2.84	7.4	31.3	186.4	7.0	0.89
Capital NPKS	2.90	6.8	29.5	176.7	7.1	0.78
Maintenance litter	2.81	7.6	29.7	160.0	7.1	1.19
Capital litter	2.84	8.1	32.7	182.7	7.7	1.21
High C litter	3.12	9.0	40.5	208.0	7.6	1.34
P value	*n.s*	*0.02*	*0.001*	*n.s*	*n.s*	*0.0001*
L.S.D (5%)	*0.35*	*1.2*	*4.6*	*48.9*	*1.7*	*0.22*
Desired level for sub clover**	*1.50-3.00*	*5-30*	*15-50*	*50-400*	*20-100*	*>0.40*
Desired level for ryegrass**	*2.00-4.50*	*6-20*	*15-50*	*50-400*	*10-25*	*>0.25*
Minimum DM nutrient content for sheep**	*0.45*	*5.0*	*20.0*	*40.0*	*	*0.10*

n.s = not significant * no interpretation guidelines ** Hosking *et al.* (1986)

Pasture growth

Glenaroua

There was a significant (P≤0.05) treatment effect on pasture growth at the Glenaroua site at most harvests (Table 13, Figures 5 and 6). The treatments that produced the extra pasture mass relative to the Controls were the two rates of NPKS inorganic fertiliser and the three rates of litter application. A summary of the extra pasture grown relative to the average of the Controls, and when it occurred, is shown in Table 14. Note that not all the data shown in Table 14 is significant (P≤0.05), but has been included to show the broad trends.

The pasture growth responses were primarily due to nitrogen. There was no significant phosphorus/sulphur response and potassium responses were unlikely given the adequate soil K levels during the experiment. The response to the two rates of NPKS inorganic fertiliser and the three rates of litter occurred each winter (July 2010, 2011 and 2012) following autumn application (Tables 13 and 14, Figure 5). A response was still evident at the spring harvests (Oct 2010, 2011, 2012) for only the Capital rates of NPKS fertiliser and litter, and the High C rate of litter (Figure 6). Summer harvests also showed an ongoing response by the High C litter treatment in March 2010 and February 2011 and by the Capital rate of litter in February 2011. Nitrogen does not have a residual fertiliser effect in soils like phosphorus, and is usually used up within four to six weeks after application, assuming there is adequate moisture for plant growth. For this reason, it is most likely that the carryover yield responses observed were due to changes in pasture composition.

Table 13. Pasture yields (kg DM/ha) each harvest at the Glenaroua site

Treatment	Oct 09	Mar 10	Jul 10	Oct 10	Feb 11	Jul 11	Oct 11	Mar 12	Jul 12	Oct 12
Control A	1089	1588	747	1249	3485	3078	1453	637	125	1583
Control B	1216	1572	855	1197	3730	3105	1317	582	144	1258
Maint PS	1084	1464	786	1247	3324	3170	1518	551	93	1280
Maint PS + Humic	1292	1570	757	1022	3200	2978	1418	520	143	1588
Capital PS	1174	1460	994	1235	3222	3059	1540	614	127	1555
Maint NPKS	1377	1597	1060	1285	3622	3521	1417	576	149	1573
Capital NPKS	1580	1344	1202	2168	3637	3959	1837	640	207	1946
Maint litter	1562	1548	1024	1442	3099	3185	1460	537	143	1641
Capital litter	1557	1587	994	2076	4050	3676	1988	727	175	1831
High C litter	1610	1994	1346	2470	4316	4152	2344	703	257	2585
P value	*0.002*	*0.03*	*0.002*	*0.0001*	*0.009*	*0.001*	*0.008*	*n.s*	*0.02*	*0.0001*
L.S.D (5%)	*295*	*299*	*271*	*503*	*620*	*366*	*514*	*230*	*80*	*380*

Table 14. Extra pasture grown (kg DM/ha) each harvest relative to Control treatments at Glenaroua

Treatment	Oct 09	Mar 10	Jul 10	Oct 10	Feb 11	Jul 11	Oct 11	Mar 12	Jul 12	Oct 12
Maint PS	-	-	-	-	-	-	130	-	-	-
Maint PS + Humic	-	-	-	-	-	-	-	-	-	-
Capital PS	-	-	200	-	-	-	150	-	-	-
Maint NPKS	230	-	260	-	-	430	-	-	-	150
Capital NPKS	430	-	400	950	-	900	500	-	80	530
Maint litter	410	-	220	-	-	-	-	-	-	220
Capital litter	410	-	200	850	450	600	600	-	50	400
High C litter	460	400	550	1250	700	1100	1000	-	120	1200

Over the three years, the Capital rates of NPKS fertiliser and litter and the High rate of litter produced significantly more pasture than other treatments (Table 15). The Maintenance rates of NPKS fertiliser and litter produced more pasture than the Controls but this was not significant at the 5% level. Humic acid had no effect.

Table 15. Extra pasture grown, from 2009-2012, relative to Control treatments at Glenaroua

Treatment	Total extra pasture (kg DM/ha)
Maint PS	0
Maint PS + Humic	0
Capital PS	0
Maint NPKS	1172
Capital NPKS	3515
Maint litter	636
Capital litter	3656
High C litter	6772
P value	*<0.0001*
L.S.D (5%)	*2001*

The amount of pasture grown increased as the rate of litter increased (Figure 4). In general, the level of response was similar for both the litter and the inorganic NPKS fertiliser. So it can be assumed the N response was similar regardless of whether the N was supplied in the form of litter or urea. The only time this didn't apply was in July 2011, where the Maintenance rate of litter did not perform as well as the Maintenance rate of NPKS fertiliser (Figure 4, Table 14). Litter was applied in late March that year, so whether this effect was due to more N losses occurring in the litter during warm/drier conditions, from volatilisation, is uncertain.

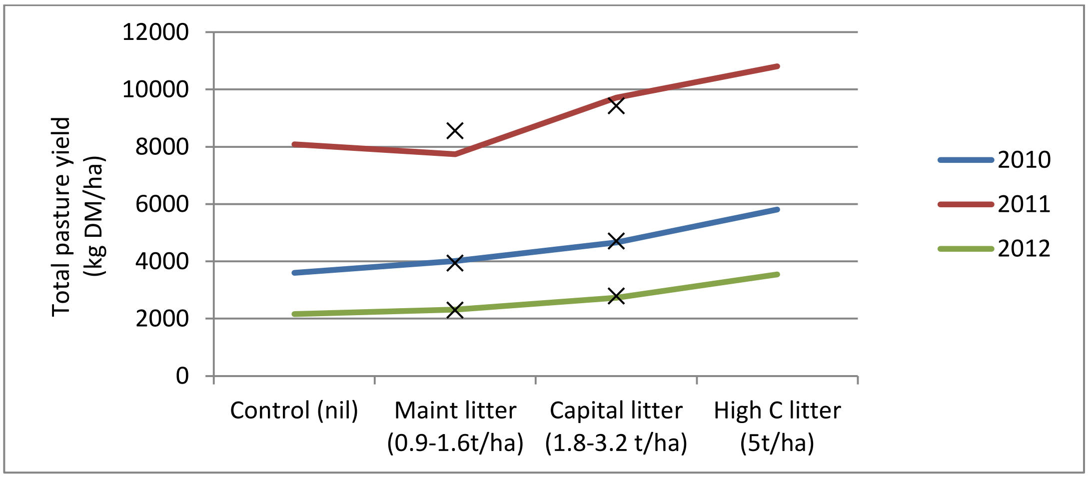


Figure 4. Effect of litter application rate on pasture yield
X = pasture yield from the inorganic fertiliser (NPKS) applied at the equivalent rate to the litter

Pastoria

There was a significant ($P \leq 0.05$) treatment effect on pasture growth at the Pastoria site only in winter and spring 2011 and 2012 (Table 16). The treatment that produced the extra pasture mass relative to the Controls and most other treatments was the High C rate of litter. The response was evident in winter and spring each year, although in 2010 was not significant at the 5% level. The Maintenance and Capital rate of NPKS fertiliser appeared to perform better than the same rates of litter in winter each year, relative to the Controls, but this was not significant at the 5% level. Clearly there were factors at this site preventing the lower rates of litter working as well as at the Glenaroua site, possibly the cooler temperatures and level of soil biological activity to breakdown the nutrients in litter to plant available forms.

The pasture growth responses were thought to be mainly due to nitrogen, similar to the Glenaroua site (Figure 7). There was no significant phosphorus/sulphur response even though the soil was S deficient. Potassium responses were likely at this site due to the deficient soil K levels, but there was no difference in yield observed between the Maintenance PKS and Maintenance NPKS treatments.

The level of variation across the site for some treatments (e.g. Control A) caused large standard errors of the mean yields and overshadowed some observed treatment effects at Pastoria. In addition, the pasture composition was not as good as at the Glenaroua site, with less desirable and less responsive perennial grasses present, although sub clover was present at adequate levels at in 2009 when the site was selected. After the extremely wet summer of 2010/11, bent grass became very dominant across the site. Bent grass is a prostrate growing perennial grass but is considered a weed due to its low winter growth rates and tendency to smother species like clover. This could explain why there was no response to K and S but does not explain why the N in the Maintenance and Capital rates of NPKS fertiliser (urea) or N in the High C rate of litter improved growth compared to the lower rates of litter.

Table 16. Pasture yields (kg DM/ha) each harvest at the Pastoria site

Treatment	Apr 10	Jul 10	Nov 10	Feb 11	Jun 11	Sep 11	Nov 11	Mar 12	Jul 12	Oct 12
Control A	2802	577	5996	5360	2721	375	1749	875	974	807
Control B *(Maint PKS Apr 11)*	2882	529	5617	5352	2353	348	1448	850	835	756
Maint PS	2838	608	5471	5464	2430	341	1381	1118	780	832
Maint PS + Humic	2693	497	5321	4861	2084	314	1227	711	678	704
Capital PS	2829	421	5586	4902	2198	402	1415	865	697	729
Maint NPKS	2950	565	**6427**	5371	**2870**	425	1783	1102	**1072**	879
Capital NPKS	2987	**878**	**6528**	5576	**2870**	411	1500	944	**1131**	824
Maint litter	2715	404	6135	5200	2418	374	1528	907	723	837
Capital litter	3013	468	5792	5323	2479	400	1576	951	970	868
High C litter	2997	**711**	**7267**	5046	**3174**	**712**	**2431**	1125	**1264**	**1431**
P value	*n.s*	*n.s*	*n.s*	*n.s*	*0.05*	*0.02*	*0.08*	*n.s*	*0.09*	*0.0001*
L.S.D (5%)	*255*	*385*	*1565*	*1004*	*651*	*195*	*677*	*440*	*419*	*217*

Over the three years, the High C rate of litter produced significantly more pasture than other treatments (Table 17, Figure 7). Maintenance and Capital rates of NPKS fertiliser produced more pasture than the Controls but this was not significant at the 5% level. The Maintenance and Capital rates of litter did not produce any more pasture than the Controls. Humic acid had no effect.

