Soil Carbon in the Monaro Region

a report from **Action on the Ground**

NSW GOVERNMENT Department of Primary Industries

MFS MONARO FARMING SYSTEMS

clean energy future

Australian Government Department of Agriculture

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Acknowledgements

This project is supported by funding from the Australian Government Department of Agriculture, Fisheries and Forestry as part of its Carbon Farming Futures - Action on the Ground program.

ISBN: 978-1-74256-816-4

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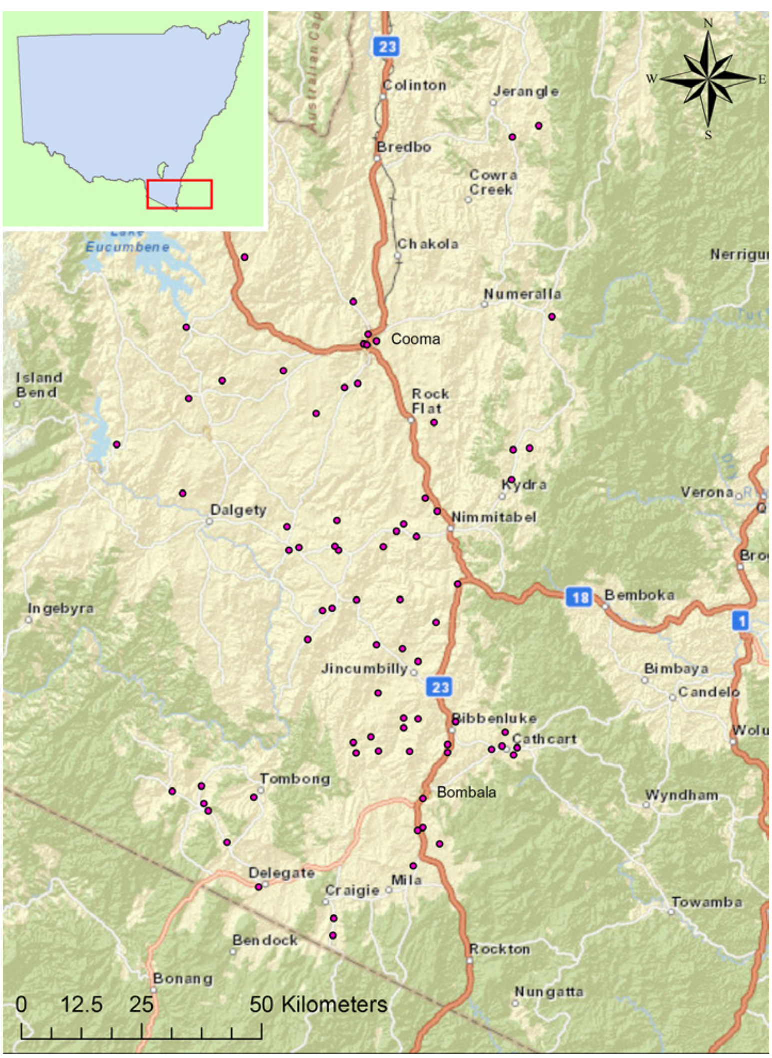
Monaro farming systems soil carbon project

Monaro Farming Systems (MFS) is a regional landholder group initiated and developed in September 2007. The group was set up, primarily, as a knowledge- and information-based organisation, to help farm businesses to be more profitable and resilient in the long term. In this way it allows peers and researchers to work together to improve practice and innovation in farming systems. MFS's work is based on world's best practise in Research Development and Extension. The group has over 100 individual members, from the Bombala, Cooma-Monaro and Snowy River Shires. These members manage approximately 30% of the privately held land on the Monaro region (over 80,000ha) and are responsible for approximately 40% of agricultural production.

In 2012 the group was successful in its bid to receive funding from the Australian Government Action on the Ground program to examine where soil carbon accumulated in the region. The soil carbon project has run for three years. Technical specialists identified 19 trial sites on 7 participating properties for the project.



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Soil carbon issues for the Monaro region

Monaro Farming Systems members wanted to compare the influence of soil type, rainfall and land management on carbon stocks.

The questions they wanted answered were:

1. Does minimum disturbance cropping influence carbon stocks over a 2 year period?
2. What is the effect of 'parent material' ie. shale, deep granite and basalt (ascending texture, fertility and structure) on carbon stocks in the Monaro region?
3. What influence does 'aspect' have on carbon stocks in a system with optimum sequestration potential ie. fertilised, permanent, perennial pasture system?
4. Does liming introduced pasture increase C sequestration?
5. What effect does soil fertility have on C stocks in the Monaro region?
6. What effect does pasture age have on the potential of a phalaris perennial pasture to sequester carbon. Does age create a 'ceiling' on sequestration potentials?

The Monaro soil carbon project aimed to demonstrate the impact of farm management strategies on the concentration and stock of carbon in soil over a two year period. Eight different land-use systems were identified by members of the Monaro Farming Systems group. The practices of interest included liming, nutrient management, introduced perennial pastures and minimum disturbance cropping. In addition the project looked at increases in biomass production within the context of reducing DSE emissions intensity and any offsets required for increases in stocking rates associated with production gains.

