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Action on the Ground

YARRAM YARRAM LANDCARE NETWORK

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Gippsland Plains Soil Carbon Trials
- **productivity and climate change responses**

Technical Report

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Contents

Summary

A producer research/demonstration project was conducted on 14 properties in the Gippsland Plains region of Victoria to demonstrate and evaluate the effectiveness of different on-farm practices to increase the sequestration of carbon in soils. On-farm practices trialled included the use of drought tolerant perennial pastures, improved management of fertilisers, application of high rates of organic material (compost, chicken litter) and improved grazing/rotational management practices.

Paddocks sown to drought tolerant pastures (in 2009), and which received improved fertiliser management, had slightly higher carbon stocks of 7 t/ha compared with Control paddocks in 2014, but this difference was not significant. At the initial assessment in 2012, average soil carbon stocks (0-30cm) across the 14 properties were 85 t/ha in the Control paddocks and 91t/ha in the improved perennial pasture paddocks. In 2012, carbon levels in the Control paddocks ranged from 2% to 5% in the topsoil, as many paddocks already had high levels of carbon from being under pasture for many years. In 2012, carbon levels in the improved pasture paddocks ranged from 3% to 6% in the topsoil. In 2014, average soil carbon stocks (0-30cm), across the 14 properties were 86.5 t/ha in the Control paddocks and 93.4t/ha in the improved perennial pasture paddocks, similar to the 2012 stocks. In 2014, carbon levels (%) in Control paddocks and improved pasture paddocks were similar to what was measured in 2012.

The addition of these high rates of organic material did not increase soil carbon stocks over the short duration of this project (2-3 years). As it takes a long time to build soil carbon, these high rates of organic material may need to be applied for up to 10 years to have an impact. In addition, the cost to purchase and apply these materials is quite high and would be a barrier to widespread adoption. The cost of the compost application in this study (total of 26 t/ha over 2 years) was around $450/ha per year, while the cost of the chicken litter (total of 14 t/ha over 2 years) was around $660/ha per year. These materials also supply other nutrients (N, P, K and S), but the cost of the high rates applied in order to increase soil carbon, was not recouped by the additional pasture/livestock production. Hence, producers would require an adequate price for the carbon sequestered to make application of high rates of organic material an economically feasible proposition.

The main response from the chicken litter was due to the nitrogen it contained. No pasture response was detected from the compost. In situations where all other nutrients are adequate and only N is limiting, it would be cheaper to apply an N fertiliser (urea) rather than chicken litter or compost to boost pasture production, with current prices. Where a range of nutrients is required, chicken litter used at maintenance rates can be a viable alternative to inorganic fertiliser. However securing a reliable supply of litter for farmers in this part of Gippsland is an issue as they are competing with the vegetable growers and dairy farmers in South Gippsland who use large quantities. The compost is readily available in the local area. However the compost did not appear to have any benefit in the short-term compared with the chicken litter and was a more expensive source of nutrients.

These findings highlight the difficulty of rapidly increasing soil carbon stocks in soils that have previously been managed as pasture paddocks with some inputs of inorganic P,K,S fertiliser, as many of these soils had a moderate soil carbon level to start with.

Introduction

The Carbon Farming Initiative (CFI) is a voluntary scheme that allows farmers and land managers to earn carbon credits by storing carbon or reducing greenhouse gas emissions on the land (Dept. Environment 2015). These credits can then be sold to people and businesses wishing to offset their emissions. The CFI methodology for “Sequestering carbon in soils in grazing systems” could benefit farmers and landholders in Australia who want to increase carbon stocks in their soils (Dept. Environment 2015).

The Emissions Reduction Fund (ERF) was established in 2014 after the repeal of the Carbon Tax and amendments to the Carbon Credits (Carbon Farming Initiative) Act of 2011. The ERF will build on the CFI. The primary objective of the ERF is to help Australia meet its international obligations under the United Nations Framework Convention on Climate Change and the Kyoto Protocol, to reduce emissions of greenhouse gases and meet its emissions reduction target of five per cent below 2000 levels by 2020. Under the ERF, businesses, local governments, community organisations and individuals can undertake approved emissions reduction projects and seek funding from the Government for those projects through a reverse auction or other purchasing process.

Under the CFI, landholders will have a choice of which land management activities to implement to build soil carbon. Activities must include at least one new management activity. Types of activities that could potentially be implemented include rejuvenating pastures or changing grazing patterns (Dept. Environment 2015).

Since site specific factors such as soil type, climate and management history all influence the potential for soil carbon sequestration, there is a level of uncertainty as to whether changes to management will build soil carbon at any particular site. Local information is required for landholders to be confident they can derive benefits from changing management.

The Low Carbon Growth Plan (LCGP) for Gippsland (ClimateWorks Australia, 2011) has identified the potential to increase soil carbon in Gippsland’s pastures and grasslands by 52,700 tonnes per year, by increasing the use of deep rooted perennial grass species, increasing fertiliser use and improving grazing management. Restoring the productivity of less productive pastures and grasslands could increase soil carbon in Gippsland by 18,000 tonnes per year.

Over the last seven years, Yarram Yarram Landcare Network (YYLN) has formed strong partnerships with local landholders, the Mackinnon Project (The University of Melbourne), the Department of Economic Development, Jobs, Transport and Resources, the West Gippsland Catchment Management Authority (WGCMA), EverGraze, Evergreen (WA), Saltland Knowledge Exchange (SA), Perennial Pasture Systems (PPS) and the Grassland Society of Southern Australia Inc. to develop and deliver the Gippsland Plains Drought Tolerant Pasture Demonstrations (GPDTPD). This is a landscape-scale sustainable farming project involving fourteen farmers who have established trials to demonstrate the use of drought tolerant perennial pasture species and improved grazing management practices to increase productivity and soil health.

The GPDTPD was a finalist in the 2011 State Landcare Awards and has achieved significant outcomes including: more than 500 hectares sown to new perennial pasture systems (from 2009-2011) which included species such as lucerne, cocksfoot, phalaris, fescue and kikuyu. These pastures have demonstrated observable and recorded changes in improved growth, persistence of species and increased ground cover/litter (Monks and Warn 2011). There is limited data available to show the impact that well managed perennial pastures might have on soil carbon stocks compared to annual or rundown perennial pastures in this environment. These demonstration sites provided an ideal opportunity to monitor changes in soil carbon stocks. This data is required if pasture improvement is to be promoted as a way to sequester more carbon.

Addition of organic material to soils is often promoted as a method to increase soil carbon as well as providing some nutrients. Rising costs of conventional fertilisers has led broad-acre livestock farmers (wool, lamb, beef) to seek alternative nutrient sources to fertilise pastures and crops. Spent litter from meat chicken farms, or compost from large scale recycling facilities, are viable alternatives particularly when key inputs like phosphorus fertiliser prices are very high or where a range of macro nutrients and trace elements are required.