Table 17. Extra pasture grown, from 2009-2012, relative to Control treatments at Pastoria

Treatment	Total extra pasture Kg DM/ha
Maint PS	0
Maint PS + Humic	0
Capital PS	0
Maint NPKS	1841
Capital NPKS	2046
Maint litter	0
Capital litter	237
High C litter	4555
P value	*0.10*
L.S.D (5%)	*4500*

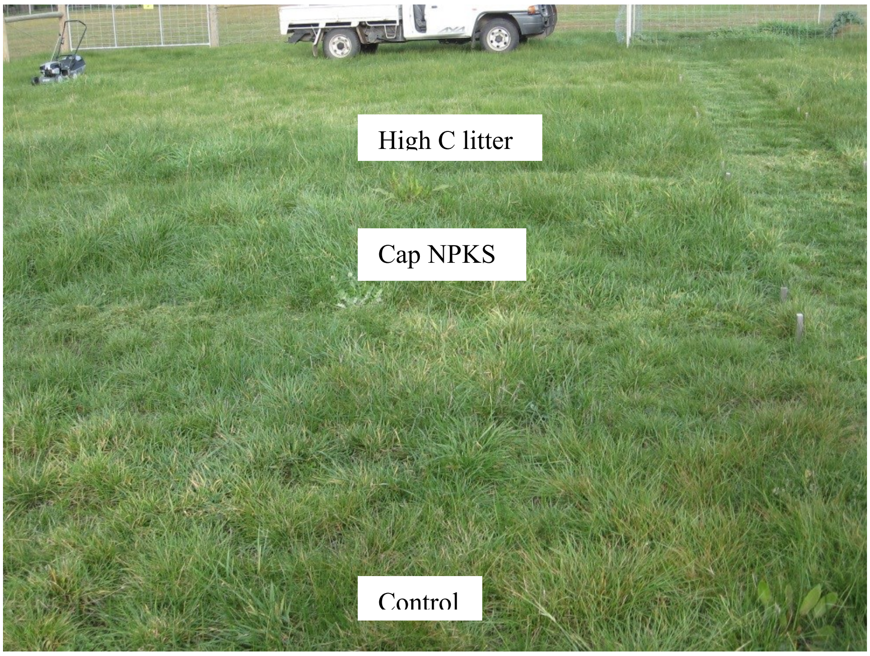


Figure 5. Pasture responses to Capital NPKS fertiliser and High C rate of litter in July 2010 at Glenaroua

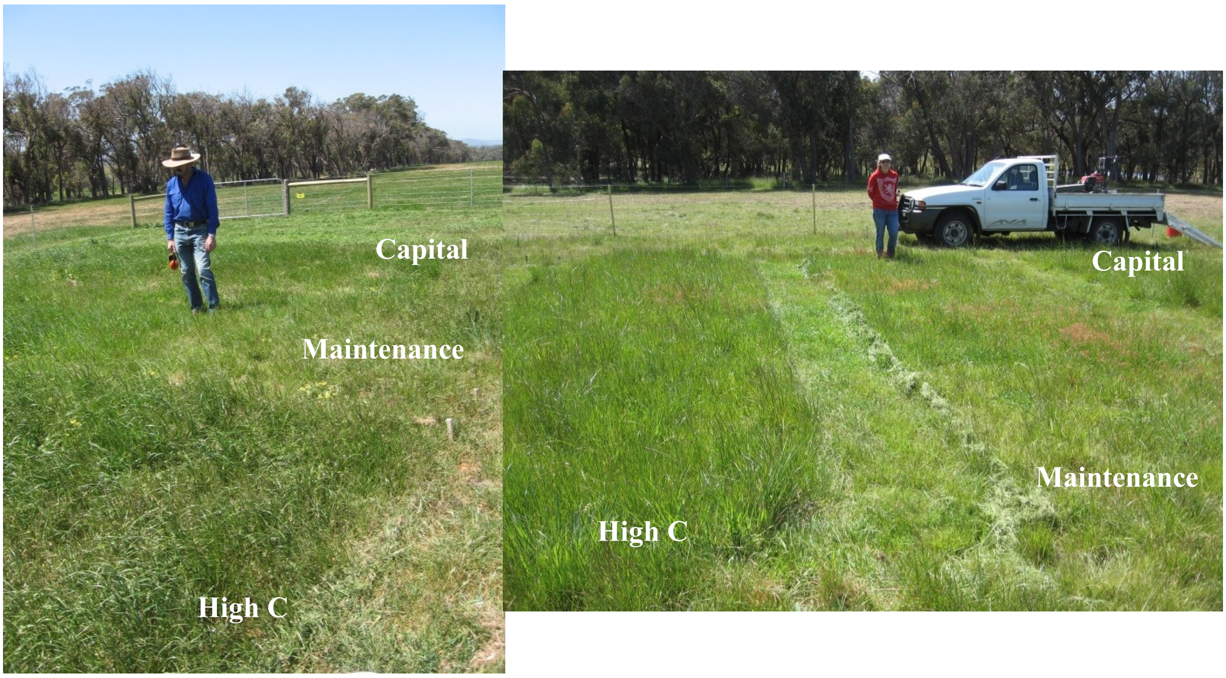


Figure 6. Pasture responses to 3 rates of litter October 2009 (left) and October 2011

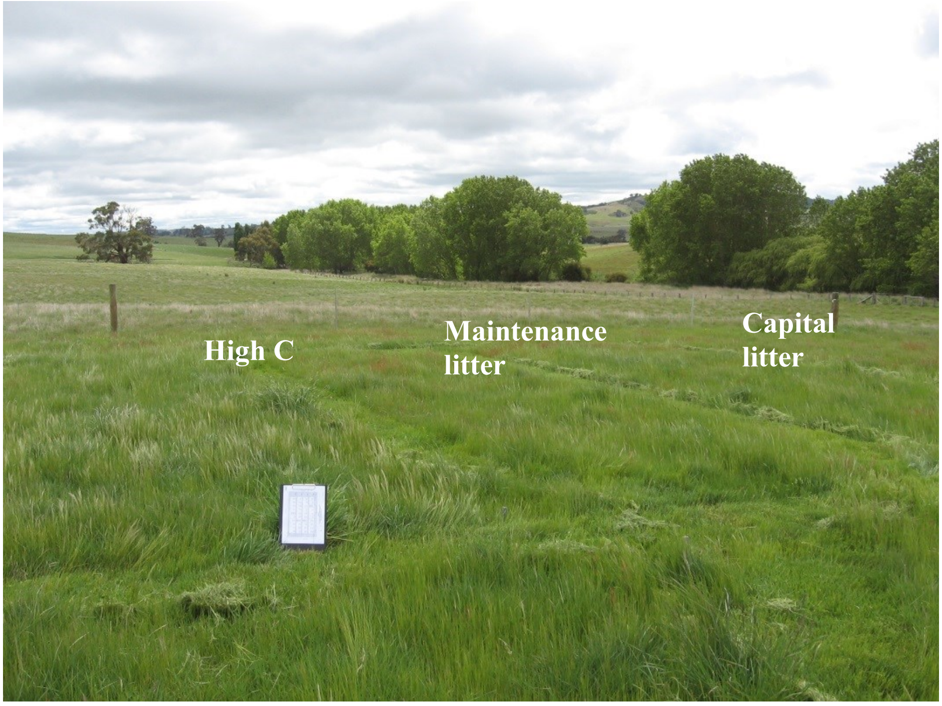


Figure 7. Pasture responses to three rates of litter in winter 2011 at Pastoria

Pasture composition

Glenaroua

There were significant ($P \leq 0.05$) treatments effects on pasture botanical composition at Glenaroua. The mass of sown perennial grasses (mainly phalaris with some perennial ryegrass) increased in response to nitrogen applications in the NPKS fertiliser and litter (Figure 8, Figure 10). The Capital NPKS treatment had significantly higher mass of sown perennial grass than the Maintenance NPKS, Maintenance litter and Capital litter treatments. The High C litter treatment has the highest mass of sown perennial grass.

There were significant ($P = 0.08$) increases in the mass of sub clover in the Capital PS fertiliser and all three litter treatments, relative to the Controls (Figure 8). Sub clover has a higher requirement for phosphorus than grasses, which can explain its better response to P inputs, although the response to the lower, maintenance rate of P fertiliser was not significant. The litter appeared to have a positive impact on both the improved perennial grass and clover content, whereas the NPKS fertilisers seemed to encourage the improved grasses.

There were significantly ($P \leq 0.05$) higher amounts of native perennial grass (Wallaby grass, Spear grass) in the Controls and Maintenance PS fertiliser treatments (Figure 8). Native grasses are less responsive to fertiliser than the improved species. Hence in the other treatments, the level of native grass was lower as it had been out-competed by the sown grasses and sub clover.

In spring 2012, there were no significant treatment differences in the small amount (50-200 kg DM/ha) of other species present, mainly annual grasses, capeweed, erodium and onion grass.