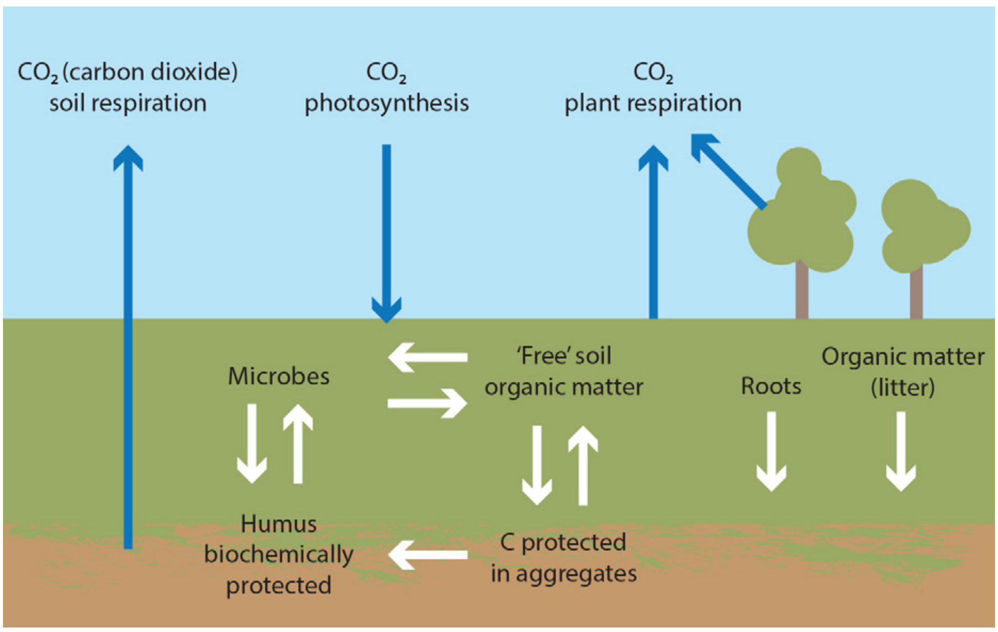
A word of caution

It is important to remember when reading this book that the project presents a series of case studies using paired paddock comparisons and as such the project may not equate to the long term replicated scientific studies that inform our understanding of soil carbon in Australia today. The snapshots presented here show results derived from only two sampling times, two years apart. Two years is a small time period in which to establish changes in soil carbon. Seasonal and/or local fluctuations at these specific years and sites may not align with long term, broad scale trends observed in other published studies.

Caption: Cropping paddock included in the survey, Delegate NSW. Comparison: Crop vs native pasture vs new introduced pasture.

First some basics about soil carbon

Carbon is one of the building blocks of life and although not a plant nutrient, it is required to build cells. It is a major component of soil organic matter, but not the only one. Soil organic matter is also made up of many other elements, such as nitrogen and sulphur.



Caption: Flows of C around the paddock

Like many other elements carbon moves around the environment. The paddock scale carbon cycle is part of a larger global cycle moving carbon around the world in response to a range of climatic, chemical and human triggers.

Soil carbon can be organic or inorganic. To a large extent soil type, climate and time govern the amount of organic carbon found in soil. Land management can also play a major part. For a good overview of the carbon cycle in the paddock you can watch the Organic carbon cycle animation.

Different forms of C in the soil

The carbon (C) found in the earth's soils is the largest part of the terrestrial (land) pool of the global carbon cycle. Carbon is found in many different forms. Diamonds are the only crystalline form. The other forms are said to be amorphous (non-crystalline) and include charcoal and humus; limestone and organic forms; and of course it is found in gaseous forms such as carbon dioxide.

The carbon not associated with living plant and animal matter such as carbonates is called soil inorganic carbon (SIC). The carbon in this group comes from rocks and sediments. The most common forms of SIC are calcite ($CaCO_3$) and dolomite ($Ca/Mg(CO_3)_2$).

Soil organic carbon (SOC) is all the carbon found in the organic matter of a soil except fresh undecomposed plant material and the carbonates and other inorganic compounds. SOC includes:

- Charcoal
- Humus
- Microbial biomass (soil living organisms)
- Partly decomposed organic matter

New plant and animal litter is technically not part of SOC as the carbon in these is readily decomposed and released back to the atmosphere as carbon dioxide (CO_2) as a product of decomposition (Chan et al. 2010).

Carbon fractions

Carbon exists in many shapes and forms in the soil, and is constantly moving and changing depending in soil conditions. Science arbitrarily divides the carbon in the soil into groups or fractions. The amount of carbon in these fractions at any one time is a function of climatic conditions, soil type and landscape and management. Carbon in all the fractions decomposes releasing some of the carbon into the atmosphere as carbon dioxide. It has been suggested that in order to determine how a soil functions and its health, it is more important to know the proportion that these various fractions make of the total rather than just the total organic carbon in soil. Particulate organic carbon is generally considered to be the carbon fraction that is most susceptible to the land use change; humus is a bit more stable and takes longer to change;, while resistant organic carbon is the substances in the soil that have been there for a long period of time and are thought to be less affected by land management.

Fraction name	Decomposition rate	Function	Examples
Active living	None, as they are living, but once dead will enter the fast pool	Decomposition Nutrient cycling Soil pore structire	Fungi, bacteria, protozoa, arthropods, earthworms
Active non-living (also known as labile or fast pool) – disolved	Hours to days	Food and energy source for soil organisms	Sugars, proteins
Active non-living – particulate	Weeks to years	Micro aggregate stability Nutrient cycling	Small pieces of organic matter
Slow pool (also known as humus)	Decades to centuries	Nutriend supply Cation exchange capacity Water holding capacity Soil structure capacity	Fats, lignins, humic substances
Stable (also known as resistant, recalcitrant, inert or inactive pool)	Centuries to millenia	Cation exchange capacity pH buffering Soil tempurature modulation	Charcoal, phytolith, biochar

Table from: Cox J et al. 2012 *Biochar in horticulture: Prospects for the use of biochar in Australian horticulture*. HAL report. ISBN 978 1 74256 349 7

Importance of soil carbon

Carbon in a soil provides one of the building blocks for healthy soil which is essential for resilient agricultural systems. Carbon in the soil is vital to ensure a healthy soil where:

- nutrients cycle through the soil readily,
- soil structure is stable allowing aeration and water movement and
- habitat and food for soil biology and plant roots are provided.

Nutrients

- In terms of soil chemistry, soil carbon is a major component of soil organic matter (SOM). In addition to carbon, SOM includes a whole array of elements such as nitrogen, sulphur, phosphorus and potassium. SOM plays an important role in retaining nutrients (through both cation and anion exchange).
- Soil carbon provides the 'fuel' for the engines that bring about nutrient cycling. Carbon helps drive the processes that making these nutrients available for plant and animal growth. The engine's agents of this cycling are living organisms, from the microscopic (eg rhizobia, other soil microbes) up to large (eg animals, humans).
- As nutrients and elements such as carbon move around the environment, they 'cycle' through different forms and locations. Some of these forms are more accessible to plants than others. The transformation of organic residues into humus (or 'humification') by soil organisms requires nitrogen, phosphorus, sulphur and potassium (and other elements in smaller quantities). These elements are constituents of organic matter and must be present in organic residues or added to the soil for humification to occur.

Soil biology

- Soil organic matter in the soil is so inextricably linked with soil biology that it can be difficult to differentiate the two. The soil biota forms part of a soil's carbon pool and in turn the carbon provides food and energy to the soil biology. Soil living organisms are processors through which carbon moves, becoming more and more stable as it is humified.
- The organic matter in the soil provides a reservoir of nutrients for the soil biota much as it does for plants. Whether this be the nutrients tied up in the living bodies of soil organisms or their actions in releasing these nutrients as they decompose and eat other pieces of organic matter, soil organic carbon is important for maintaining a functional and resilient soil biological food web.