Research has compared crop and soil responses to organic material (eg. farmyard manure) and 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. Craddock (2012) investigated the value of chicken litter in broad-acre cropping in South Australia. That study highlighted the need for some conventional starter fertilisers (MAP or DAP- mono or di-ammonium sulphate - at sowing) to be used in conjunction with chicken litter to achieve similar crop yields to using conventional fertiliser alone. Warn (2014) investigated the value of broadcasting chicken litter onto pastures in central Victoria. That research showed that if litter was applied at appropriate rates, which supplied similar levels of nutrients to inorganic fertiliser, similar pastures responses could be obtained. Warn (2014) also showed that over a four year period, increases in soil carbon could be obtained where large quantities (5t/ha per year) of litter were applied to pastures. In light of the information above, this project was established to evaluate if application of large quantities of organic material could have a positive effect on soil carbon in the sandy coastal soils of the Gippsland Plains using locally available products.

Objectives

The primary objectives of this project were to trial several farm practices to evaluate their impact on the sequestration of carbon in soils. Practices that were evaluated were the use of drought tolerant perennial pastures, improved fertiliser usage, application of recycled organic materials and improved grazing/rotational management on fourteen participating properties in the Gippsland Plains region of Victoria.

Building on the success of the GPDTPD, this project intended to:

1. Maintain and monitor the perennial pasture trials established as part of the GPDTPD project;
2. Establish 3 new trial sites to test application of organic materials to increase soil carbon;

3. Measure soil carbon levels, organic carbon (+ other nutrients), pasture composition and persistence as a result of these trials;
4. Assess the effectiveness of the trialled methodologies in increasing soil carbon; and
5. Increase community understanding about ways to increase soil carbon.

Methodology

Project location

The fourteen farms in the project were located in an area stretching from Woodside to Stradbroke on the central Gippsland coastal plains of Victoria (Figure 1). The long-term average annual rainfall in the area is around 600mm (Bureau of Meteorology, 2015) with a uniform distribution pattern throughout the year. The climate is temperate. At nearby Sale, the long term average February temperatures range from 13 -25 ^{0}C and July temperatures range from 3-14 ^{0}C (Bureau of Meteorology, 2015). The soils in the area were mainly sandy loams and loams with some clay loams along drainage lines in paddocks.

Perennial pasture sites

Perennial pastures, established by the farmers in 2009 as part of a previous project (GPDTPD), were selected for monitoring (Table 1). One 'Sown' perennial pasture paddock was compared with an adjoining 'Control' paddock on each farm. The Control paddock was either an annual pasture or a rundown perennial pasture, which had been monitored since 2009, and was on a similar soil type and position in the landscape. Both the Sown pasture paddock and the Control paddock had been monitored since 2009 for pasture composition, pasture persistence and stocking rates. The paired paddocks on each farm were soil tested regularly and appropriate fertiliser inputs were recommended. The initial organic carbon levels (%C) in the topsoil for 2008, for both paddocks on each farm, are shown in Table 1.

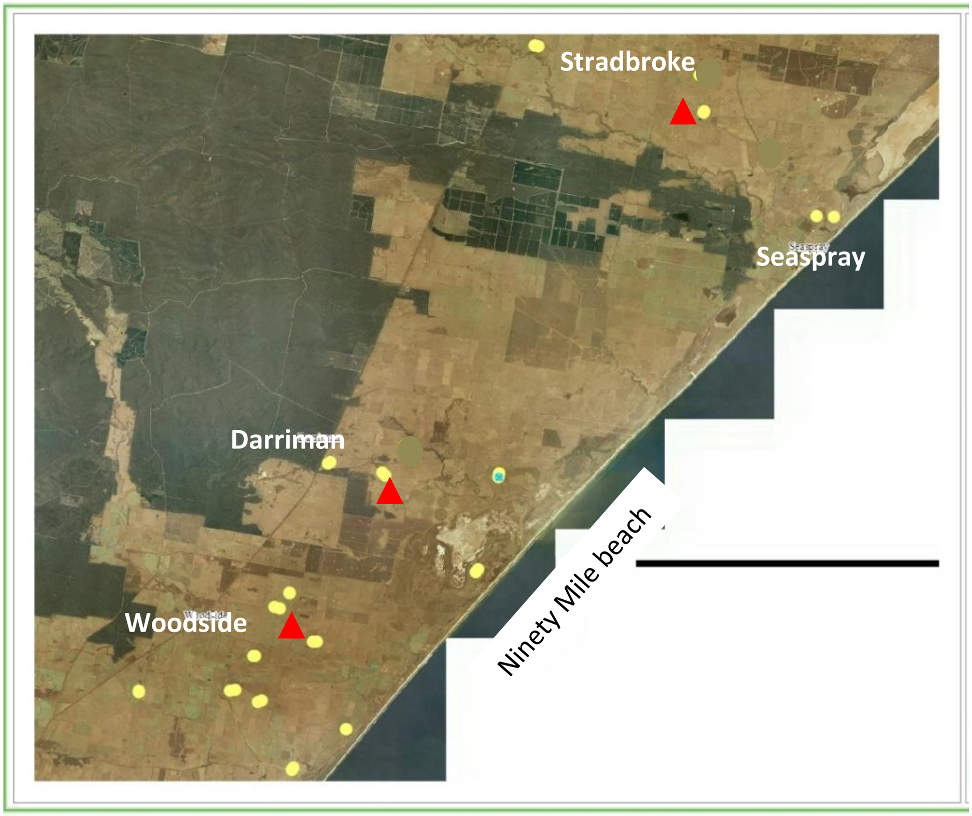

Figure 1. Yellow dots indicate the location of the 14 perennial pasture demonstration sites that were monitored from 2009 to 2011 as part of the GPDTPD, and from which soil samples were collected for carbon content in 2012 and 2014. Red triangles indicate the location of the 3 carbon trial sites.

Table 1. Characteristics of the fourteen Gippsland plains farms participating in this project.

Farm Number	Location	Enterprise	Soil type	'Control 'paddock species present	'Control' % C 2008	'Sown' paddock species sown[A]	'Sown' % C 2008
1	Darriman[B]	sheep, beef cattle	loam	annual grasses, sorrel, sub clover	3.8	Fescue,sub clover	2.4
2	Woodside	sheep	sandy loam	annual grasses, sorrel, sub clover	3.3	Cocksfoot,PRG, sub clover	3.6
3	Woodside	sheep, beef cattle	loam	PRG/cocksfoot (sown 2005)	3.9	Fescue,lucerne	3.4
4	Woodside[B]	sheep	sandy loam	silver grass. sorrel, flatweed	3.6	Kikuyu,cocksfoot, sub clover	3.9
5	Woodside	sheep, beef cattle	clay loam	PRG, phalaris, sub clover	5.1	Fescue,strawb. clover (saline)	6.5
6	Stradbroke[B]	sheep	loam	annual grasses, PRG, sub clover	2.6	Cocksfoot,PRG, sub clover	2.3
7	Woodside	sheep, beef cattle	loam	annual grasses, PRG, sub clover	3.1	Cocksfoot,lucerne	2.5
8	Stradbroke	beef cattle	loam	annual grasses, PRG, sub clover	2.5	Cocksfoot, PRG, sub clover	2.5
9	Woodside	beef cattle	loam	Cocksfoot,PRG (sown 2004)	4.2	Cocksfoot,lucerne	3.9
10	Woodside	sheep, cattle	loam	PRG,sub clover (old)	4.3	Cocksfoot, fescue,sub clover	3.4
11	Woodside	beef cattle	loam	PRG,sub clover (old)	3.6	Cocksfoot,lucerne	3.9
12	Woodside	beef cattle	loam & s.c.loam	PRG,sub clover (old)	4.1	Fescue, clovers (some salt patches)	7.5
13	Seaspray	beef cattle	clay loam	Kikuyu,annual grasses	7.9	Fescue,strawb. clover (saline)	7.9
14	Woodside	beef cattle	loam	Cocksfoot,fescue sub clover (sown 2005)	3.7	Cocksfoot,fescue, sub clover	4.1