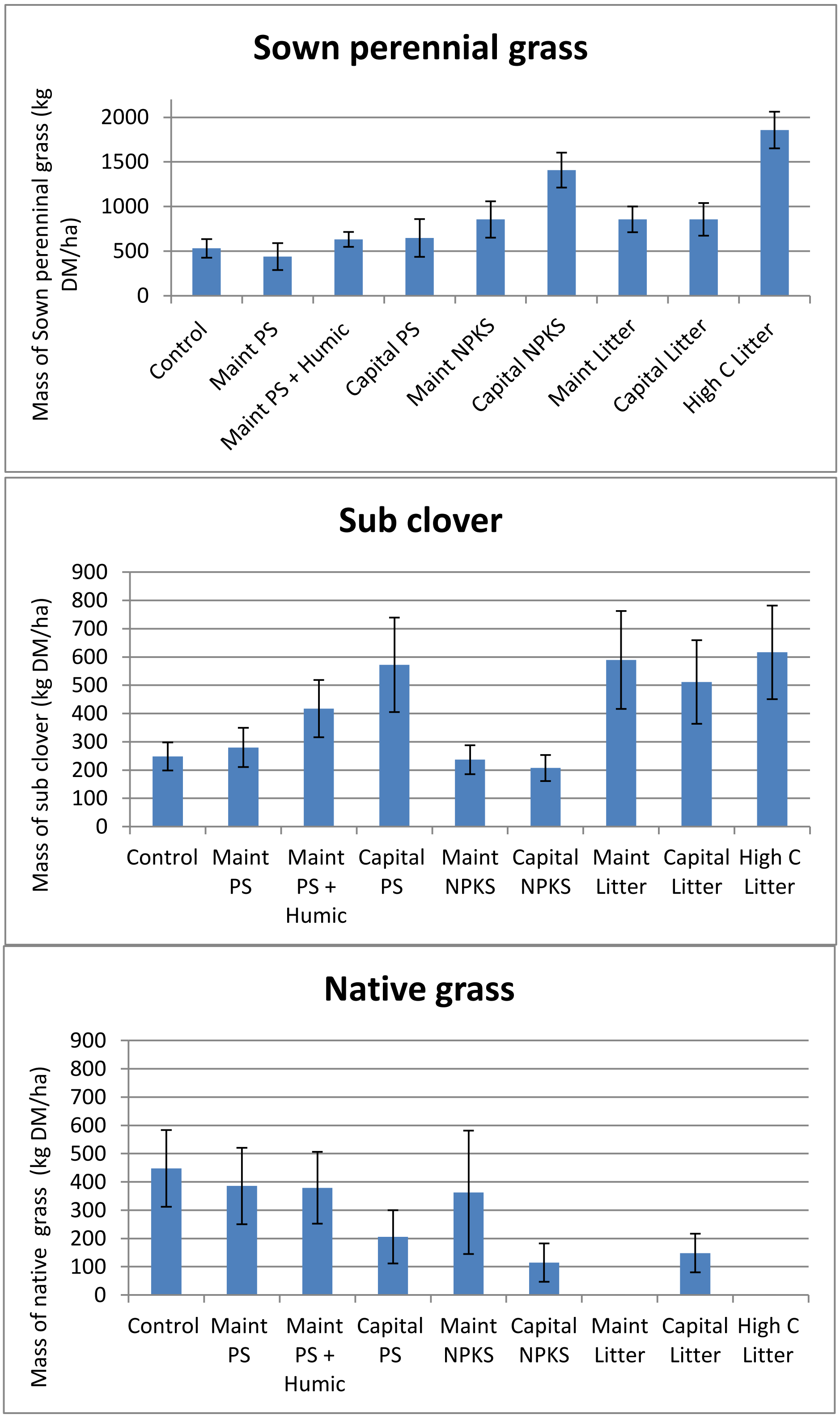


Figure 8. Mass of pasture species (kg DM/ha) present in October 2012 at Glenaroua
Error bars indicate standard error of the means

Pastoria

There were significant treatment effects on pasture botanical composition at Pastoria. The mass of sown perennial grass (mainly cocksfoot with some perennial ryegrass) significantly ($P = 0.08$) increased in response to all fertiliser and litter treatments relative to the Control (Figure 9). The High C litter rate produced the largest mass of sown perennial grass. Cocksfoot became more obvious in this treatment over time which was a result of an increase in size of initial plants and some new plants establishing (Figure 11).

At the start of the experiment, bent grass was present in small patches but was not the dominant species. After the very wet summer of 2010/11, bent grass became more dominant and by spring 2012 made up 70% of the species composition on the Control and 40-50% of the composition for other treatments. There were no significant differences in the actual mass (kg DM/ha) of bent grass between treatments, with around 400-500 kg DM/ha measured in spring 2012 (data not shown).

There were significantly ($P \leq 0.05$) higher amounts of annual grasses (Silver grass/*Vulpia spp.,* brome grass) in the Capital and High C rates of litter compared with the Controls (Figure 9).

There was no significant difference in the mass of sub clover between treatments, however there was a trend for less clover in the Control (Figure 9). The low level of sub clover at the site was largely due to the increase in bent grass after the wet summer of 2010/11. Bent grass is a summer active, prostrate grass, which meant there was a good mat of ground cover by the time of the autumn break year which would have hampered sub clover establishment.

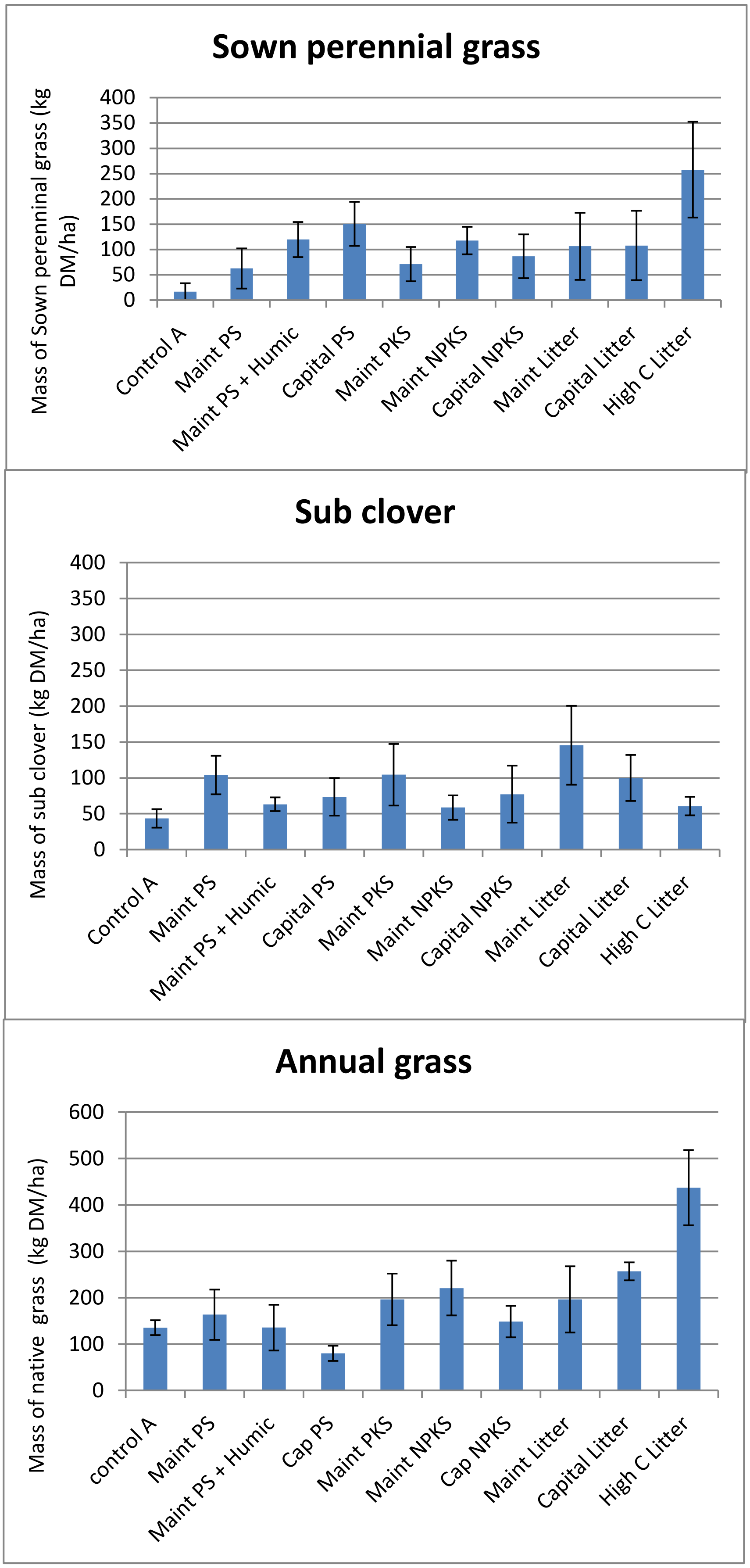


Figure 9. Mass of pasture species (kg DM/ha) present in October 2012 at Pastoria
Error bars indicate standard error of the means

Figure 10. Pasture composition at Glenaroua in October 2012
The Control had a higher content of native grasses (left) and High C rate of litter had more sub clover and sown grasses

Figure 11. Pasture composition at Pastoria in November 2011
The Control had higher content of bent grass (left) and High C rate of litter had more cocksfoot and annual grasses

Pasture quality

Glenaroua

There were significant treatment (P ≤0.05) effects on the feed quality of pastures at Glenaroua (Table 18). The Capital NPKS, Capital litter and High C litter treatments produced pasture with a higher energy content, of up to 2 MJ ME/kg DM/ha, relative to the Controls in July and October 2012. These three treatments also had higher protein levels, of 5-6%, in the pasture, compared with the Controls, in July 2012. All three litter treatments had 3-4% higher protein levels in the pasture, compared with the Controls in October 2012.

Table 18. Herbage quality at Glenaroua in 2012

Treatment	**Energy (MJ ME/kg DM)**			**Protein (%)**		
	Mar	***Jul***	***Oct***	***Mar***	***Jul***	***Oct***
Control A (nil)	8.6	8.5	9.6	12.1	14.5	12.8
Control B (nil)	8.6	8.1	9.6	12.3	14.3	13.3
Maintenance PS	8.3	7.6	9.6	11.7	13.0	14.9
Maintenance PS + Humic acid	8.8	7.9	9.4	13.2	13.7	14.9
Capital PS	8.5	8.2	9.5	12.4	14.0	13.8
Maintenance NPKS	8.7	8.7	9.8	12.6	16.5	13.1
Capital NPKS	9.0	10.3	10.5	13.6	22.0	13.2
Maintenance Litter	8.3	8.3	10.0	11.9	15.6	15.9
Capital Litter	8.7	9.3	10.4	12.8	19.1	16.5
High C rate Litter	9.1	10.6	10.5	14.4	22.6	16.8
P value	*n.s*	*0.0001*	*0.008*	*n.s*	*0.001*	*0.02*
L.S.D (5%)	*0.7*	*1.1*	*0.7*	*1.8*	*3.3*	*2.5*

n.s = not significant

Pastoria

There were significant treatment (P ≤0.05) effects on the feed quality of pastures at Pastoria (Table 19). The Maintenance and Capital NPKS treatments produced pasture with a higher energy content, of around 2 MJ ME/kg DM/ha, relative to the Controls in July. These two treatments also had higher protein levels, of 3-5%, in the pasture, compared with the Controls, in July 2012. All three litter treatments had higher protein levels in the pasture, compared with the Controls in July 2012, but this was only significant for the High C litter treatment.

Table 19. Herbage quality at Pastoria in 2012

Treatment	Energy (MJ ME/kg DM)			Protein (%)		
	Mar	*Jul*	*Oct*	*Mar*	*Jul*	*Oct*
Control A (nil)	9.5	8.2	10.9	15.7	18.3	18.9
Control B (nil)	9.4	8.5	10.7	14.6	18.1	19.6
Maintenance PS	9.7	8.1	11.1	15.4	17.0	19.8
Maintenance PS + Humic acid	9.5	8.9	11.2	14.5	19.6	21.2
Capital PS	9.5	8.4	10.8	15.7	17.8	19.5
Maintenance NPKS	9.2	10.1	10.9	15.0	21.5	18.9
Capital NPKS	9.4	10.4	11.2	15.0	23.3	20.1
Maintenance litter	9.5	8.5	11.1	15.0	19.5	20.5
Capital litter	9.5	8.8	11.0	14.9	19.4	20.1
High C litter	9.8	8.8	11.0	17.3	21.2	19.7
P value	*n.s*	*0.01*	*n.s*	*n.s*	*0.0001*	*n.s*
L.S.D (5%)	*0.7*	*1.2*	*0.4*	*2.8*	*2.1*	*1.7*

n.s = not significant

Value of extra pasture grown and improved feed quality

At the Glenaroua site, the NPKS fertiliser and litter treatments produced extra kg DM/ha and improved the feed quality and composition of the pasture grown. The nitrogen produced extra feed in winter, a critical time for livestock when pasture growth rates are low. The extra energy produced in winter can be valued against the cost of supplying supplementary feed at that time. A summary of the cost of the extra energy produced in winter, in cents per kilojoules of metabolisable energy, is show in Table 20. The cost of just applying urea alone has also been included in the comparison.