Physical soil

- The way a soil is structured, how much water it can hold, how susceptible it is to erosion and the resilience of its structure, is all due in some part to the carbon or organic matter in the soil.

Soil carbon is important in building and maintaining the structural stability of a soil. It is this structure, the arrangement of soil particles and the spaces in between that govern a soil's aeration, density, ability to retain water and the movement of gases and liquids within a soil.

Caption: Soil cores (Yellow Chromosol) from an old introduced pasture included in the survey, Delegate NSW.

Soil carbon in pasture based systems

Permanent pastures are thought to be one of the best ways to capture and retain soil carbon in the soil. Perennial pasture systems have:

- Deep roots that deposit carbon to deeper sections in the soil profile.
- Minimal soil disturbance which slows organic matter decomposition and thus carbon loss.
- The ability to persist longer in periods of low rainfall due to deep root systems. The pasture grows and contributes to soil carbon for longer than most annual pastures and crop over the long term.
- Slower rates of organic matter decomposition due to perennial roots creating a drier soil profile compared with cropping soils (especially those under fallow). A drier soil reduces the biological activity required to decompose organic matter and release carbon.

However, to fully achieve these benefits the pasture must be well managed with sufficient nutrients and water to grow to their potential; have few constraints such as salinity and acidity that reduce growth; and not be overgrazed.

What governs soil carbon sequestration?

The potential for any soil to sequester carbon is largely driven by soil type and climate. One of the most important aspects of soil type is the clay content. Soils with higher clay contents usually allow greater plant growth due to their nutrient and water holding capacities and this translates into increased soil carbon levels. The clay present, in turn, then helps protect the carbon in the soil from loss. Therefore carbon levels on sandy soils (e.g. Kandosols or Chromosols) may never reach the levels seen in clay rich soils such as Dermosols , Ferrosols or Vertosols. It is important to understand the nature of a soil when determining its capacity to store carbon and not to expect different soil types to be able to capture and store the same quantities of carbon.

Climate further mitigates the effect of soil types on soil carbon sequestration due the influence of temperature and rainfall on plant growth and organic matter decomposition. When conditions are favourable—that is sufficient water and temperatures not extreme—plant growth will be unhindered (assuming there are no other constraints, such as nutrient deficiencies). In these conditions soil biological activity is also at its best. If a system is run in the same way for a significant time it may reach equilibrium where soil carbon level does not change significantly. However extremes of heat, cold or lack of water slow both plant growth and biological activity. This means that very little carbon from new plant sources enters the soil and very little is used by soil biology as their functioning slows. If organic material such as animal or plant products are still removed from the paddock and soil and/or there is erosion then the soil carbon stores will be depleted.

In the Monaro region the annual cycle of cold winters and warmer moist summers, means the addition of organic matter to the soil ebbs and flows. When years are abnormally good or bad this ebb and flow is more pronounced.

If you want more information about soil type and soil carbon in the Monaro region see: What is the effect of 'parent material' on carbon stocks in the Monaro region?

Caption: The Monaro region is typified by a diverse range of landuses; native pastures, introduced pastures, cropping, forestry plantations and national parks.

What is a 'carbon stock'?

The amount of carbon shown in your soil test is a concentration of carbon in a given volume of soil (often presented as percentage). It is not the entire 'stock' of carbon present in your soil. To calculate the carbon stock contained in the soil, you need to know the density (g/cm^3) of the soil as well as the total organic carbon concentration (g/100g). There is a three step process to calculate the soil carbon stock:

Step 1*	Step 2	Step 3
Carbon concentration (g/100g, equivalent to %) × bulk density (g/cm3) × depth of soil(cm) × gravel correction factor (1-% gravel)	Calculate the reference soil mass (this may be the time zero measurement, a reference site or some other reference soil mass)	Calculate the SOC stocks based on an equivalent mass of soil.

* **Step 1** is all you need to do a one point in time calculation. This number cannot be used to compare different sites or results from different years. For comparisons you need to continue to steps 2 and 3

Finally, to convert all calculations of a carbon stock to tonnes of carbon dioxide equivalents (CO_2e), multiply the carbon stock (t/C/ha) by 3.66 (based on the atomic weight of carbon and oxygen). **Carbon dioxide equivalents (CO_2e) = Carbon stock (t/C/ha) × 3.66**

Monitoring soil carbon

The carbon content of a soil is in part influenced by landscape features including parent material, clay content, soil depth, aspect, topography and relief. At the paddock level, variation in soil carbon levels can be great or very little depending on the degree to which the paddock has any of these attributes. For monitoring soil carbon levels it is important to remember that using a 25 × 25 m quadrat will not represent the entire area under a specific management technique due to spatial variability of soil carbon. This project showed that a better estimate of soil carbon is achieved by increasing the number of transects per paddock rather than increasing the number of samples in a given transect. That is, 10 transects where 5 samples are collected along each transect provide a better estimation than 2 transects with 25 samples. Ideally each sample would be composited (subsamples mixed) and analysed separately for each transect to provide an understanding of variability.

To calculate carbon stocks you need to know the bulk density of the soil and gravel content. See equations presented in: What is a carbon stock?

More information about soil carbon can be found in these NSW DPI publications:

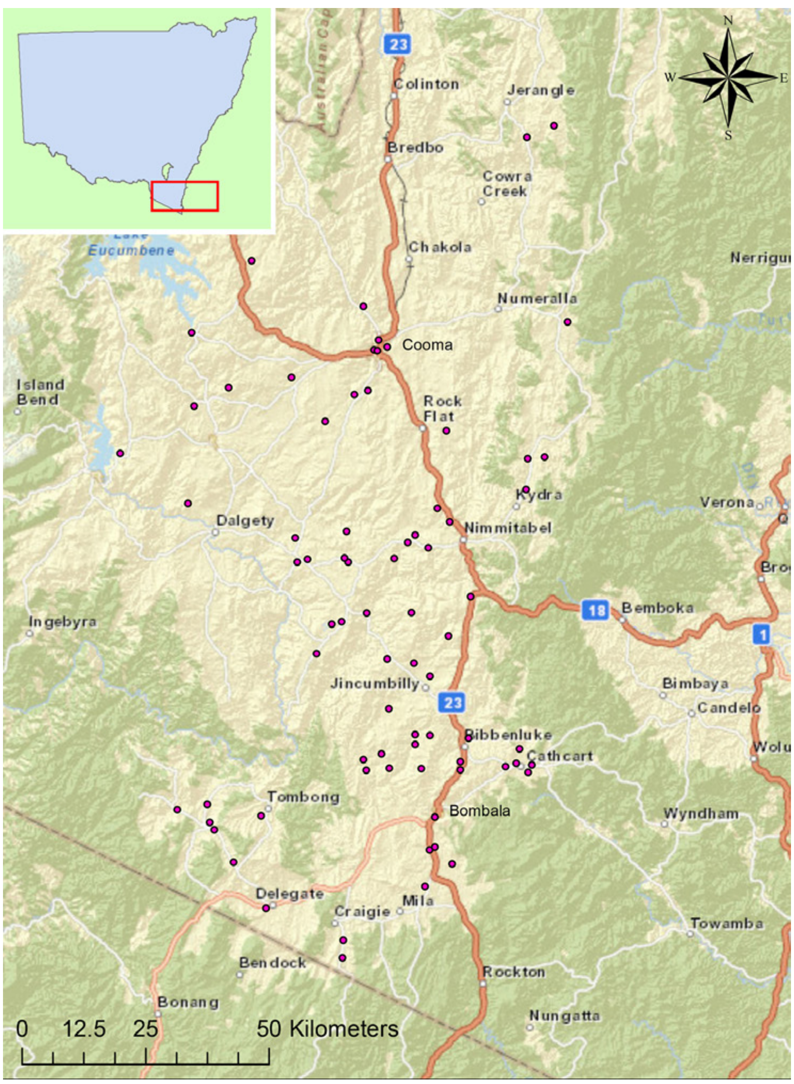
A farmer's guide to increasing soil carbon under pastures