[A] PRG stands for perennial ryegrass; [B] This farm also hosted a soil carbon trial

Soil carbon trials

In 2013, three of the GPDTPD farms were selected for the establishment of additional demonstrations to investigate the impact of application of high rates of recycled, organic wastes on soil carbon stocks (Figure 1). One farm used compost, made from food and green waste, which was obtained from a local waste recycling facility, "Dutson Downs", near Sale. The other two farms used chicken litter sourced from meat chicken sheds in the south Gippsland area. The chicken litter and compost treated paddocks were compared with a 'Control' paddock that received conventional, inorganic fertiliser inputs.

The farm trialling compost (at Stradbroke) and one farm trialling chicken litter (at Darriman) were chosen based on previous soil tests (taken as part of the GDTPD) that indicated the paddocks had very low soil carbon contents (% C) in the topsoil. The Stradbroke farm used two adjoining old perennial ryegrass/cocksfoot paddocks (i.e. not sown as part of the GPDTPD) for this evaluation. The Darriman farm subdivided a recently sown lucerne/cocksfoot paddock (sown 1/6/13 – i.e. not sown as part of the GPDTPD) to create the two paddocks needed for this trial. The third farm (at

Woodside), trialled chicken litter, and had higher initial soil carbon content (%C) than the other two farms. This farm made use of two adjoining paddocks both of which were sown in May 2011 to cocksfoot/sub clover (where only the treatment paddock was sown as part of the GPDTPD).

Treatments

Fresh (non-composted) chicken litter was used at the two chicken litter trial sites, which was sourced from near Labertouche in Gippsland. On all occasions, the litter was from a single batch of chickens. Upon delivery, the stockpile of litter was fenced off from stock prior to spreading on trial paddocks. The litter was spread using conventional fertiliser spreading equipment by local contractors. Grazing was delayed for at least a month after application, to reduce risk of stock picking up any pathogens. The compost was sourced from "Dutson Downs" and would have contained green waste and food wastes mainly from the dairy industry. Grazing was delayed for a few weeks after application to allow compost to move down into soil.

Each batch of litter and compost was analysed for composition to allow an appropriate application rate of carbon to be determined. The aim was to apply similar amounts of carbon to each of the 3 treatment paddocks, not necessarily a similar amount of the macronutrients. The products were applied at very high rates – far above those required to supply the maintenance rates of nutrients that are typically applied as granular, inorganic fertiliser. The litter and compost were applied around the time of the autumn break each year, when there was some green pasture and soil moisture present. Due to the large quantities of compost required, it had to be applied as split applications, so was applied again in spring.

A sample of each batch of litter and compost was taken by the farmer and sent to Farmright Technical Services, Kyabram, for analysis. After the litter or compost was dumped on site, ten samples were taken from different parts of the pile with a shovel and put into a bucket and mixed thoroughly. From the bucket, a 1kg sub-sample was collected, put into plastic bag (double bagged) and sent for analysis. The 2015 samples were processed at Incitec Pivot's laboratory at Werribee due to the closure of the Farmright lab. The samples were analysed for pH, EC (salt), dry matter, organic matter, C, N, P, K, S, Na, Ca, Mg, and trace elements.

The range in composition of the batches of litter or compost applied to the three farms is shown in Table 2. Carbon and nutrient content varied from batch to batch. The compost had much lower content of carbon and nutrients than the chicken litter on a dry weight basis. Dry matter (%) and the carbon to nitrogen ratios of both products were similar.

Table 2. Variation in composition of litter and compost from batches applied to farms in 2013, 2014 and 2015

Analysis	Units	Chicken litter	Compost
pH (1:5 water)		6.5 – 7.4	6.4 – 8.0
pH ($CaC1_2$)		6.3 – 7.0	6.1 - 6.9
Salinity (EC) (1:5 water)	dS/m	8.0 -12.5	2.0 – 4.0
Organic Matter	mg/kg	65.0 – 73.2	16.0 – 29.9
Total Carbon	%	38 - 43	9 - 17
Carbon / Nitrogen ratio		10-15 to 1	11-15 to 1
Dry Matter	%	75 - 79	74 - 80
<u>TOTAL NUTRIENTS *</u>			
Total Nitrogen	%	2.5 - 4.1	0.9 - 1.5
Phosphorus	%	1.0 – 1.4	0.3 – 0.4
Potassium	%	1.5 – 2.4	0.4 – 0.8
Sulphur	%	0.4 – 0.6	0.2 – 0.5
Calcium	%	1.4 -2.3	0.9 – 2.2
Magnesium	%	0.4 -0.6	0.2 – 0.4
Sodium	%	0.3 -0.5	0.14 -0.2
Chloride	%	0.4 - 0.7	0.2 - 0.3
Copper	mg/kg	96.0 -125.2	36.9 – 69.0
Zinc	mg/kg	220 -361	128 – 252
Manganese	mg/kg	310 – 547	142 – 275
Boron	mg/kg	25.0 – 43.0	10.8 – 27.0
Iron	mg/kg	1276- 3350	7830 - 12302
Molybdenum	mg/kg	5.3 – 8.3	1.3 – 2.7
Cobalt	mg/kg	1.2 -2.0	4.3

** Total nutrients reported on a dry weight basis*

The application rate of each product for each site was adjusted based on the carbon content of each batch and is shown in Table 3. Litter was applied in autumn each year and the compost was applied as a split application in autumn and spring due to the large quantities that were required. The first application of litter at Darriman was delayed until 14th September (2013) to allow the new pasture (sown on 1st June) time to establish.

Table 3. Product application rates and total amount of nutrient applied over the two years.

Site	2013 t/ha	2014 t/ha	Total product applied t/ha	Carbon applied t C/ha	Nitrogen applied kg/ha	Phosphorus applied kg/ha	Potassium applied kg/ha	Sulphur applied kg/ha
Darriman - litter	5	9	14	4	350	112	224	56
Woodside - litter	9	5	14	4	350	112	224	56
Stradbroke- compost *	11	15	26	3	234	78	104	78

**compost application split over autumn and spring*

The amount of carbon and macronutrients applied in a tonne (wet weight) of each product is shown in Table 4. A comparison is made with single superphosphate which is the conventional fertiliser used to supply phosphorus and sulphur.