In 2011, the extra energy produced from applying NPKS fertiliser or litter to pasture was cheaper than feeding supplements. In 2010, the cost of extra energy from applying NPKS fertiliser was similar to feeding supplements, however using urea alone instead of NPKS mix would have been cheaper. Litter was slightly more expensive. In 2012, with a very late autumn break, the pasture had not grown much by the time of the July harvest, hence the cost of the extra energy was relatively high.

The NPKS fertiliser and litter treatment also caused protein levels to increase in the pasture in winter, but protein is not usually limiting livestock in winter or early spring so hasn’t been included in the valuations. There were also carryover responses in spring from the two higher rates of litter but this has not been included in the valuations.

Table 20. Value of extra energy in pasture in winter, relative to the Controls, at Glenaroua

Treatment		Cost $/ha	Cents/MJ ME 2010	Cents/MJ ME 2011	Cents/MJ ME 2012
Maintenance NPKS		100	2.4	0.4	76
	Urea only	*45*	*1.0*	*0.2*	*33*
Capital NPKS		200	3.5	0.6	21
	Urea only	*90*	*1.5*	*0.3*	*9*
Maintenance litter		60-120	3.1	0.4	114
Capital litter		120-220	6.3	0.8	25
High C litter		350	5.1	1.0	21
Oats (11MJME/kg DM)		$220/t fed	2.2	2.2	2.2
Hay (8 MJ ME kg DM)		$180/t fed	2.7	2.7	2.7

The three rates of litter and the Capital PS fertiliser all increased the amount of clover in the pasture at Glenaroua. In spring 2012, there was around 250 kg DM/ha of clover in the Controls (around 15% of composition) compared with 500 - 600kg DM/ha clover in the Litter and Capital PS treatments (around 30% of composition). The amount of legume in a pasture is important for several reasons: it improves feed quality, it produces nitrogen for the grasses and it influences feed intake and weight gain in sheep and cattle. For example, an increase from 15% to 30% clover in a pasture with 1,500 kg DM/ha green feed available can increase second-cross lamb live-weight gains by 20-30 g/head per day (GrazFeed). This would equate to an extra 2-3 kg live-weight gain per lamb over the spring period. If lambs were stocked at 10/ha, this would be an extra 20-30kg live-weight/ha or an extra $40-60/ha meat income.

Soil carbon stocks

Glenaroua

The High C rate of litter treatment gave rise to a significantly ($P=0.06$; LSD =0.69) higher total organic carbon (approximately 0.7- 0.9% higher TOC%) in the topsoil than the Control, the Maintenance PS and the Maintenance NPKS treatments at Glenaroua by the end of the experiment. This difference was significant when only these four treatments were analysed separately using ANOVA. The least significant difference (LSD) calculated when all ten treatments were compared (Table 21) also supports this finding. Although the High C rate of litter had a higher TOC% in the topsoil compared with the other five treatments, this was not significant at the 5% level.

There were no significant treatment differences ($P \leq 0.05$) in the total organic carbon % in the subsoil at Glenaroua by the end of the experiment (Table 21). However, there was a trend for the three litter treatments to have the highest TOC% in the subsoil.

There were no significant treatment differences in the bulk density of the topsoil at Glenaroua by the end of the experiment (Table 21). However, the bulk density of the subsoil in the High C litter treatment was significantly ($P=0.06$) lower than the Control. This indicates that the build-up of organic matter in the High C litter treatment was having an impact on soil physical properties at depth. In effect the application of high rates of litter was building up topsoil and increasing the depth of topsoil.

There were no significant treatment differences detected ($P \leq 0.05$) in the total organic carbon when converted to t/ha in the topsoil or subsoil at Glenaroua by the end of the experiment (Table 21). However, the High C rate of litter had the highest stock of TOC of all treatments in the topsoil at 40.1 t/ha (approximately 4.5 t/ha more than the Control and the Maintenance P,S treatment). The three litter treatments also had the highest stocks of TOC in the subsoil of all treatments (approximately 4.3-6.8 t/ha higher than the Control). Over the 0-30cm depth of soil, the High C litter treatment had a carbon stock of 10.1 t/ha higher than the Control and 8.9 t/ha higher than the Maintenance P,S treatment. The carbon stocks over the 0-30cm soil depth for each treatment, and the standard errors, are shown in Figure 12.

Soil carbon levels need to be monitored over a long time period as changes tend to occur relatively slowly, and the annual increases can be small relative to the total carbon stocks. However, the trend with soil carbon levels observed, from addition of the High C rate of litter (20t/ha over the four years), is encouraging.

Table 21. Total organic carbon (% LECO and t/ha), soil bulk density and profile carbon stocks at Glenaroua in Oct 2012

Treatment	TOC % 0-10cm	TOC % 10-30cm	Topsoil bulk density g/cm^3	Subsoil bulk density g/cm^3	TOC t/ha 0-10cm	TOC t/ha 10-30cm	TOC t/ha 0-30cm (standard error)
Control A & B (nil)	3.46	1.04	1.03	1.33	35.53	26.61	60.87 (2.52)
Maintenance PS	3.65	1.18	0.97	1.26	35.58	28.69	62.11 (4.04)
Maintenance PS + Humic acid	3.70	1.19	1.06	1.26	38.86	29.94	68.80 (4.66)
Capital PS	3.94	1.04	0.95	1.18	37.27	25.01	62.28 (7.72)
Maintenance NPKS	3.42	1.02	0.98	1.30	33.89	26.43	60.32 (2.62)
Capital NPKS	3.74	0.89	0.97	1.22	36.42	21.69	58.11 (4.81)
Maintenance Litter	3.81	1.30	0.90	1.26	34.22	32.98	67.20 (7.56)
Capital Litter	3.67	1.24	1.01	1.35	36.46	33.38	69.85 (7.61)
High C rate Litter	4.37	1.37	0.92	1.11	40.13	30.88	71.02 (8.42)
P value	*n.s**	*n.s*	*n.s*	*n.s*	*n.s*	*n.s*	*n.s*
L.S.D (5%)	*0.70*	*0.47*	*0.19*	*0.18*	*8.35*	*12.50*	*16.89*

n.s = not significant. * see text for clarification

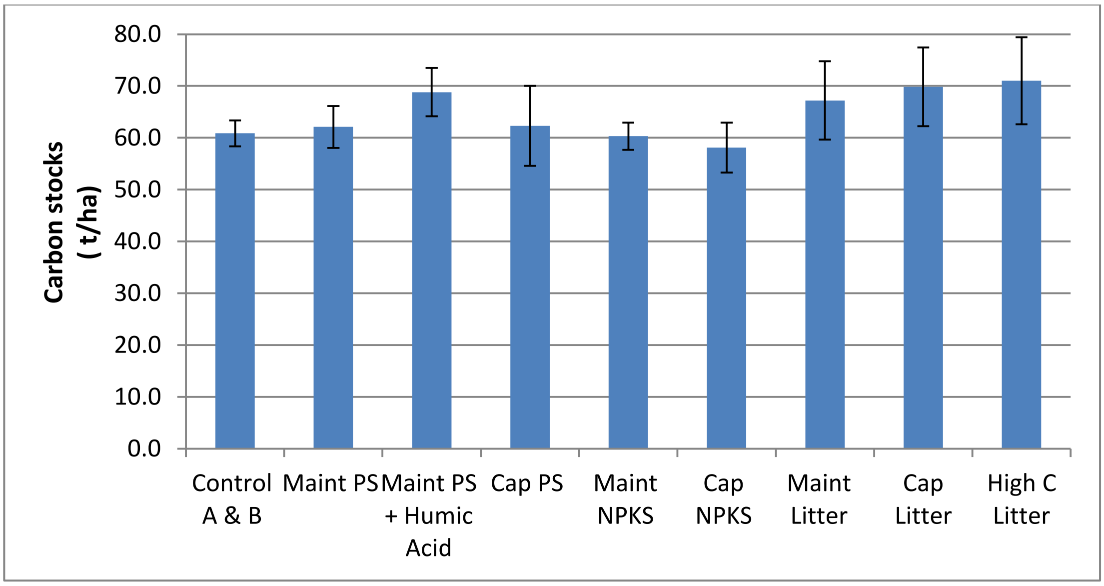


Figure 12. Carbon stocks (t/ha) in the 0-30cm soil depth at Glenaroua, October 2012
The error bars represent the standard error of the means.

The predicted pools of carbon (POC, HOC and ROC) were also determined for the top soil and subsoil. In the top soil, there was no significant difference in the amount of carbon in each pool between treatments using ANOVA (Table 22). However, there was a clear trend for the High C litter treatment to have a higher POC than the Control. Further analysis of these two treatments, using a t-test, showed that there was a significance difference (*P = 0.03*) between them. In the subsoil, there was no significant difference in the amount of carbon in each pool between treatments (Table 23).

It would appear that the higher total organic carbon stock (t/ha) in the soil profile of the High C litter treatment was being driven by an increase in POC and not HOC or ROC. As ROC represents resistant carbon stored as charcoal in the soil, it would not be expected to change.

Table 22. Predicted values for particulate (POC), humus (HOC), and resistant (ROC) organic carbon, in the topsoil (0-10cm) at Glenaroua, October 2012

Treatment	POC t/ha	HOC t/ha	ROC t/ha
Control A & B (nil)	6.7	17.1	11.6
Maintenance PS	7.1	17.3	11.1
Maintenance PS + Humic acid	7.4	18.3	13.1
Capital PS	7.6	18.5	11.2
Maintenance NPKS	6.7	16.0	11.2
Capital NPKS	8.2	17.0	11.2
Maintenance Litter	7.5	16.2	10.6
Capital P Litter	7.9	16.8	11.7
High C rate Litter	9.6	17.8	12.7
P value	*n.s*	*n.s*	*n.s*
L.S.D (5%)	*3.1*	*4.1*	*3.0*

n.s = not significant

Table 23. Predicted values for particulate (POC), humus (HOC), and resistant (ROC) organic carbon, in the subsoil (10-30 cm) at Glenaroua, October 2012

Treatment	POC t/ha	HOC t/ha	ROC t/ha
Control A & B (nil)	2.3	16.8	7.5
Maintenance PS	2.2	18.2	8.4
Maintenance PS + Humic acid	2.0	20.3	7.6
Capital PS	2.1	15.3	7.7
Maintenance NPKS	3.2	15.6	7.7
Capital NPKS	2.0	13.4	6.4
Maintenance Litter	2.2	19.7	11.1
Capital Litter	2.4	19.1	11.9
High C rate Litter	2.1	16.4	12.4
P value	*n.s*	*n.s*	*n.s*
L.S.D (5%)	*1.4*	*7.0*	*6.2*

Pastoria

There were no significant treatment differences detected (P≤ 0.05) in the percentage of total organic carbon (TOC %) in the topsoil or subsoils at Pastoria by the end of the experiment (Table 24). However, there was a trend for increasing carbon % in the topsoil with increasing rate of litter and the High C rate of litter had the highest topsoil carbon % of all treatments, similar to what was as observed at Glenaroua.