Key soil carbon messages

Increasing soil organic carbon of agricultural land

The Monaro region

The Monaro region is a celebrated agricultural region, famous for the production of wool and livestock. Its 490,000 ha of pasture supports 1,150,000 sheep, 73,000 cattle and produces 6,305,000 kg of wool annually.



Key soil carbon messages for the Monaro region

1. Seasonal conditions and soil type have a greater effect on carbon than management
2. Providing necessary nutrients and pH for best pasture production will potentially increase soil carbon.
3. Cropping in a good season may not decrease soil carbon stocks on certain soil types. Opportunities may exist for Monaro landholders to diversity their enterprises when the conditions are right without depleting their soil carbon.
4. A rapid increase of soil carbon can easily be followed by a rapid decrease.

Soils

The soils of the Monaro region are mostly of granitic origin, with sandy, leached topsoils and heavier clay subsoils. They are formed on extremely old Palaeozoic rock which have been significantly altered and deformed by geological activity. However there are a few areas to the north east where basalt parent material has given rise to some of NSW's best brown Ferrosol and Dermosol soils.

Sites for this study cover the three main parent materials of the Monaro soils, the basalts, granites and metasediments. See more detailed information about this in: What is the effect of 'parent material' on carbon stocks in the Monaro region?

Climate

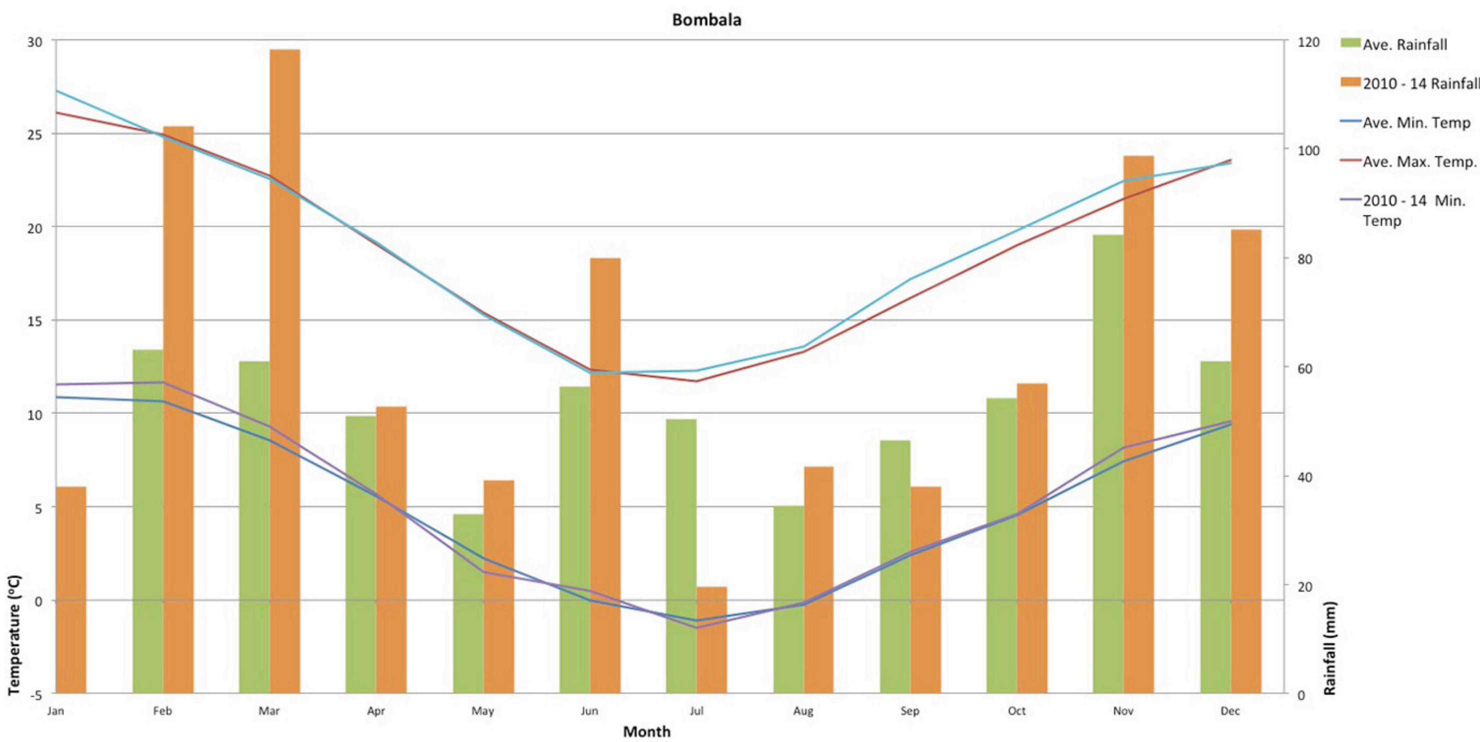
Interestingly the region is typified by cool dry winters and warm wet summers.

The rainfall drops dramatically from east to west. The town on the eastern side of the plateau can receive 700mm whilst further west only 400mm.

Temperature is likewise variable. The extreme cold experienced in winter months means the main agricultural enterprise since first white settlement in the 1830s is grazing of sheep and cattle.