Table 4. Amount of macro nutrients applied per tonne of compost and chicken litter (wet weight), and compared with a tonne of single superphosphate.

Product	C kg	N kg	P kg	K kg	S kg
Chicken litter (78% DM)	320	25	8	16	4
Compost (79% DM)	100	9	3	4	3
Single superphosphate	-	-	90	-	110

Value of nutrients and carbon in organic material

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

The organic matter (organic carbon) in litter and compost has an inherent value but is difficult to assign an economic value to it. The method described by Warn (2014) can be used to value the carbon in litter and compost, in addition to the value of the nutrients. In this way any additional carbon (t/ha, or Mg/ha) measured under litter or compost paddocks, relative to the other treatments, can be assigned a dollar value.

This method (Warn 2014) made use of carbon prices determined under the Compliance market mechanisms that were in use up until February 2015. In the compliance market, businesses could 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 was $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 has been developed which will build on the CFI and includes an emission reduction fund (Clean Energy Regulator, 2014).

Although storage of soil carbon is not included in any of the schemes at present, the prices of $15.00 and $24.15 for a CO_2e can be used to value the carbon in litter and compost. Any additional carbon stored in the soil (i.e. greater than that in the Control paddocks) can be multiplied by 3.67, to convert carbon to CO_2e and then multiplied by the carbon price of $15.00 or $24.15. The methodology suggested here can be used to value the carbon in litter or compost regardless of what carbon pricing mechanism is in operation in the future.

Soil nutrient analysis

Perennial pasture sites

Topsoil (0-10cm) samples were taken from each paddock in 2008 prior to pasture establishment in 2009 and then in spring every second year to assist producers with fertiliser recommendations. Thirty soil samples per paddock were taken along a transect, using a soil sampler with a 10 cm depth sampling tip, and were combined to form the sample submitted to the laboratory. Samples were sent to Farmright Technical Services, Kyabram, Vic. Analyses undertaken included: macro nutrients (Olsen P, Colwell K, KCl40 S, nitrate, ammonium), trace elements (Cu, Zn, Fe, Mn, Bo), pH (water and $CaCl_2$), electrical conductivity, total organic carbon (Leco) and exchangeable cations (Ca, Mg, K, Na).

Soil carbon trials

Topsoil (0-10cm) samples were taken from each paddock prior to the application of treatments in 2013 and then in spring each year. The same sampling procedure was undertaken and same analysis performed as used for the perennial pasture sites.

Soil carbon stocks

Soil samples were taken from each perennial pasture site (Control and Sown paddocks) in November of 2012 and 2014. These samples were collected for analysis of total organic carbon and calculation of carbon stocks (t C/ha) in the soil down to 30 cm according to the national Soil Carbon Research Programme (SCaRP; Sanderman *et al.,* 2011) methodology. Samples were collected with a Christie Hydraulic Soil Sampler using a 25m x 25m grid with 5m intersects and then randomly selecting 10 intersects at which to take the samples. The 10 cores were divided into 0-10cm, 10-20cm and 20-30cm sections, bulked together to form three depth stratified samples per site. Topsoil (0-10 cm) and subsoil (10-30cm) samples were also taken from the three carbon trial paddocks (Control and Treatment) in November of 2012 and 2014 using a different sampling method. Ten cores were taken randomly along a transect in the paddock. Each sample was kept separate and analysed separately to allow calculation of average soil carbon stocks and a standard deviation. The 10 cores were divided into 0-10cm and 10-30cm sections.

The soil samples were sent to the Department of Economic Development, Jobs, Transport and Resources laboratory at Macleod where total organic carbon (Leco) and bulk density (g/cm^3) were measured.

The position where samples were taken from was recorded with a GPS so that a similar position could be sampled in 2014 to that sampled in 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 SCaRP programme (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) was multiplied by soil bulk density for each soil depth to derive figures for tonnes carbon per ha (metric t C/ha or Mg/ha).

Pasture measurements

Perennial pasture persistence

All pastures sown during the GPDTPD project already had permanent quadrats pegged out (9 per paddock) for monitoring perennial pasture persistence. Permanent quadrats were also pegged out soon after the pasture was sown in the new Carbon Trial paddocks (Treatment and Control) at the Darriman site. The point quadrat method (Cayley and Bird 1996) was used to monitor basal cover of the sown perennial species after the autumn break each year. A 1m x 1m weld-mesh grid, with 10cm squares was placed over the pegs and the number of perennial grass tiller bases that are found under each grid intersect is recorded. The basal cover score is out of a maximum of 81.

Botanical composition and ground cover

Botanical composition was visually estimated in perennial pasture paddocks and carbon trial paddocks, after the autumn break each year, using the percent ground cover method (Prograze, 2002). The proportion of green and dead herbage present and the ground cover (%) was also assessed. Assessments were made in two 30cm x 30cm squares within the area covered by the 1m x 1m permanent quadrat. In the compost trial paddocks botanical composition and ground cover were assessed using a 25cm x 25cm quadrat thrown 20 times at random on a transect across the paddocks.

Pasture production

The three producers with the carbon trials recorded grazing days and the amount, if any, of hay/silage cut from their Control and Carbon Treatment paddocks during the project. As producers were rotationally grazing their paddocks, details of stock (class, numbers) and dates moved in/out of paddocks was used to calculate an average annual stocking rate in dry sheep equivalents per hectare (DSE/ha).

Statistical Analysis

Soil carbon content (t/ha) data for both the perennial pasture sites and the soil carbon trials were analysed using a paired t-test in the Analyse-it program. The carbon content of the soil samples collected at three depths from the 14 pairs of Control and Sown paddocks was compared for the perennial pasture sites.

The carbon content (t/ha) of the 10 pairs of individual soil samples taken at two depths in each Control and Carbon treatment paddock was compared for the carbon sequestration demonstrations.

Extension and communication

Numerous extension activities were conducted during the project to promote project findings and train producers to objectively compare the cost and benefits of alternative fertilisers like litter and compost against conventional inorganic fertilisers. The extension activities also addressed other concerns of producers regarding handling and application of these organic amendments. Farm walks and field days were held to improve the producers' knowledge of soil carbon.

Results

Soil carbon trials

Cost of organic materials and carbon

The chicken litter cost \$32/m^3 delivered to the farm and \$12/m^3 to spread, a total of \$44/m^3 applied to the paddock. There is around 2.2 m^3 per tonne of litter, so the cost per tonne is around \$97/ t. The compost was \$44/t delivered and spread. The total cost of the products applied over the 2 years, and the cost of the carbon applied is shown in Table 5.