There were no significant treatment differences (P≤ 0.05) in the total organic carbon % in the subsoil at Pastoria by the end of the experiment (Table 24). This was different to what was observed at Glenaroua where there was a trend for the three litter treatments to have the highest TOC% in the subsoil.

There were no significant treatment differences in the bulk density of the topsoil or subsoil at Pastoria by the end of the experiment (Table 24).

There were no significant treatment differences detected (P≤ 0.05) in the total organic carbon when converted to t TOC /ha in the topsoil or subsoils at Pastoria by the end of the experiment (Table 24). However, there was a trend for increasing t TOC/ha in the top soil with increasing rate of litter. Unlike at Glenaroua, where the High C litter treatment had the highest carbon stock, several treatments at Pastoria had higher carbon stocks than the Control. They were the Maintenance PS, Maintenance NPKS, Capital NPKS and the High C litter treatments (Figure 13).

Table 24. Total organic carbon (% LECO and t/ha), soil bulk density and profile carbon stocks at Pastoria in October 2012

Treatment	**TOC % 0-10cm**	**TOC % 10-30cm**	**Topsoil bulk density (g/cm^3)**	**Subsoil bulk density (g/cm^3)**	**TOC t/ha 0-10cm**	**TOC t/ha 10-30cm**	**TOC t/ha 0-30cm** (standard error)
Control A (nil)	2.42	0.63	0.96	1.39	23.13	17.47	40.60 (3.42)
Maintenance PS	2.52	0.62	1.06	1.28	27.13	15.74	42.87 (4.28)
Maintenance PS + Humic acid	2.29	0.50	1.09	1.37	24.90	13.63	38.52 (0.72)
Capital PS	2.42	0.58	1.06	1.33	25.24	15.31	40.55 (3.08)
Maintenance PKS	2.45	0.57	1.00	1.32	24.33	15.06	39.39 (2.11)
Maintenance NPKS	2.62	0.64	1.03	1.36	26.85	17.48	44.32 (3.24)
Capital NPKS	2.49	0.64	1.15	1.37	28.54	17.55	46.09 (2.79)
Maintenance Litter	2.39	0.50	1.02	1.41	24.22	14.22	38.44 (1.67)
Capital Litter	2.47	0.61	1.01	1.37	24.19	16.55	40.74 (2.20)
High C rate Litter	2.88	0.60	0.97	1.32	27.74	15.85	43.59 (2.89)
P value	*n.s*	*n.s*	*n.s*	*n.s*	*n.s*	*n.s*	*n.s*
L.S.D (5%)	*0.57*	*0.17*	*0.14*	*0.12*	*4.87*	*4.40*	*8.16*

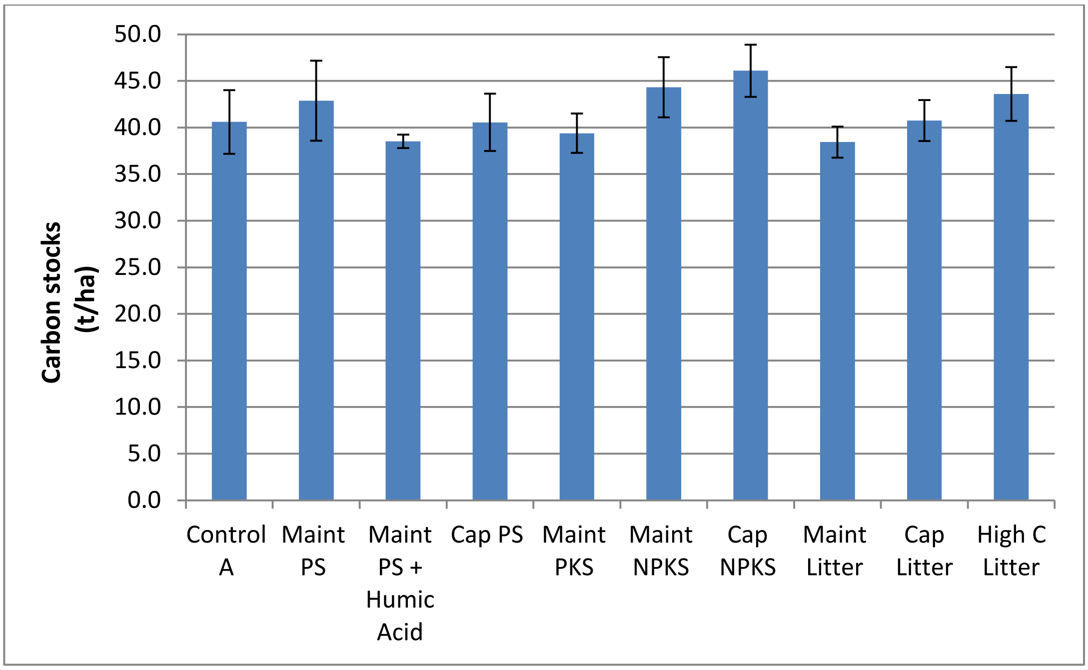


Figure 13. Carbon stocks (t/ha) in the 0-30cm soil depth at Pastoria, October 2012
The error bars represent the standard error of the means

The predicted pools of carbon (POC, HOC and ROC) were also determined for the topsoil and subsoil. There were no significant differences in the amount of carbon in each pool between treatments in the topsoil (Table 25) or subsoil (Table 26).

There was a trend for the treatments with the highest total organic carbon stocks (t/ha) in the soil profile (High C litter, Maintenance NPKS, Capital NPKS, Maintenance PS) to have higher levels of topsoil POC and to a lesser extent HOC than other treatments. Increases in topsoil POC were most likely responsible for the increases in total organic carbon - a similar trend was observed at Glenaroua.

Table 25. Predicted values for particulate (POC), humus (HOC), and resistant (ROC) organic carbon, in the topsoil (0-10cm) at Pastoria, October 2012

Treatment	POC t/ha	HOC t/ha	ROC t/ha
Control A	7.9	10.0	5.3
Maintenance PS	10.0	11.3	5.9
Maintenance PS + Humic acid	10.1	9.7	5.1
Capital PS	8.5	11.1	5.7
Maintenance PKS	9.4	9.7	5.2
Maintenance NPKS	9.2	11.4	6.2
Capital NPKS	10.1	12.2	6.2
Maintenance Litter	7.1	11.1	6.1
Capital Litter	7.5	10.7	6.0
High C rate Litter	9.4	11.8	6.6
P value	*n.s*	*n.s*	*n.s*
L.S.D (5%)	*3.1*	*2.7*	*1.1*

Table 26. Predicted values for particulate (POC), humus (HOC), and resistant (ROC) organic carbon, in the subsoil (10-30cm) at Pastoria, October 2012

Treatment	POC t/ha	HOC t/ha	ROC t/ha
Control A	2.4	9.8	5.2
Maintenance PS	2.3	8.9	4.5
Maintenance PS + Humic acid	2.9	7.2	3.5
Capital PS	2.4	8.6	4.3
Maintenance PKS	2.4	8.2	4.5
Maintenance NPKS	3.6	8.6	5.2
Capital NPKS	2.7	9.4	5.5
Maintenance Litter	2.4	7.8	4.0
Capital Litter	2.9	8.8	4.9
High C rate Litter	2.6	8.8	4.5
P value	*n.s*	*n.s*	*n.s*
L.S.D (5%)	*1.1*	*2.4*	*1.9*

Soil microbial activity

There were no significant treatment differences on the level of soil microbial activity, as measured by the FDA enzyme test, at either site (Figures 14 and 15). The main driver of level of activity was the time of the year, with substantially more activity during the warmer spring conditions (October 2012). A similar rate of activity was measured at both sites of around 5 µg sodium fluorescein/gram dry soil per minute in winter and up to 13 µg/g per minute in spring.

Microbial biomass carbon (mg biomass/g soil) was similar from winter to spring at Glenaroua (Figure 14). At Pastoria, biomass carbon was around 40% of that measured at Glenaroua in winter, but it doubled in spring (Figure 15).