It is important to note here that the results of this project are highly influenced by the weather preceding the project years. In the two years before the first round of sampling in 2012 the Monaro region experienced very favourable conditions (see graphs). This would, more than likely, have reduced the difference in soil carbon levels between different systems and landscapes. In drier years the difference between soils, landscape and management would be more apparent.

Tap this table to enlarge it, depending on your reading device.



Managing carbon and other Greenhouse gases at the farm scale on the Monaro region

In this project there was remarkable consistency in the enterprise emissions produced on a DSE basis. For example, for low fertility native pasture systems running the self-replacing merino enterprise typical of the Monaro region, emissions are estimated to be 195 kg CO_2-e/DSE. Introduced pastures at moderate fertility levels achieved a DSE emissions intensity of around 180 kg CO_2-e/DSE. When optimally fertilised, this can be reduced by a further 5 kg CO_2-e/DSE. However, to claim reduced net emissions (that is, more C sequestration), management that improves pasture production and increases carrying capacity of a native pasture by 2 DSE/ha will first need to offset an increase in methane emissions of around 400 kg CO_2-e/ha or 110 kg of carbon. In rough terms if only 20% of any extra biomass produced is retained in the soil then the first 600-700kg of extra above-ground biomass production would be needed to offset extra livestock emissions even before accounting for any changes in other emissions sources.

Economically, there are production gains associated with increasing soil fertility, but only when the extra pasture produced is utilised. This means increasing stocking rates, and with that, livestock emissions. Calculations such as these make it clear that on-farm decisions to increase pasture productivity will be made mostly to increase livestock production and any value coming from C sequestration in soil will be relatively minor given its current market value and its variability in pasture-based systems.

Soil carbon capture schemes and the Monaro region

Currently, farmers can participate voluntarily in the Australian Government's soil carbon trading scheme by using an approved methodology (e.g., the soil carbon for grazing methodology). Trading is administered under the Emissions Reduction Fund, formerly the *Carbon Credits (Carbon Farming Initiative) Act 2011*. The Emissions Reduction Fund supports forestry, revegetation and soil carbon projects. Farmers can nominate the year permanence period they will be paid under, either 100 or 25 years. Opting for a lesser period returns a lower payment. During the nominated permanence period carbon storage must be maintained or credits issued returned. If carbon stores are reduced due to a change in management then the farmer will not receive credits (payment) until carbon stores recover. The scheme is set up with a risk buffer so that the farmer does not have to pay back credits if carbon stores are lost due to natural events such as a drought or bushfire. Participants can opt out at any time, but they will need to hand back the same number of credits that were issued to the project.

At the time of writing this publication, a new, draft method has been released for public comment: 'sequestration of carbon in soil using modelled abatement estimates'. In contrast to the 'soil carbon for grazing methodology' which requires measuring and monitoring of soil carbon, this draft method uses modelled estimates of sequestration. This means monitoring is not required by the farmer participant. This method aims to provide a low-cost path for soil carbon projects in cropping, pasture and mixed farming systems so it is easier to participate in the Emissions Reduction Fund.

Question 1. Does minimum disturbance cropping influence carbon stocks over a two year period?

Answer: In good years, cropping may maintain or increase soil C stocks relative to perennial pastures.

Evidence suggests that on some soil types continued cropping reduces soil carbon levels, even in minimum disturbance systems such as zero tillage. It has been recommended that pasture phases be included in rotation with cropping to help reduce the loss of soil carbon during the cropping phases. But what happens when opportunistic cropping is undertaken in a pasture dominated system? What are the effects of cultivation, fertiliser, cropping practices and new species mixes on soil carbon stocks? The following three case studies look at answering these questions.

Caption: Paula Charnock and Helen King soil sampling in canola crop, 'Corrowong'

And what about long term forestry operations? One of the project case studies focuses on assessing soil carbon stocks under a 12 year old pine forestry plantation.

Caption: Helen King with hydraulic soil corer in wheat crop, 'Delegate Station'

Where

Four sites were chosen to look at the variations of typical Monaro land management options with cropping.

CASE STUDY 1
Cropping vs native pasture vs new introduced pasture

Location: Corrowong

Caption: David Mitchell drenching lambs, 'Corrowong'

A comparison of semi-native and native perennial pasture (phalaris, spear grass, cork screw grass and sub clover); a newly introduced perennial pasture of phalaris, lucerne and sub clover; and a new wheat/canola cropping system was undertaken on Dave and Andrea Mitchell's Corrowong property.

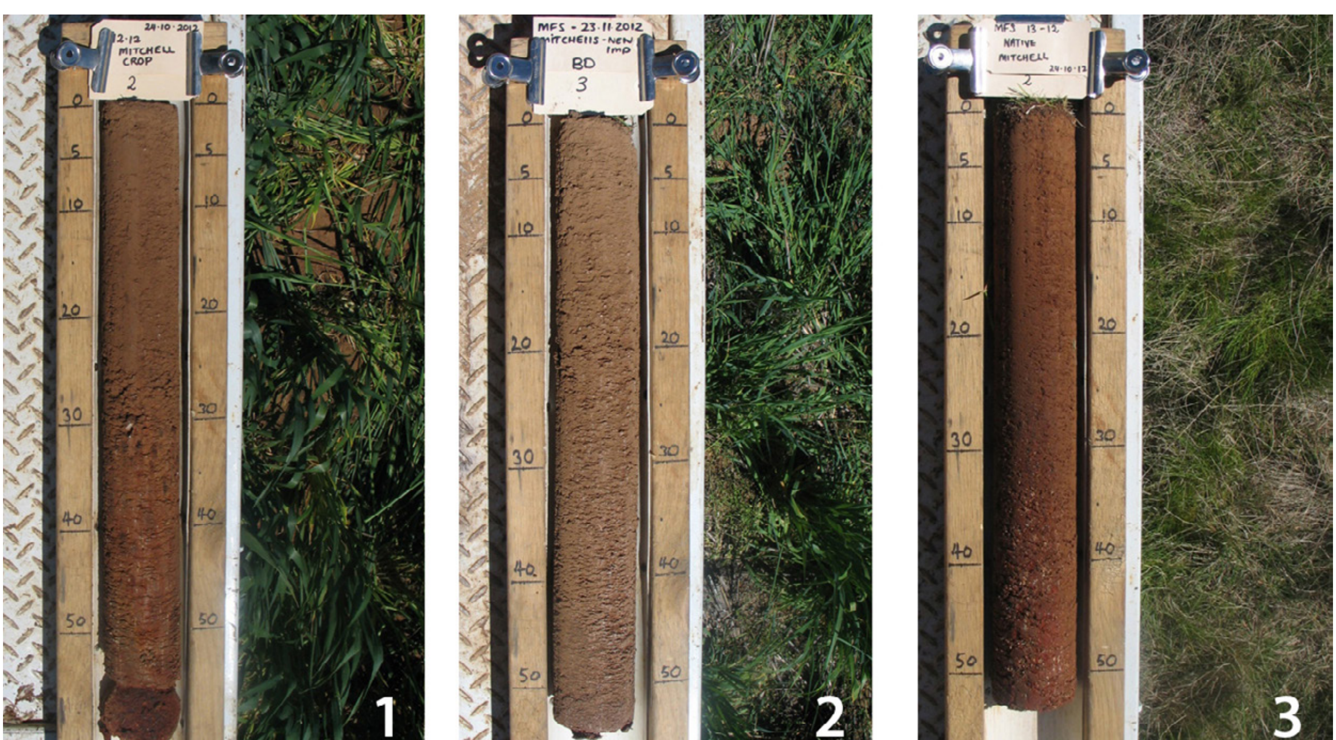
The introduced pasture paddock with a red Kandosol soil is managed in a rotation. An improved pasture was first established in 2001 when phalaris and cocksfoot were sown into a native pasture base. Barley was sown in 2009 then canola in 2010 followed by wheat in 2011. These rotations included several sprays, fertiliser applications and fallow periods. This paddock was then sown down to lucerne, phalaris and sub-clover in May 2012.