Table 5. Cost of the products used

Product	Cost delivered & spread	Cost \$/t spread	Product applied 2013-14 t/ha	Total cost per site \$/ha	Cost of carbon applied per tonne per site \$/t
Chicken litter	\$ 32/m^3 + \$ 12/m^3	97	14	1358	340
Compost	\$ 44/t	44	26	1144	381

On an individual nutrient basis, the litter and compost were always more expensive than the conventional, inorganic fertilisers. However, where more than one nutrient is required litter or compost can start to become cost-effective. The litter would have to be approximately \$11/m^3 delivered (a third of the price), if spreading costs \$12/m^3, to supply a key nutrient like P at a similar cost to superphosphate (at \$400/t spread or \$4.50/kg P). In some districts, litter is closer to this price. The compost would have to approximately \$10/t spread (one quarter of the price) to supply P at the same cost as superphosphate.

Soil fertility

Changes in soil fertility (macro nutrients P,K,S), pH and organic carbon at the 3 carbon trials sites is shown in Table 6. The 2013 soils tests were conducted in April – prior to application of products. The 2014 tests were taken in November 2014. Allowing for the usual variation in results obtained when soil samples are taken at different times of the year, some trends are still evident. Soil test data for the 14 perennial pasture sites is not shown here, as the aim of the soil tests were to inform farmers about fertiliser requirements.

At the Darriman site, P and S levels were adequate in April 2013 but K was marginal in both paddocks. Maintenance rates of P fertiliser as single superphosphate (80 kg P/ha per year) as well as some potash (50 kg K/ha for 1 year) were recommended for the Control paddock. By 2014, the Control paddock had adequate levels of P and K but S was slightly below target levels. Compared with the Control paddock, the addition of the chicken litter caused a large rise in levels of P (by 10 units) and K (by 150 units) in the Treatment paddock and slight increase in organic carbon.

At the Woodside site, P and S levels were adequate in April 2013, and K was adequate in the Control but marginal in the Treatment paddock. Maintenance rates of P fertiliser as single superphosphate (80 kg P/ha) was recommended for the Control paddock. By 2014, the Control paddock still had adequate levels of P, K and S, but the P levels appeared to have dropped by 10 units (the extent of which could suggest a sampling error). Compared with the Control paddock, the addition of the litter caused a small rise in K levels and carbon % in the Treatment paddock. Phosphorus levels in the Treatment paddock rose slightly (by 3 units) compared to the autumn 2013 soil test.

At the Stradbroke site P and S levels were adequate in April 2013 but K was marginal in both paddocks, similar to the Darriman site. Maintenance rates of P fertiliser (80 kg P/ha as single superphosphate per year) with some potash (50 kg K/ha for 1 year) were recommended for the Control paddock. By 2014, the Control paddock had adequate levels of P and S but K was still below target levels. Unlike the chicken litter results, the addition of compost caused only small increases in P and K levels in the Treatment paddock from 2013 to 2014, and no increase in organic carbon compared with the Control.

Table 6. Changes in pH ($CaCl_2$), carbon and macro nutrient status in the topsoil (0-10cm) at the 3 carbon trial sites

Treatment	**pH ($CaCl_2$)**	**Carbon (%)**	**Olsen P (mg/kg)**	**Colwell K (mg/kg)**	**KCl-40 S (mg/kg)**
Darriman (loam)					
Control 2013	4.8	3.54	20.6	93.0	16.2
Control 2014	5.3	2.43	19.9	194.0	5.8
Chicken litter 2013	4.9	3.07	17.3	126.0	18.5
Chicken litter 2014	5.2	2.65	30.0	350.0	9.7
Woodside (sandy loam)					
Control 2013	4.4	5.11	21.8	192.0	18.1
Control 2014	4.3	3.11	10.5	142.0	10.1
Chicken litter 2013	4.3	5.41	17.4	137.0	17.3
Chicken litter 2014	4.4	3.96	20.9	156.0	5.7
Stradbroke (sandy loam)					
Control 2013	4.5	3.15	15.7	100.0	13.4
Control 2014	4.4	2.30	14.2	82.0	7.7
Compost 2013	4.4	3.82	25.6	136.0	13.1
Compost 2014	4.7	2.29	27.6	186.0	9.0
Target level/range	4.5 -		12-15	140-160	8-12

Pasture production

The chicken litter produced an obvious visual response in pasture growth at Darriman (Figure 3) and Woodside, which was evident in winter soon after the autumn application of litter. The increase in pasture growth was most likely due to a nitrogen response as all other macronutrients were not limiting at both sites (Table 6).

At Darriman, the two lucerne /cocksfoot pastures were sown on 1/6/13, so only 1 grazing was possible in 2013. However a large quantity of hay was cut from both paddocks in 2013. At Darriman, the pasture available (kg DM/ha) at June 2014 on the chicken litter paddock was up to double that of the Control paddock which was obvious at the field day held at that time. Both paddocks had had around 3 week rest periods since the previous grazing. The stock numbers (DSE/ha) carried on the chicken litter treated paddock was around 60% higher than the Control paddock in 2014 and 2015, and most importantly, additional carrying capacity was achieved through the winter. For the winter period 2014, the Control paddock carried 1.5 DSE/ha while the litter paddock carried 5.0 DSE/ha. The production records for the Darriman site are shown in Table 7.

At Woodside, the producer also noticed that their paddocks treated with chicken litter appeared to remain green a bit later in late spring/summer. Grazing records for the Woodside site were incomplete and are not presented here.

At Stradbroke, there was no obvious visual response in pasture growth to the application of the compost at any time during the year, compared to the Control paddock. Phosphorus and sulphur were not limiting on either paddock but potassium was low in in the Control paddock and marginal in the compost paddock before treatments were applied, so perhaps a K response could have been expected in the Compost paddock. Unlike the paddocks treated with chicken litter, there was no obvious N response from the compost. The producer observed that whenever sheep grazed the compost paddock throughout the year, they developed scours, unlike the sheep grazing the Control paddock. This is being investigated further with herbage analysis but internal parasites (worms) do not seem to be responsible. The production records for the Stradbroke site are shown in Table 7.

Table 7. Paddock production records for two of the soil carbon trial sites

Site	**DSE/ha 2013**	**DSE/ha 2014**	**DSE/ha 2015 (until May)**
Darriman (Lucerne/cocksfoot –sown 1/6/13)			
Control paddock	2.2 (1.3 t/ha DM cut)	12.1	6.3
Chicken litter paddock	1.8 (1.2 t/ha DM cut)	18.7	9.9
Stradbroke (perennial rye/cocksfoot/sub clover)			
Control paddock	7.2	10.9	4.2
Compost paddock	8.6	9.9	4.3

Pasture composition

In October 2014, there was no difference in the percentage of the sown species (lucerne and cocksfoot) in the pastures in the Control and Chicken litter paddocks at the Darriman site. Both pastures consisted of around 90% sown species with very little weed content or bare ground (Figure 2). However, the proportion of lucerne to cocksfoot appeared to be higher in the paddock where chicken litter was applied. At Woodside, there was a higher percentage of cocksfoot present, and a lower percentage of sub clover present, in the Chicken litter paddock compared with the Control. Reduction in sub clover could have been due the increased grass growth and not increasing the grazing pressure adequately. At Stradbroke, the two paddocks had different pasture compositions at the start of the trial, but had been sown down as one paddock and then sub-divided many years ago. The Control paddock had more sub clover and cocksfoot in 2013 than the Compost treated paddock, and this difference was still apparent in spring 2014. The farmer selected the poorer paddock to apply the compost to see if the pasture composition and productivity could be improved.