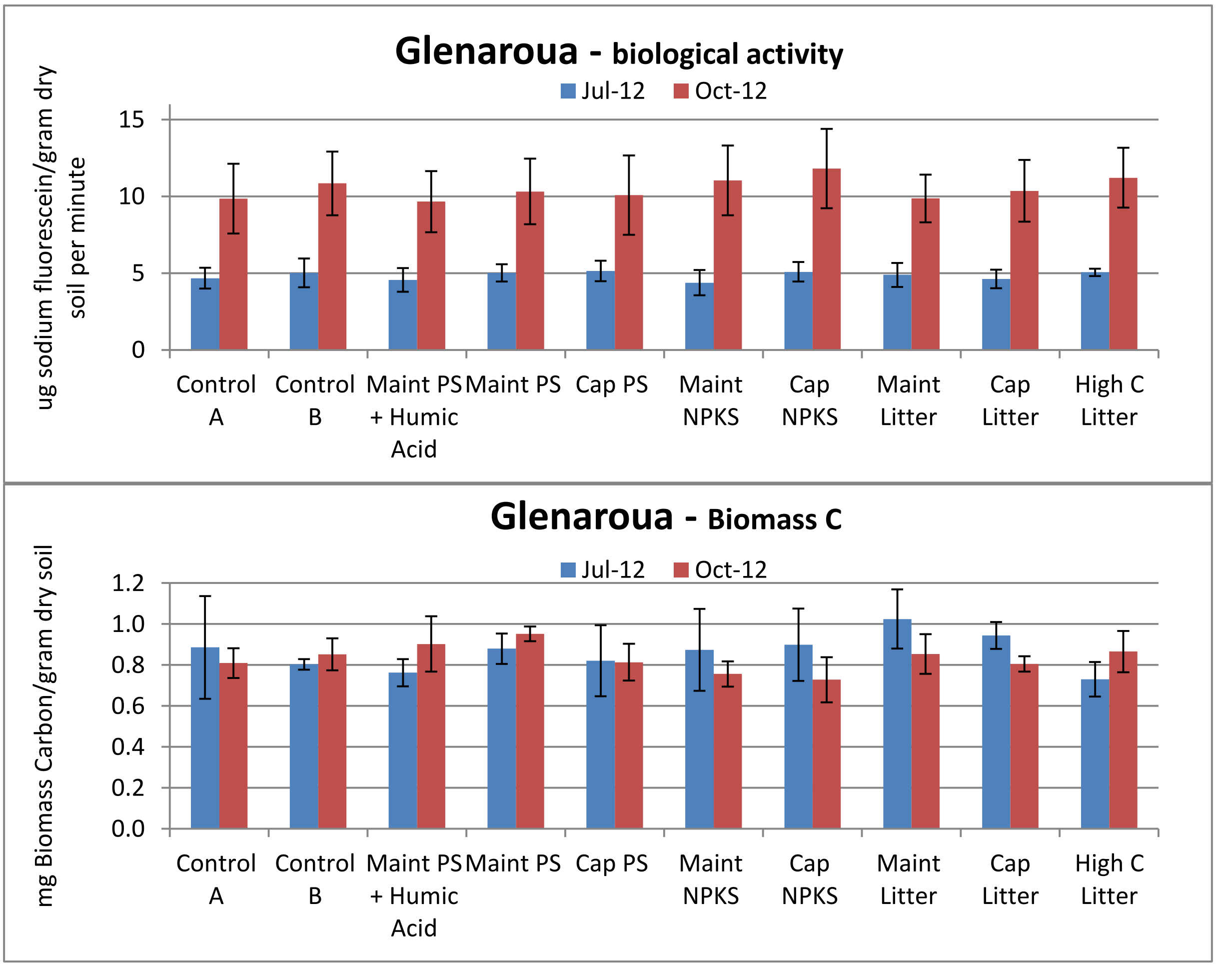
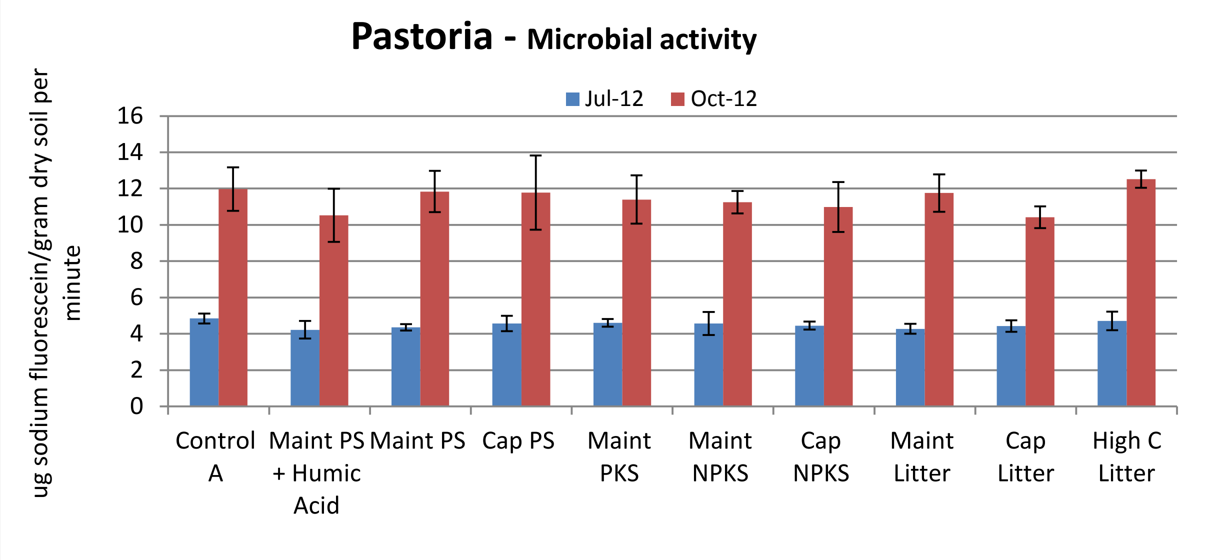


Figure 14. Soil microbial activity and biomass carbon, July and October 2012, at Glenaroua
Standard errors for each mean are shown by the error bars



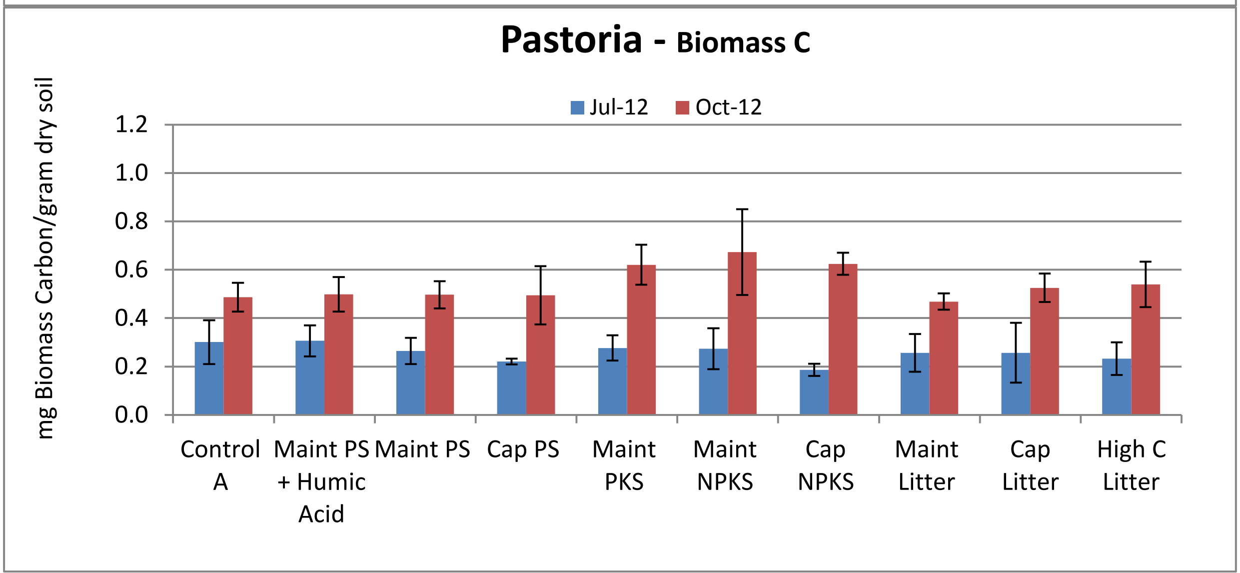


Figure 15. Soil microbial activity and biomass carbon, July and October 2012, at Pastoria
Standard errors for each mean are shown by the error bars

Extension and communication

A summary of extension activities and communication conducted to promote the results of the experiments and general information on using litter and alternative fertilisers is shown in Table 27.

Table 27. Extension activities and other communications delivered

Date	Activity	Number of people
October 2009	**Article** in Mackinnon newsletter – creating awareness about the research	500 circulation (Vic, Tas, NSW, SA)
February 2010	**Farm walk** at Pastoria site with Pastoria Evergraze group – using poultry litter & experiment details	20
February 2010	**Article** in Grassland Society of Southern Australia newsletter – creating awareness about the research	1500 circulation (Vic, Tas, NSW, SA)
April 2010	**Presentation** to Seymour Wool Group at Seymour – research results update	15
June 2010	**Presentation** to Holbrook Landcare group at Holbrook – value of poultry litter as an alternative fertiliser and results update from pasture experiments	40
June 2010	**Presentation** at soil health seminar at Beaufort run by Ballarat Bestwool/Bestlamb group – assessing alternative fertiliser options and results update from pasture experiments	80
November 2010	**Presentation** to Seymour Wool Group at Seymour – research results update	15
January 2011	**Farm walk** at Pastoria site with Pastoria Evergraze group – research results update.	15
February 2011	**Article** in Mackinnon newsletter – research update	500 circulation
June 2011	**Farm walk** at Pastoria site with Pastoria Evergraze group – research update.	15
August 2011	**Farm walk** at Glenaroua site with Seymour Wool Group – update.	20
August 2011	**Field day** at Pastoria site held in conjunction with the Grasslands Society of Southern Australia	40
May 2012	**Presentation** to Glenaroua Landcare group – research update.	25
May 2012	**Presentation** at Australian Veterinary conference Canberra (sheep vets group). Paper produced	50
November 2012	**Workshop** on using chicken litter at Nagambie. Results from pasture cropping research with poultry litter in Vic & SA.	70
November 2012	**Article** in Mackinnon newsletter – summary of key information presented at Nagambie workshop	500 circulation
April 2013	**Article** in Grassland Society of southern Australia newsletter – summary of key information presented at Nagambie	1500 circulation (Vic, Tas, NSW, SA)
March 2014	**Poster/paper** presented at Soil Matters conference, Bendigo.	500

Figure 16. Farms walks were held at both sites for local producers to inspect field experiments and hear latest results

Discussion

Effectiveness of poultry litter as an alternative source of nutrients for pastures

Soil and plant nutrition

Chicken litter was as effective as conventional fertiliser at increasing soil fertility, when applied at similar rates of nutrients. Soil phosphorus levels increased with increasing rates of fertiliser or litter. Soil potassium and sulphur levels did not show a consistent trend to increasing rate of applied K and S. At Glenaroua, soil K levels were the highest in the three litter treatments, relative to the Control, whereas at Pastoria, the Capital NPKS fertiliser and High C litter treatments had the highest soil K levels. The leaf analysis was a more sensitive measure of the effect of increased K nutrition. The K content in the herbage showed a trend to increase with rates of K applied in fertiliser or litter. Soil S levels were lowest in the Controls at both sites. The S content in the herbage showed a trend to increase with rates of S applied in fertiliser or litter.

Despite, a large amount of K being applied in litter over the four years (300 kg K/ha), the High C litter treatment only increased soil K levels by around 10 mg/kg (relative to the Control) at Pastoria and by 40 mg/kg at Glenaroua. Similarly, a large amount of S was applied in the High C rate of litter over four years (83 kg S/ha), but soil S levels were no higher than the other fertiliser and litter treatments. There are two reasons why high levels of soil K and S didn't accumulate at either site. Firstly, some K and S would have been used to produce extra pasture growth, driven by the N inputs, and some K and S were tied up in the herbage. There were similar levels of S in herbage at both sites in spring 2012, but K levels were higher in herbage at Pastoria. The high proportion of bent grass in the pasture at Pastoria would have been effectively tying up some K as this weed forms a thick matt of rhizomes and roots. Secondly, some K and S could have leached beyond the root zone. Potassium and sulphur are more mobile nutrients in soil than phosphorus which tends to remain close to the soil surface. Leaching losses would be expected to be greater at Pastoria which has a lighter soils and higher rainfall than Glenaroua. Further investigation of K and S levels in the sub soil is warranted to see if leaching losses were any different between the fertiliser and litter treatments.

Cation exchange capacity (total cations) is an indicator of the soils ability to retain nutrients and is generally higher in heavier soil types with more clay content. There were no significant treatment effects on soil cation exchange capacity (CEC) at either site. However, there was a clear trend for CEC to increase with increasing rates of litter. The increase in cations measured (Ca, Mg, K, Na) was mainly due to increasing calcium levels. The High C rate of litter supplied 60-110 kg Ca/ha each year and this treatment increased CEC from 6.54 to 8.22 meq/100g at Glenaroua and from 3.65 to 4.22 meq/100g at Pastoria, relative to the Controls. The clay loam soil at Glenaroua had a naturally higher CEC, than the lighter soil at Pastoria, due to the higher clay content. Cation exchange capacity is a soil property which is not easily changed in the short-term, but the trend that the higher rates of litter can have some impact is encouraging.