Dave and his wife Andrea with their three children own and manage a family farm business on a 7,000 acre (2916 ha) property approximately 25kms west of the township of Delegate, southern NSW. The property was purchased in 1992 from David's parents.

The business is based mainly on Merino sheep and crops approx. 400 ha. The enterprise is split into allocations of 15% cropping, 60% merino enterprise and 25% to a meat sheep enterprise. Dave and Andrea took over the farm business in 2000, entering into land leased agreements in 2002 and 2008 and crop share farming partnerships with local producers.

Dave was a founding member of Monaro Farming Systems in 2007 acting as Chairman and driving force of the organisation for the first five years. Currently Dave is the Chair of the SE Local Land Services Board and his wife Andrea recently finished a seven year employment period with the local Snowy River Interstate Landcare Committee.

Dave believes opportunities to capitalise on soil carbon should be linked to productivity improvements in soil, pasture and stocking rate capacities as well as aligning with environmental gains.



Caption: 1. Corrowong - crop | 2. Corrowong - new pasture | 3. Corrowong - native.

CASE STUDY 2

New cropping vs old native pasture vs new introduced pasture

Location: Delegate Station

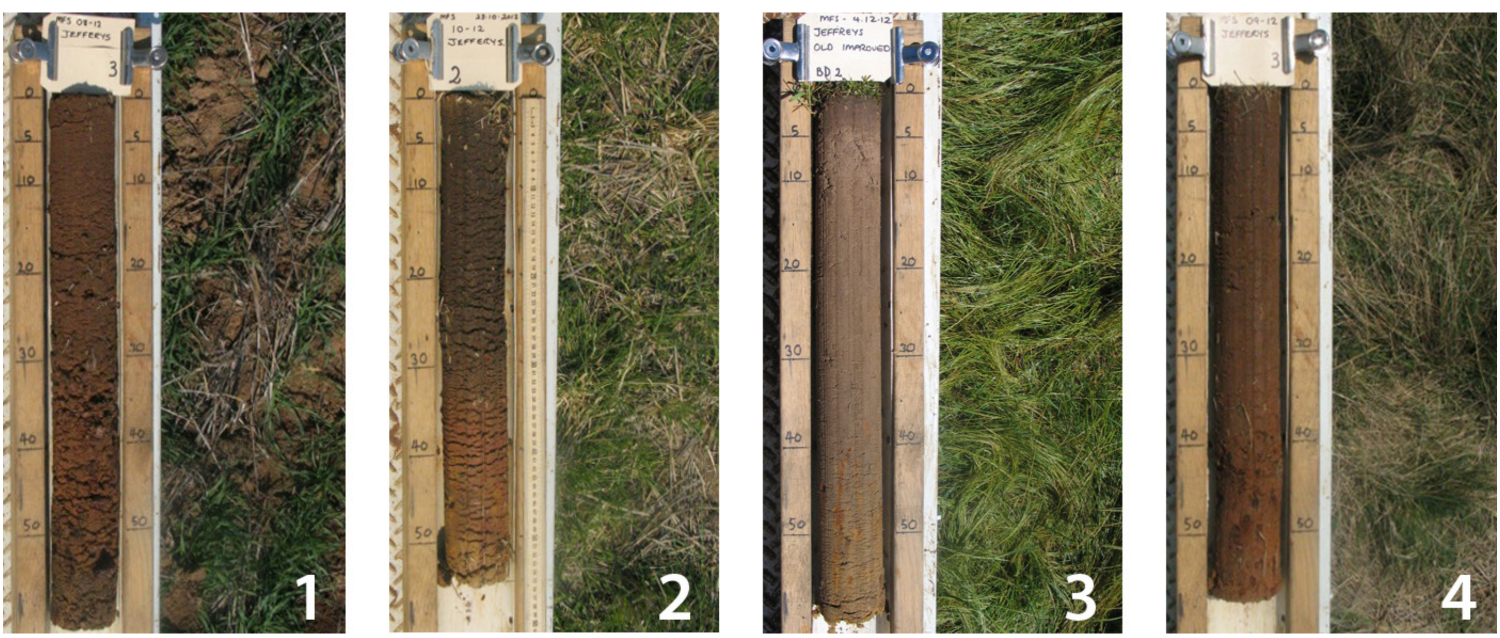
Caption: John and Jen Jeffreys, Delegate Station at the MFS Event, 'Carbon Day Out'

The Jefferys run some of the largest cropping operations in the region. Their Delegate property was used to compare a much newer cropping system and a very old native pasture system (35 yrs +) on a red Chromosol soil with a new introduced pasture system of legume, cocksfoot and phalaris on a yellow Chromosol.

The Jefferys property is situated near the NSW township of Delegate, approximately 20km north of the Victorian Border and 35kms south of Bombala. Seven hundred and fifty (750) ha of the 1900 ha property is cropped and the balance is pasture. Canola and cereal crops typically yield between 2-6 t/ha. Livestock includes 4,500 cross-bred ewes, 3,500 fat lambs and approx. 120 cattle.