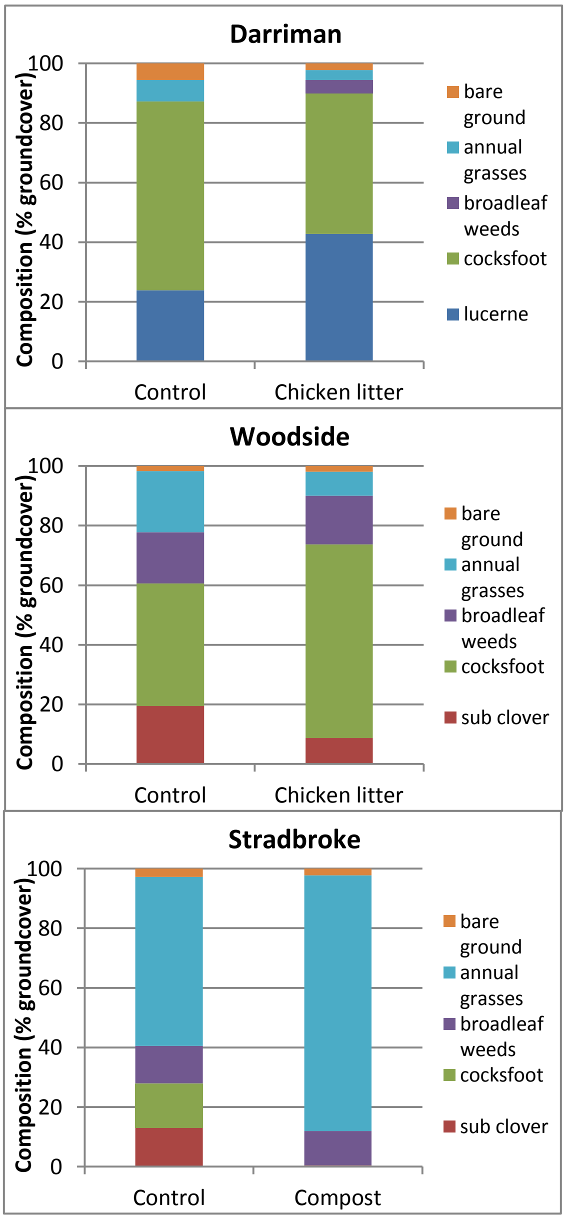

Figure 2. Pasture composition in Carbon trial paddocks in October 2014

Changes in soil carbon stocks

Perennial pasture sites

In November 2012, there were no significant differences (at $P<0.05$) in soil carbon between the Control paddocks and Sown perennial pasture paddocks at any of the three depths sampled (Table 8). The same result was obtained again in November 2014. Although the perennial pasture paddocks had around 6 t/ha and 7 t/ha of additional carbon in the 0-30 cm profile, in 2012 and 2014 respectively, this difference was not significant (at $P<0.05$). The carbon stocks in both paddocks appeared to be static.

Table 8. Carbon stocks in perennial pasture demonstration paddocks for each soil depth, in Nov 2012 and Nov 2014. Data is the average of 14 paddocks.

	2012				2014			
				Total Stocks				Total Stocks
Paddock	**0-10**	**10-20**	**20-30**	**0-30**	**0-10**	**10-20**	**20-30**	**0-30**
	t /ha	**t /ha**	**t /ha**	**t /ha**	**t /ha**	**t /ha**	**t /ha**	**t /ha**
Control	46.2	22.7	15.4	**84.3**	48.1	22.4	16.0	**86.5**
Sown	47.5	26.4	16.7	**90.8**	49.4	26.6	16.8	**92.9**
P <0.05	ns	ns	ns	**ns**	ns	ns	ns	**ns**

Soil carbon trials

In November 2012, prior to application of organic materials, there were no significant differences (at $P<0.05$) in soil carbon between the Control paddocks and Treatment paddocks at Darriman and Stradbroke (Tables 9 and 11).

In November 2012, at Woodside, topsoil carbon stocks were similar for both paddocks but the Control paddock had significantly ($P<0.05$) higher stocks of carbon at the 10-30cm depth (Table 10). Organic carbon (%) in the 10-30 cm soil depth was very high (average of 3.1 % but ranged from 1.2 - 4.7 % C) in the Control paddock at Woodside, suggesting that part of the paddock sampled may have been an old swamp/drainage line. The average organic carbon (%) in the 10-30cm depth for the Treatment paddock was 1.82 % (ranging from 0.9 to 3.3 %C) which is more typical of carbon levels found in subsoils.

At Darriman, the soil carbon stocks in the profile appeared to remain static for both the Control and chicken litter paddocks from 2012 to 2014 (Table 9). The application of 14 t/ha of chicken litter (4t/ha of carbon) did not increase soil carbon stocks in this short period.

At Woodside, the soil carbon stocks in the profile appeared to remain static for the Treatment paddock from 2012 to 2014 (Table 10). Application of 14t/ha of chicken litter (4t/ha of carbon) did not increase soil carbon stocks in this short period, similar to the observations at the Darriman site. The carbon stocks in the Control paddock appeared to have dropped dramatically between 2012 and 2014, which is most likely due to paddock variability. The Control paddock had highly variable carbon levels in the subsoil when tested in 2012, so a slight change in sampling position could have produced this result in 2014, even though the sampling sites were located by GPS each time. The average organic carbon % in the 10-30cm depth in the Control paddock was only 1.1 % (and ranged from 0.6 to 2.6) in 2014 compared with the average of 3.1%C (range 1.2-4.7 %C) in 2012. The average organic carbon % in the 10-30cm depth in the Treatment paddock was 2.3 (and ranged from 0.9-3.3 % C) in 2014, similar to the average and the variation measured in 2012. The average percent organic carbon in the 0-10 cm depth for the Control paddock was 6.6% in 2012 and only 4.5% in 2014, which reduced the t C/ha calculated in 2014. The average organic carbon in the 0-10cm depth for the Treatment paddock was 6.1% in 2012 and 6.3% in 2014. So although the statistical analysis in 2014 indicated that there had been a significant ($P<0.05$) increase in soil carbon stocks in the 0-30 cm profile at Woodside by 34t/ha compared with the Control paddock, this comparison should be viewed with caution based on possible sampling variation in the Control paddock.

At Stradbroke, the soil carbon stocks in the profile appeared to remain static for both the Control and Compost paddocks from 2012 to 2014 (Table 11). Application of 26 t/ha of compost (3t/ha of carbon) did not significantly ($P<0.05$) increase soil carbon stocks over the two years.

Table 9. Carbon stocks in Carbon trial paddocks for each soil depth, in Nov 2012 and Nov 2014 at Darriman. Data shown is the average of 10 individual cores.