Chicken litter is also a valuable source of the trace elements copper, zinc and molybdenum, which can be deficient in certain soil types. Copper and zinc levels in soil increased with increased rates of litter at both sites. There were no significant treatment effects on soil iron or manganese content. Plant tissue levels of copper and molybdenum also increased with increased rates of litter. While the trace element boron was also applied in litter, there was no significant increase in soil or leaf boron in litter treatments relative to the other treatments. At Glenaroua and Pastoria, leaf analysis in spring 2012 indicated that copper and zinc content was adequate, across all treatments, for pasture and livestock requirements. Leaf boron content was marginal in all treatments for clover requirements. At Glenaroua, molybdenum was marginal for clover requirements in all treatments except the Capital and High rates of litter. Molybdenum content was adequate for clover requirements at Pastoria across all treatments. Use of soil and leaf analysis is critical to define which trace elements are required and if the litter is well placed to supply them at a cheaper price than conventional fertilisers.

The cost of litter (spread) can vary from \$16 to \$28/m^3 depending on the source. There is around 2.5 m^3 of litter per tonne (fresh). The cost can range from \$40 to \$70/t of fresh litter. Whether litter is good value for one or more nutrients depends on the relative price of the litter (and its composition) and the inorganic fertilisers at the time. Table 28 shows what price of litter is economic for a livestock producer to pay based on the number of nutrients required and the costs of conventional fertilisers. Litter may be a cheaper source of P than Superphosphate (at \$400/t) if the litter can be spread for less than \$19/m^3. If a soil requires more than one macro nutrient or trace elements, litter can still be an economic alternative even if litter prices are at the higher end of the price range. However, litter needs to be competitively priced to encourage more livestock producers to use it.

Table 28. Impact of nutrients required for pasture on upper price could pay for litter, based on cost of nutrients in conventional fertiliser

Nutrients required for pasture	Fertiliser price (spread) \$/t	Upper price for litter* (spread) \$/m^3
Phosphorus (&S)	Superphosphate @ \$400/t	\$ 19/m^3
Phosphorus (&S) + Molybdenum	Super with molybdenum 0.025% @ \$450/t	\$ 30/m^3
Phosphorus (&S) + Molybdenum + Copper	Super with moly 0.025% & copper 0.5% @ \$490/t	\$41/m^3
Phosphorus (&S) + potash (K)	Superphosphate @ \$400/t plus muriate of potash @ \$ 740/t	\$23/m^3

**Assuming litter has a composition of: 85% dry matter, 4%N, 1.2%P, 1.8%K, 0.6%S, 118 ppm Cu and 3.6 ppm Mo.*

While litter can supply important trace elements for pasture and livestock nutrition, accumulation of certain elements, the heavy metals, is a concern where high rates of litter are applied. Investigation of composition of chicken litter by other researchers (Parkinson *et.al.,* 1999) has shown that the content of most heavy metals (arsenic, cadmium, chromium, mercury, nickel, lead, selenium and zinc) fall within the EPA guidelines for unrestricted use of composts and other organic wastes (EPA, 1996). These researchers found that the copper and zinc content of chicken litter sometimes exceeded the EPA guidelines of 60 ppm for copper and 200 ppm for zinc. The other important EPA guidelines relate to the maximum allowable loading (annual or cumulative) for copper and zinc. The maximum, allowable annual loading (application rate) is 50 kg/ha for zinc and 20 kg/ha for copper. Litter used in this research had variable copper and zinc contents but they tended to exceed EPA guidelines. However, annual application rates of copper (0.1 -0.6 kg/ha) and zinc (0.4 - 2.0 kg/ha) were well under the EPA's maximum allowable limit. Copper and zinc were still at acceptable levels in soils and plant tissue where very high rates of litter were applied over the four years. Where the lower, maintenance rates of litter were applied, soil copper and zinc levels were only slightly higher than the other fertilised treatments. Clearly, levels of these nutrients in soils need to be monitored by producers who are applying large quantities of litter that are well above their nutrient requirements.

Pasture responses

Broadcasting chicken litter onto pastures can give similar pasture yield responses to conventional, inorganic fertilisers. There was no additional pasture yield response to litter over and above that of the conventional fertilisers after four years of applications. Increases in other soil properties, like organic carbon and cation exchange capacity, did not translate into additional yield but may do so in the long-term. In the short-term, the decision to use chicken litter will depend on price relative to conventional fertilisers.

Significant phosphorus responses were not detected in dry matter yields. Olsen P levels at Pastoria were around 16 mg/kg, and at Glenaroua were around 13 mg/kg, at the start of the experiment. The target range for Olsen P is 12-15 mg/kg. Over the four years, it was expected P levels would drop enough at Glenaroua on the Controls (nil fertiliser) to show up any P responses to fertiliser or litter, but this didn't occur. The research sites would need to be monitored for a longer period to show significant yield responses to phosphorus. Producers who use litter on pastures are using it as a substitute for their maintenance P,S fertiliser (superphosphate) on their improved pastures as well as a capital application to boost PKS levels of highly deficient soils. Hence, investigating responses of litter on soils with relatively good Olsen P levels was relevant to users. This work confirms recommendations by agronomists that it is safe to leave maintenance fertiliser off pastures for a few years if Olsen P levels are high and not penalise pasture production.

The pasture yield responses observed in this research were mainly due to nitrogen. For soils with adequate phosphorus levels it is more cost-effective to apply nitrogen (urea) alone rather than litter, in the short-term. At Glenaroua, there were similar winter pasture yield responses to N whether it was supplied as urea or litter. The Capital rate of fertiliser and Capital and High rates of litter also had a carryover yield responses in spring. Nitrogen does not have a residual fertiliser effect in soils like phosphorus does, and is usually used up within four to six weeks after application, assuming there is adequate moisture for plant growth. For this reason, it is most likely that the carryover yield responses observed were due to changes in pasture composition. The content of improved perennial grasses increased in response to the N applications in litter or fertiliser.

At Pastoria, there were poorer winter yield responses to N in the maintenance and capital rates of litter, compared with the urea. This could be due to difference in the availability of N in the litter at the two sites. Pastoria has cooler winter temperatures than Glenaroua and the litter was applied slightly later than at Glenaroua each year, so perhaps the release of plant available N by microbial activity was delayed. The High rate of litter produced good winter responses, and this could be due to the substantially higher amount of available N applied. In winter, microbial activity was similar at both sites based on the FDA enzyme test, but the total biomass carbon was substantially lower at the Pastoria site. If the lower microbial activity was the explanation for slower N release and poorer winter response to the lower rates of litter, it might be expected that the response would be delayed and detected in spring but this was not the case either.

Composition analysis of litter indicates total nutrients not their availability. Nutrients in litter are in both mineral and organic forms. This means a proportion of the N,P,K,S is immediately available to plants while the remainder (organic) must be converted to a form plants can use. Some references indicate that most of the nitrogen in chicken litter is available to plants soon after spreading – with up to 80% available in the first year. Around 25% (range 10% - 50%) of the N is in the ammonia form which can be lost to the atmosphere unless cultivated or washed into the soil within a few days of spreading (Griffiths, 2007). Most of the other N in litter becomes urea within a short time of spreading, and from then on acts like urea. It is unlikely that there would have been any greater losses in N in litter, due to ammonia volatilisation, at Pastoria than at Glenaroua.

In addition to the yield responses described, nitrogen application also improved pasture feed quality. At Glenaroua, Capital rates of fertiliser and litter and the High rate of litter, increased pasture energy content by around 2 MJ ME/kg DM in winter and 1 MJ ME/kg DM spring, relative to the Controls. Protein levels in the pasture also increased by 5-6 % in winter. At Pastoria, the Maintenance and Capital rates of fertiliser improved pasture energy content by around 2 MJ ME/kg DM in winter, and protein by 3-5%, relative to the Control. Within the litter treatments, only the High rate of litter produced pasture with higher protein levels in winter, relative to the Controls.

There were no significant potassium responses in dry matter yields at Pastoria. Soil potassium levels were low and deficient at this site and you would expect a yield response to K. However, the wet summer of 2010/11, caused the summer-active bent grass to dominate the previously clover dominant plots. Grasses in general have a lower requirement for K than legumes, so this is perhaps why a K response was not detected in the Maintenance PKS treatment.

While significant phosphorus responses were not detected in the dry matter yields, a P response was apparent by the end of the experiment by the change in pasture composition. At Glenaroua, the Capital rate of PS fertiliser and all three rates of litter had more sub clover present than the other treatments. At Pastoria, there was more sub clover present in all treatments compared with the Control. Sub clover has a higher requirement for phosphorus than grasses, which can explain its better response to P inputs. The litter appeared to have a positive impact on both the improved perennial grass and clover content, whereas the NPKS fertilisers seemed to encourage the improved grasses. At Glenaroua, this positive effect of litter on the clover content could have been due to a molybdenum response in addition to a P response. All three rates of litter showed a similar increase in clover content, but only the Capital and High C rates of litter supplied enough molybdenum to overcome the marginal molybdenum status at the site. Since the Capital rate of PS fertiliser also improved clover content, a molybdenum response was discounted.

The amount of legume in a pasture is important for several reasons: it improves feed quality, it produces nitrogen for the grasses and it influences feed intake and weight gain in sheep and cattle. For example, an increase from 15% to 30% clover in a pasture with 1,500 kg DM/ha green feed available (like what was observed at Glenaroua) can increase second-cross lamb live-weight gains by 20-30 g/head per day (GrazFeed). This would equate to an extra 2-3 kg live-weight gain per lamb over the spring period. If lambs were stocked at 10/ha, this would be an extra 20-30kg live-weight/ha or an extra $40-60/ha meat income.

The change in pasture composition, due to phosphorus response, would have been reflected in improved livestock performance if the treatments were grazed. The compositional changes and changes in soil fertility between treatments would eventually impact on dry matter yield if the experiment was monitored for a longer period.

Lower rates of litter, based on nutrient removal, were effective at maintaining pasture yield and soil fertility. This highlights that very high rates are not required to get benefit from litter applications as is the perception by some producers. Very high rates of litter are not essential, unless the objective is to increase soil carbon.

Value of organic matter in litter – effect on total organic carbon in soil

Broadcasting chicken litter on the soil surface had a positive effect on topsoil organic carbon. Top soil organic carbon increased, where high rates of litter were applied relative to the Control (nil fertiliser) by 0.5% and 0.9% at Pastoria and Glenaroua, respectively. There was a trend for soil organic carbon in the topsoil to increase by around 3-5 t/ha at both sites where high rates of litter (20 t/ha over four years) were applied, compared with the Controls. At Glenaroua, the 0-30cm soil profile had around 10 t/ha more carbon than the Controls, while at Pastoria, with the lighter soil type, this increase was more modest at 3t/ha.

At Glenaroua, there was a trend for the Maintenance and Capital rates of litter to have higher carbon stocks than the Maintenance NPKS and Capital NPKS treatments. The increase in soil carbon did not translate into pasture yield responses over and above that of the conventional fertilisers, at least not in the short-term.