John's father Peter first worked on the property for many years before purchasing it in 1984. Since then John and his brother Will purchased the property from their parents and John currently lives on-farm with his wife Jen and their twin girls Georgia and Amelia.

Several CSIRO funded, dual-purpose cropping and varietal evaluation trials have been conducted on Delegate Station helping John and others to refine their management operations for their climate and soil types.



Caption: 1. Delegate - crop | 2. Delegate - new introduced pasture | 3. Delegate - old improved pasture | 4. Delegate - native pasture.

CASE STUDY 3
Native pasture vs new cropping

Location: Maffra

Caption: Andrew Rolfe (left) and Stephen Rolfe (right) – inspecting pasture on Maffra

A comparison of native poa tussock/stipa based perennial pasture, with a brand new cropping system (barley) was made on the South Bukalong property of the Rolfe family.

Stephen Rolfe and his wife Jo and son Andrew run an evidence-based farm business on a property to the west of Nimmitabel, NSW. Their approximately 10,000 acres, including leased country, is predominantly basalt soils (Dermosols).

Previously running a self-replacing merino flock, Steve and his family are moving towards running and trading wethers and also incorporating some cropping and pasture improvement into their systems. Recently the business invested significant resources in cropping rotations and pasture improvement especially on the more highly productive basalt country with a history of love-grass infestations. The Rolfes are currently involved in district trials run by the South East Local Land Services (LLS) to assess the effectiveness of various management strategies to control African lovegrass on the more productive basalt country.

Stephen has 34 years of experience in the grazing industry on the Monaro region while Andrew also works part-time as an agronomist in the Bombala and Cooma districts as well as helping run the family partnership.

Caption: 1. Rolfe - crop | 2. Rolfe - pasture.

CASE STUDY 4

Pine plantation vs cropping and very old introduced pasture

The site chosen on the property owned and managed by Snowy Mountains Forests is a 12+ year old pine plantation on a poorer yellow Chromosol soil. Prior to being planted to pines in July 2002, the vegetation was mainly improved pasture species having been over sown with trifolium spp and phalaris. It had been heavily grazed and undergone several years of successive cropping events. Site preparation included a broad acre burning in May 2002 as well as chemical herbicide treatments.

The site is due to be thinned in the next year (when trees are approximately 13 years old) and then will be clear-felled in a further 10 years' time.

Snowy Mountains Forests, with the head office located in Tumut NSW, was established in 2012 and manages a sustainable softwood plantation estate of approximately 22,000 stocked hectares in the Bombala and south-west Slopes region of southern NSW Australia.

The crop site in this comparison (airstrip) is the only cropping site that had been cropped for more than 3 years, and is the oldest cropping site in the project.

Caption: 1. Pine plantation | 2. Airstrip | 3. Very old introduced pasture.

What we found

As with many of the observed differences in soil carbon in this project the difference between land management systems was confined to the top 30 cm of soil indicating the influence of management on this section of the soil profile, particularly in the early years after a change in management.

Three of the four cropped sites had been cropped for less than three years, and these years coincided with three years of above-average annual rainfall in the Monaro region. Soil nutrient management programs, favourable climate years (prior to and during this project), and minimal soil disturbance all contributed to carbon stocks in both pasture and cropping sites being comparable.

Two of the cropping sites—one on sedimentary-derived soil and one on basalt-derived soil—had a lower soil C stock compared with their perennial pasture pair, (see Table 18). However, there was no difference in soil carbon at the cropped and pasture site on granite-derived soil and there was a greater stock of soil C under the cropped site compared with the native perennial pasture on the remaining sedimentary-derived soil.

It is thought that the nutrient management program associated with a move to cropping has allowed greater biomass production in the years of the study which were favourable for plant growth.

The study did not investigate the longevity of this carbon to determine which management systems both build soil carbon and retain it in the long term. Furthermore, the vulnerability of carbon to decomposition was not investigated in this study and it suspected that under different climatic circumstances these results may differ.

CASE STUDY 1 RESULTS

Cropping vs native pasture vs new introduced pasture

Carbon stocks at all sites in this comparison increased from 2012 to 2014. The management regime with the most soil carbon in 2012 was the native pasture but by 2014 carbon levels in both the cropping and native pasture soils were the greatest. That is, the cropping soil showed the largest increase in soil carbon levels over the sampling period, particularly in the top 30 cm. This is probably due to the increased nutrients supplied for the crop which led to greater plant growth and subsequently increased organic matter supply and thus carbon addition to the soil.

Table 1: Soil carbon changes from 2012 -2014 at two depths. (t/ha)

Management	Soil C trend over 2 years	0 – 30 cm		0 – 50 cm	
		In 2012	In 2014	In 2012	In 2014
Crop	↑↑	40.2	53.2	54.9	67.3
Native pasture	↑	39.9	46.8	54.9	62.5
New Introduced pasture	↑	36.7	42.8	47.6	54.7

The native pasture had higher carbon levels when compared with the introduced pastures across both years and both depth measurements. It is interesting to note that in the native pasture soil more soil carbon was found below 30 cm than in the new introduced pasture. The introduced pasture was only sown in 2012 and the prior history of the paddock may influence the results.

Table 2: Comparisons between treatments *

Comparisons	0-30 cm		0-50cm	
	2012	2014	2012	2014
Native pasture vs new pasture	3.28	4.01	7.23	7.76
Native pasture vs crop	-0.27	-6.39	-0.04	-4.81

* The comparison table shows the difference in soil carbon between the two management options specified. A positive number indicates the first management option in the comparison is better than the second option in the comparison. A negative result means it is not as good. So this table shows native pasture had more carbon at all depths in all years than the new pasture, but it had less soil carbon than the cropped soils for all years at all depths.

Compare this with other project trial sites.

CASE STUDY 2 RESULTS

New cropping vs native pasture vs new introduced pasture

It appears from the results that the soil in the native pasture had the greatest increase in soil carbon over the life of the project. However the management with the highest soil carbon levels in both 2012 and 2014 was the new introduced pasture. Increases in soil carbon following pasture improvement are not uncommon. Increased biomass from more vigorous varieties and improved nutrition from legumes can increase soil carbon levels. This may be the reason why the difference between the carbon levels in the introduced pasture and the native pasture were higher in the topsoil. Over time this difference between the two pasture systems increased.

It is important to make a note of the prior history of any paddock when assessing the capacity of the soil to build soil carbon in both the short and long term. The new introduced pasture paddock had previously been cropped, which may have left behind nutrient reserves to boost pasture production especially as the period of this study followed a significant drought and/or its soil carbon levels may have been depleted.