	2012			**2014**		
			Total Stocks			**Total Stocks**
Paddock	**0-10**	**10-30**	**0-30**	**0-10**	**10-30**	**0-30**
	t /ha	**t /ha**	**t /ha**	**t /ha**	**t /ha**	**t /ha**
Control	44.14	33.43	**77.57**	43.28	31.45	**74.73**
Chicken litter	42.21	32.26	**74.47**	39.80	32.68	**72.48**
P <0.05	ns	ns	**ns**	ns	ns	**ns**

Table 10. Carbon stocks in Carbon trial paddocks for each soil depth, in Nov 2012 and Nov 2014 at Woodside. Data shown is the average of 10 individual cores.

Paddock	2012			2014		
			Total Stocks			Total Stocks
	0-10 t /ha	10-30 t /ha	0-30 t /ha	0-10 t /ha	10-30 t /ha	0-30 t /ha
Control	65.54	75.91	**141.45**	46.77	33.46	**80.23**
Chicken litter	64.12	53.17	**117.29**	64.17	50.20	**114.37**
P≤0.05	ns	0.03	**0.04**	0.0001	0.05	**0.05**

Table 11. Carbon stocks in Carbon trial paddocks for each soil depth, in Nov 2012 and Nov 2014 at Stradbroke. Data shown is the average of 10 individual cores.

Paddock	2012			2014		
			Total C Stocks			Total C Stocks
	0-10 t /ha	10-30 t /ha	0-30 t /ha	0-10 t /ha	10-30 t /ha	0-30 t /ha
Control	36.04	31.77	**67.81**	31.42	34.78	**66.20**
Compost	34.61	33.88	**68.49**	34.12	31.58	**65.71**
P <0.05	ns	ns	**ns**	ns	ns	**ns**

Extension and communication

A summary of extension activities and communication conducted to promote the results of the trials, and general information on soil carbon and impact of management practices may have on building carbon stocks, is shown in Table 12 (also see Figure 3). Field day handouts were also produced.

Table 12. Extension activities and other communications delivered

Date	Activity	Number of people attended
July 2012	**Project Launch & Workshop –** Mapping project sites	19
June 2013	**Field day** at the Stradbroke site: "Soils, Carbon & Compost - using compost to increase soil carbon".	40
August 2013	**Field day** at Woodside chicken litter trial site - GPDTPD/Lismore Landcare Groups	35
November 2013	**Group Tour** to Dutson Downs Farm, Gippsland Water Soil Organic Recycling Facility (SORF) Dutson.	15
December 2013	**Presentation Night** for Landcare groups at Seaspray - GPDTPD pasture persistence data and soil test results/fertiliser needs and update on Carbon trials.	30
June 2014	**Field day** at Darriman and Woodside trial sites. Field day publication produced: "Using chicken litter to increase soil carbon".	25
November 2014	**Workshop** – Understanding how soils affect your production, Narkoojee, Glengarry	24
May 2015	**Study Tour** to Ararat & Western Victoria for project participants – perennial pasture and carbon sequestration focus.	25

Figure 3. Carbon trial field day at Darriman on 19th June 2014. The Control paddock is on the left and the chicken litter treated paddock on the right, highlighting the response in pasture growth most likely due to a nitrogen response. Litter was applied on 30th May. Both paddocks had been rested for 3 weeks.

Discussion

The establishment of drought tolerant pastures (sown in 2009) and the associated improved fertiliser management resulted in a small but insignificant response in carbon stocks (7 t/ha) compared with Control paddocks in 2014. These soils all had moderate to high levels of carbon from being under pasture for many years, which could explain why little change was detected.

Addition of high rates of organic matter in the short period of this project (2-3 years) did not change either soil carbon contents in the topsoil or soil carbon stocks. It has been shown that it takes a long time to build soil carbon from a low level of 35 t/ha (Chan *et al.* 2010). In these Gippsland soils with relatively high carbon stocks (60 to 100 t/ha) the high rates of organic material may need to be continued for well in excess of the 12 years recorded elsewhere to have a measurable impact. Further short-term fluctuations in soil carbon levels mean that to accurately quantify changes in soil carbon, measurements over a number of years are required (Chan *et al.* 2010).

The cost of the materials and of application is quite high and would be a barrier to widespread adoption of this management option. The cost of the high rate of compost application used (total of 26 t/ha over 2 years) was around $450/ha per year, while the cost of the high rate of chicken litter (total of 14 t/ha over 2 years) was around $660/ha per year. These materials also supply nutrients, but the cost of the high rates applied in order to increase soil carbon, was not recouped by the additional pasture/livestock production. Hence, producers would require an adequate price for the carbon sequestered to make application of high rates of organic material to be an economic proposition.

These results differ from those of Warn (2014), who found that broadcasting 20 t/ha of chicken litter on to perennial pasture over four years had a positive effect on topsoil organic carbon which showed a significant increase of 0.8% compared with pastures receiving maintenance P and S fertiliser at Seymour (600 mm rainfall, clay loam soil). A trend for organic carbon in the topsoil to increase by around 5 t/ha, and by a total of 10t/ha in the 0-30cm depth was observed where the high rates of litter was applied, compared with pastures receiving maintenance P and S fertiliser.

In the study by Warn (2014), the value of the increased carbon stored in soils (carbon sequestration) was calculated using two prices in an attempt to value the carbon supplied in chicken litter. One price used was $24.15/t carbon dioxide equivalent (CO_{2e}), which was the price in the compliance market in Australia in 2013/14. The other price used was $15/t which was to be set by the Clean Energy Regulator at in July 2015 in the advent of an emission trading scheme. However, now that a new Direct Action policy and Emission Reduction fund is in place, it is difficult to place a future price on the value of carbon. At the Seymour site the additional 10t/ha of carbon sequestered in the profile was estimated to be worth $884/ha or $549/ha if carbon was priced at $24.15/t or $15/t, respectively. The total cost of the 20t/ha litter used at that site was $1400/ha. In addition to the nutrient value in litter, the value of the carbon in the litter was estimated to be worth $44/t ($17.60/m^3) or $27/t (10.80/m^3) at a price of $24.15/t or $15/t, respectively. For the three carbon trial sites in Gippsland, as there was no increase in soil carbon during the project, no value can be calculated for the carbon in the chicken litter or compost used, at this stage.

In this Gippsland study, the main response to the chicken litter was observed in pasture growth due to the nitrogen it contained. By contrast, no pasture response to the compost was detected. In situations where all other nutrients are adequate and only N is limiting, it would be cheaper to apply an N fertiliser (urea) rather than chicken litter or compost to boost pasture production. Where a range of nutrients is required, chicken litter used at maintenance rates can be a viable alternative to inorganic fertiliser. However, securing a reliable supply of chicken litter for farmers in this part of Gippsland is an issue as they are competing with the vegetable growers and dairy farmers in south Gippsland who use large quantities. While the compost is readily available in the local area it did not appear to have any benefit in the short-term compared with the chicken litter.