However, increased carbon stored in soils (carbon sequestration) does have an economic value. In the compliance market for carbon, in the 2013/14 fiscal year, Australia has a carbon price of $24.15/t carbon dioxide equivalent (CO_{2e}). This price was to be set by the Clean Energy Regulator at $15/t in July 2015 in the advent of an emission trading scheme. However, given the change in Government and that the new Direct Action policy is still being formulated, it is difficult to place a future price on the value of carbon. Table 29 summarises what the additional carbon stored in the soil at Glenaroua and Pastoria could be worth in two different carbon price scenarios.

Table 29. Value of carbon in chicken litter based on different carbon price scenarios

Site	Additional carbon stored in High C litter treatment over 4 years- compared with Control (C t/ha in 0-30cm)	Additional Carbon stored over 4 years ($t\ CO_2$ equivalents)	Value of carbon stored @ Carbon price \$24.15/t CO_2e	Value of carbon stored @ Carbon price \$15.00/t CO_2e
Pastoria (loam)	3.0	11.0	\$ 266	\$ 165
Glenaroua (clay loam)	10.0	36.6	\$ 884	\$ 549

If carbon is worth \$24.15/t, and soil carbon increased by up to 3-10 t/ha, then the value of the sequestered carbon is around \$266-884/ha over four years (\$ 67 – \$ 221/year). At each site, 20t/ha of litter was applied over four years at a cost of \$1400/ha. Dividing the benefit \$266-884/ha of carbon sequestered by the 20t of litter applied, gives a carbon value of \$13.00 - 44.00/t of litter. In addition to the nutrient value in litter, the value of the carbon sequestration could add \$13-44/t to the price of litter which equates to \$5.20 -\$17.60/m^3. If the carbon price fell to \$15/t, the value of the carbon sequestration is around \$165-549/ha over four years (\$41-137/year). With a carbon price of \$15/t this could add \$8.00 – \$27.00/t to the price of litter which equates to \$3.20 -\$10.80/m^3.

Research has been conducted on crop and soil responses to farmyard manure (containing various amounts of organic matter) in comparison to conventional fertilisers in a number of long-term experiments conducted overseas (Edmeades, 2003). Manured soils had higher levels of organic matter, and number of microfauna than fertilised soils and were more enriched in P,K,Ca and Mg in topsoils. However, the trials showed there was no significant difference between fertilisers and manures in their long- term effects on crop production. The only trial that showed any production differences was the Rothamsted long- term experiment and this was due to the larger inputs of manures and much larger accumulation of soil organic matter. In this trial, inputs of 35 t/ha of manure were applied annually since the 1850's and it took until the 1980s for production differences between fertilised and manured treatments to become apparent. In these crop production trials, soil organic matter increased by 300%, from 1% to 3%. In other trials manure inputs range from 4 to 22 t/ha per year.

If coming from a low soil carbon level, it appears manures can have a big impact on increasing soil carbon and crop yields relative to fertiliser, but very high rates need to be applied over a long time frame. This research on chicken litter showed that topsoil organic carbon could be improved in a relatively short time period but, based on findings from the overseas crop trials, the high inputs of litter would need to continue for many years to influence pasture production above the nutrient responses. Also, if the soil carbon levels are already moderate to high (>3%) as they commonly are in many pasture soils in the higher rainfall areas, the soil stores may already be saturated with carbon, hence no production response might occur.

Promotion of the use of chicken litter as alternative fertiliser and producer training.

Numerous extension activities were conducted during the project to promote the research findings and train producers in how to objectively compare cost/benefits of alternatives like litter against conventional inorganic fertilisers and to address concerns such as handling/application. Good attendances were recorded at each event indicating the high level of interest in alternative fertilisers and the desire to learn more.

Market research undertaken as part of the National Poultry Litter program highlighted a range of barriers to greater adoption of poultry litter on broad-acre farms (Dorahy, 2008). Key barriers were: the need to demonstrate the value of litter to potential end users; difficulties associated with storing, handling and applying litter; and perceived lack of information about what is in litter and its performance benefits. Other questions frequently asked by potential litter users, who attended the activities held during this project, related to availability of nutrients in litter and if there is a lag time to release of nutrients, application rates, potential pathogen risks and heavy metals. All of these concerns/issues were addressed in presentations to groups and in written material produced during this project.

A key milestone for the project was the delivery of training workshops at the end of the project. The aim of the workshop was to improve the confidence, knowledge and skills of sheep/cattle producers and their advisors to achieve greater adoption of chicken litter as an alternative fertiliser. One large workshop was held at Nagambie in 2012, and attracted around 70 people. Those attending included sheep and cattle producers, croppers, chicken meat company technical staff (from Hazeldene Chicken Farms and Baiada Poultry), litter spreading and clean-out contractors, researchers, and advisors. The workshop also included presentations on recent research undertaken in cropping. Tony Craddock (from Rural Directions) presented results of using litter in broad-acre cropping (RIRDC PRJ-005346) and demonstrated of the use of the POOCALC spreadsheet tool for comparing the cost of litter against inorganic fertilisers. Dr Peter Sale (LaTrobe University) presented results of subsoil manuring research whereby chicken litter is incorporated into heavy clay subsoils with deep-ripping, to improve crop yields.

The workshop was assessed to be very successful and to have achieved its aim. Key points from the evaluation of the workshop were:

- 60% of the producers attending had already trialled chicken litter on their farm and the other 40% all said they would trial it after the workshop.
- Typical rates of litter applied were 4-5 m^3/ha (approx.1.6-2 t/ha) in one application, with the range from 1-10 m^3/ha.
- Areas fertilised with litter ranged from 40 - 1,500 ha per annum.
- Participants learnt:
    - that the level of nutrients in litter can vary and that litter can be easily /cheaply tested for composition to assist with determining application rates and costs;
    - the value/cost of nutrients in litter and value of trace elements for some soils;
    - the importance of getting soil tested to help assess likely response from litter and better understanding of target nutrient levels for soil;
    - that there could be good agronomic responses from litter and positive effects on soil carbon and structure - highly valued having some scientific data on pasture and crop responses;
    - better understanding of safe storage and handling, methods of spreading litter and application rates;
    - risks of heavy metal contamination in soil and pathogen issues were low; and
    - litter could be at least as economic as conventional fertilisers.

  Participants indicated that they would like further information on:
    - longer term impacts on pastures, soil carbon and total cations – and hoped existing trials continued;
    - more trials on litter to demonstrate responses compared to inorganic fertiliser, covering a wider range of soils and pasture types;
    - likely nitrogen losses from broadcast litter and how to reduce N losses; and
    - how to get litter cheaper.

  Several local, broad-acre livestock producers have gone on to establish their own on-farm trials to evaluate the cost/benefits of subsoil manuring using chicken litter.

Implications

Grazing industries (Wool, lamb and beef)
Chicken litter contains a range of valuable nutrients for pasture production and can be a cheaper alternative than conventional fertiliser. There was no additional pasture yield response to litter over and above that of the conventional fertilisers after four years of applications. In the short-term, increases in soil carbon and cations, from application of high rates of litter, did not translate into additional yield but may do so in the long term. Hence, the cost-effectiveness of litter will depend on the composition of the litter, what nutrients the soils require, and the price of litter relative to inorganic fertilisers. This work relates to single batch litter, but multi batch litter may have higher nutrient levels and may be cheaper on a $/kg nutrient basis. High rates of litter can also be used to improve poor soils and degraded pastures. There is an opportunity for producers located close to meat chicken farms to access litter as an alternative fertiliser.

Changes in soil carbon, from applying high rates of chicken litter, could provide opportunities for generating carbon credits if future Government Emission Reduction schemes (carbon trading/tax) include soil storage of carbon.

Chicken Meat industry
The grazing industries are an important outlet for used litter from meat chicken sheds. There may be opportunities to increase returns from litter, but the litter will still need to be competitively priced relative to conventional fertilisers. In addition to the nutrient value in litter, the value of carbon sequestration, from application of high rates of litter, could be worth a further \$3.20 - \$5.20/m^3 (at least) on the price of litter, based on a carbon price of \$15.00 -24.15/t.

Increased demand for litter will mean litter may be transported direct from the chicken shed to broad-acre farm. This will reduce the need for double handling/carting litter to and from stockpiles and could reduce costs for contractors who supply litter.

Forecast growth of the chicken meat industry may result in increased volumes of used litter which could have waste management and environmental ramifications. Increasing the demand of used litter by the grazing industries is a positive solution to achieve effective utilisation of the increasing volumes of litter.

Communities
Greater demand for used litter from meat chicken farms will reduce environmental impacts associated with stockpiling litter.

Changes in soil carbon, from applying high rates of chicken litter, could provide opportunities for generating carbon credits if future Government Emission Reduction schemes (carbon trading/tax) include soil storage of carbon.

Recommendations

There is a need for a continued extension effort to promote the benefits of chicken litter to broad-acre livestock producers, and to provide information and tools so they can utilise litter effectively on their farms. This will be important as the chicken meat industry grows and the amount of used litter increases.

In this respect, it is noted that:

- Findings from this research will be published, by RIRDC, in a practical guide to using chicken litter targeting producers in the grazing and cropping industries.
- The Mackinnon Project (The University of Melbourne) will continue to extend these research findings and promote the use of chicken litter as an alternative fertiliser, where appropriate, to sheep and cattle producers in south-eastern Australia, particularly those who are located in close proximity to the meat chicken farms.
- The Mackinnon Project, with support from the Goulburn Broken Catchment Management Authority, delivered producer workshops in 2014.
- In collaboration with the Mackinnon Project, two sites were established in 2013 by the Yarram yarram Landcare Network to demonstrate the use of chicken litter as an alternative fertiliser pasture for sheep and beef producers in east Gippsland and several field days were conducted in 2013 and 2014.
- The Euroa Bestwool /Bestlamb group established their own on-farm trial to evaluate the cost-benefits of sub soil manuring using chicken litter, after attending the Nagambie Seminar in 2012.
- Research results also need to be disseminated to Departments of Primary Industries, Catchment Management Authorities and Landcare groups who are interested in soil health and soil carbon aspects of using alternative fertiliser products that contain organic matter.

There is also a need to study the long-term impacts of regular applications of high rates of chicken litter on pastures and the impact on soil parameters such as total organic carbon and total cations. These soil properties affect nutrient retention, while carbon also affects the water holding capacity of soils. A preliminary attempt to value the organic matter and carbon in litter has been made in this report but this benefit could be higher in the long- term. With this in mind, and with the assistance from the Goulburn Broken Catchment Management Authority, the Glenaroua research site was retained and pasture assessments and limited soil sampling continued through 2013. The Pastoria site received no further inputs of fertiliser or litter in 2013 but could be started up again if funding is obtained.

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By Lisa Warn

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RURAL INDUSTRIES
Research & Development Corporation

Phone: 02 6271 4100

Fax: 02 6271 4199

Bookshop: 1300 634 313

Email: rirdc@rirdc.gov.au

Postal Address: PO Box 4776,
Kingston ACT 2604

Street Address: Level 2, 15 National Circuit,
Barton ACT 2600

www.rirdc.gov.au