Some questions were raised about whether the C:N ratio might be the reason why the compost did not produce a pasture response to nitrogen at Stradbroke. The carbon to nitrogen ratios of the compost and the chicken litter were in the range of 10: 1 to 15:1, which is satisfactory to be able to supply adequate nitrogen to plants without being tied up by microbial break down of the carbon. It has also been estimated that around 85 kg N is required for every tonne of carbon to build soil carbon levels (T.Gardner, pers com.). In this study, around 80 kg N was applied for every tonne of carbon applied in chicken litter, while about 90 kg N was applied for every tonne of carbon applied in the compost.

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 responses to application of manures was the Rothamsted long-term experiment, due to the larger inputs of manures and much larger accumulation of soil organic matter. In that trial, inputs of 35 t/ha of manure were applied annually since the 1850s with production differences between fertilised and manured treatments only becoming apparent in the 1980s. In those crop production trials, soil organic matter increased by 300%, from 1% to 3%. In the other trials reported by Edmeades (2003) manure inputs ranged from 4 to 22 t/ha per year.

When starting at 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 (i.e. decades). Based on findings from the overseas crop trials, the high inputs of chicken litter or compost used in this project would need to continue for many years for soil carbon to improve and potentially influence pasture production over and above any nutrient responses. More locally (Chan *et al.* 2010), changes in soil carbon in pastures under improved management were only recorded after 12 years in New South Wales. Also, if the soil carbon levels are already moderate to high (>3%) as they commonly are in many pasture soils in higher rainfall areas, the soil stores may already be saturated with carbon, hence no production response might occur. In addition, short-term fluctuations in soil carbon levels mean that to accurately quantify changes in soil carbon, measurements over a number of years are required (Chan *et al.* 2010).

Implications and recommendations

These finding highlight the difficulty of rapidly increasing soil carbon stocks in soils that have previously been managed as pasture paddocks with some inputs of inorganic P,K,S fertiliser, as many of these soils had a moderate soil carbon level to start with. Well fertilised perennial pastures, sown in 2009, did not have any higher stocks of carbon than well fertilised annual pastures (or rundown perennial pasture) by 2014.

The findings also indicate that the addition of relatively large quantities of organic material (equivalent to 3-4t/ha of carbon in 2 years) to these soils did not have a significant impact on soil carbon stocks in the short period of this project. Building soil carbon takes a long time, so it would be worthwhile continuing to apply the treatments to the three Carbon trial paddocks with a view to soil testing them again in two to three years. There is also a need to study the long-term impacts of regular applications of high rates of chicken litter or compost 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, so could provide other benefits in the longer term.

Other studies (Warn 2014) have demonstrated that it is possible to increase soil carbon stocks with large additions of materials such as chicken litter over a four year period, but the quantities required make it a very expensive option. These materials also supply nutrients, but the cost of the high rates applied in order to increase soil carbon, was not recouped by the additional pasture production (Warn 2014). A preliminary attempt was made, in that study, to value the organic matter and carbon in chicken litter based on its impact on soil carbon.

The current Government's Emission Reduction Fund aims to reduce greenhouse gas emissions through a range of projects, such as cleaning up power stations, capturing landfill gas, reforesting marginal lands or improving soil carbon. If the application of waste materials did prove to be a successful method for building carbon in soils it is possible that farmers could then submit tenders as part of the ERF's reverse auction process. Emission reductions would have to be from additional measures to what is normally done on the farm and the estimates of CO_2 equivalent reductions have to be verifiable. However, for this methodology to be considered within the ERF reverse auction, data needs to be collected over a longer time period to properly validate the methodology.

These 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 a need for a continued extension to provide information and tools so producers can utilise chicken litter or compost effectively on their farms and evaluate if it will be of economic benefit.

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Appendix 1. Carbon stocks in individual perennial pasture paddocks, Nov 2012.

	Control paddocks				Sown paddocks			
Site	C 0-10 t /ha	C 10-20 t /ha	C 20-30 t /ha	Total C stocks 0-30 cm t /ha	C 0-10 t /ha	C 10-20 t /ha	C 20-30 t /ha	Total C stocks 0-30 cm t /ha
1	39.36	15.80	13.11	**68.26**	41.02	19.10	11.41	**71.53**
2	45.86	18.29	10.52	**74.67**	41.72	23.42	13.84	**78.97**
3	40.35	15.12	7.76	**63.24**	44.84	15.77	9.21	**69.81**
4	46.97	31.16	25.88	**104.01**	44.15	28.01	21.55	**93.71**
5	43.09	31.90	28.93	**103.92**	50.10	39.83	28.71	**118.65**
6	31.50	14.32	9.19	**55.01**	34.22	16.10	10.23	**60.55**
7	44.73	20.57	11.77	**77.07**	37.31	18.70	12.71	**68.72**
8	27.91	15.82	11.13	**54.86**	37.88	16.87	11.88	**66.63**
9	54.38	29.62	22.91	**106.91**	49.52	30.33	19.60	**99.45**
10	53.96	32.46	17.88	**104.30**	43.61	24.61	12.54	**80.76**
11	47.76	26.99	14.54	**89.29**	46.73	26.87	16.38	**89.98**
12	42.78	24.62	13.51	**80.90**	51.33	27.43	20.37	**99.13**
13	78.29	26.88	19.63	**124.80**	94.94	54.53	32.74	**182.21**
14	49.96	13.55	8.69	**72.20**	47.61	27.91	15.19	**90.71**

Appendix 2. Carbon stocks in individual perennial pasture paddocks, Nov 2014.

	Control paddocks				Sown paddocks			
Site	C 0-10 t /ha	C 10-20 t /ha	C 20-30 t /ha	Total C stocks 0-30 cm t /ha	C 0-10 t /ha	C 10-20 t /ha	C 20-30 t /ha	Total C stocks 0-30 cm t /ha
1	51.53	22.86	14.55	**88.94**	42.06	22.61	8.66	**73.33**
2	40.24	19.70	15.38	**75.33**	40.41	26.17	13.22	**79.79**
3	45.27	13.46	8.20	**66.93**	43.49	16.80	11.51	**71.80**
4	56.00	42.07	24.37	**122.44**	56.09	28.97	22.89	**107.95**
5	48.91	33.26	34.39	**116.56**	47.32	34.35	23.34	**105.01**
6	33.88	11.52	21.86	**67.26**	25.93	15.11	8.04	**49.09**
7	39.18	19.84	11.89	**70.91**	46.82	22.58	13.70	**83.10**
8	29.12	12.73	7.16	**49.01**	45.86	17.34	10.39	**73.59**
9	67.02	27.13	19.99	**114.14**	53.54	32.41	26.70	**112.65**
10	43.92	24.93	14.28	**83.12**	42.96	22.27	13.26	**78.49**
11	41.73	19.78	11.52	**73.04**	47.84	25.92	19.70	**93.46**
12	57.06	22.88	12.48	**92.42**	44.28	23.06	16.91	**84.25**
13	67.89	29.25	17.35	**114.49**	101.33	57.43	33.52	**192.28**
14	51.05	14.47	11.02	**76.54**	53.83	27.85	13.46	**95.14**