Although initially carbon stocks in the crop paddock were higher in the top 30 cm than the native pasture they did decline over the life of the project compared to both pasture paddocks where the carbon increased.

Table 3: Soil carbon changes from 2012 – 2014 at two depths (t/ha)

Management	Soil C trend over 2 years	0 – 30 cm		0 – 50 cm	
		2012	2014	2012	2014
New Crop	↓	47.7	45.4	55.7	52.4
Native pasture	↑ ↑	45.2	55.9	56.8	70.3
New Introduced pasture	↑	68.9	69.9	84.8	86.7

Table 4: Comparisons*

Comparisons	0-30 cm		0-50cm	
	2012	2014	2012	2014
Native vs new introduced pasture	-23.81	-13.99	-28.00	-16.38
Native pasture vs crop	-2.50	10.55	1.07	17.91

Compare this with other project trial sites.

CASE STUDY 3 RESULTS
Native pasture vs new cropping

The greatest increase in carbon stocks was seen under the native pasture with this management having the highest soil carbon level in both 2012 and 2014. Native pasture also showed the greatest increase in soil carbon levels over time.

Table 5: Soil carbon change from 2012 -2014 at two depths (t/ha)

Management	Soil C trend over 2 years	0 – 30 cm		0 – 50 cm	
		2012	2014	2012	2014
Crop	↑	46.4	50.1	71.7	77.1
Native pasture	↑	59.9	64.9	80.8	87.1

Table 6: Comparisons*

Comparisons	0-30 cm		0-50cm	
	2012	2014	2012	2014
Native pasture vs crop	13.59	14.82	9.08	10.01

* The comparison table shows the difference in soil carbon between the two management options specified. A positive number indicates the first management option in the comparison is better than the second option in the comparison. A negative result means it is not as good. So this table shows native pasture had more carbon at all depths in all years than the new pasture, but it had less soil carbon than the cropped soils for all years at all depths.

Compare this with other project trial sites.

When compared with the cropping sites, native pasture showed more carbon, with this difference increasing over time, especially in the top 30 cm of the soil profile. The size of the difference between the two different land management regimes seems too large for minimal disturbance cropping. It is difficult to explain why from using a case with only two sampling periods. Perhaps these two paddocks historically had different soil carbon levels.

CASE STUDY 4 RESULTS

Pine plantation vs old introduced pasture and cropping

In both 2012 and 2014 the soil with the pine plantation had the most carbon of the three management options being compared. Over the period of the project the pine plantation showed the largest increase in carbon levels. The extent of this increase is likely to represent the considerable variability within the sampling area and not actual sequestration due from management. Although the older pasture carbon levels were a little more than crop levels in 2012, by 2014 the older introduced pastures carbon level decreased slightly so that the crop soils had more carbon. The improvement in soil carbon levels in the cropping soil was more marked in the top 30cm, which points to the effect of management on carbon levels here.

The increase in soil carbon in the cropping site may well be due to increased nutrient application followed by increased plant growth and favourable climatic conditions, coupled with the minimal soil disturbance cropping methods used. Under drier conditions where water limits plant growth carbon stocks could well decline more than those of a pasture.

Table 7: Soil carbon change from 2012 -2014 at two depths (t/ha).

Management	Soil C trend over 2 years	0 – 30 cm		0 – 50 cm	
		2012	2014	2012	2014
Pine plantation	↑ ↑ ↑	66.8	93.9	85.1	125.1
Crop	↑	42.4	46.5	53.8	57.2
Old Introduced pasture	↓	44.9	43.6	59.3	55.8

Table 8: Comparisons*

Comparisons	0-30 cm		0-50cm	
	2012	2014	2012	2014
Old into pasture vs crop	2.56	-2.90	5.51	-1.92
Old intro pasture vs Pine	-21.90	-50.24	-25.73	-69.34

* The comparison table shows the difference in soil carbon between the two management options specified. A positive number indicates the first management option in the comparison is better than the second option in the comparison. A negative result means it is not as good. So this table shows native pasture had more carbon at all depths in all years than the new pasture, but it had less soil carbon than the cropped soils for all years at all depths.

Compare this with other project trial sites.

What does it mean for the Monaro region?

In this field survey minimal disturbance cropping did not decrease soil C stocks at all sites. Cropping in years when climatic conditions are favourable may therefore offer an opportunity for landholders to diversify their enterprise and to at least maintain or increase C stocks to levels that are comparable to introduced pastures without compromising soil C. However, under drier conditions and over the long term the carbon stocks may well decline to a greater extent under a crop when compared with a perennial pasture.

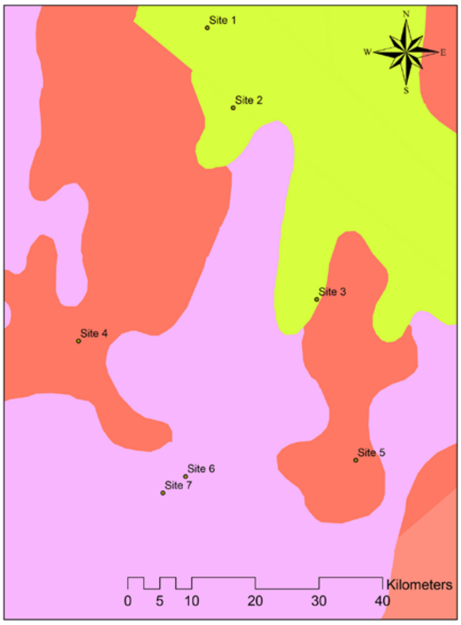
Question 2. What is the effect of 'parent material' on carbon stocks in the Monaro region?

Answer: Parent material influences soil properties such as fertility and clay content, both of which drive biomass production (organic matter supply) and the protection of organic matter in soil.

Soil type affects soil carbon levels because it influences potential plant growth through its texture, structure and fertility. In addition, the clay content of a soil affects how exposed soil carbon is to further breakdown and loss by decomposition from the soil. Clay can bind soil carbon, protecting it from breakdown and protecting existing soil carbon stores.

Soil type is a result of the soil forming processes that have occurred over time and the parent material from which they are formed. The different rock types on the Monaro plain give rise to different soil types. The less fertile, Chromosols and Kandosols, are derived from the granitic and sedimentary rock while the richer Ferrosols and Dermosols (red and brown) are derived from material of basaltic origin.

Where



Caption: Geology of the study region. Basalt in yellow, low grade metamorphics in pink and granite in red

Table 9

Site ID from map	Comparison details		
Site 1	Crop (R01) B	Native pasture (R02) B	
Site 2	High P (Mc19) B	Low P (Mc18) B	
Site 3	Old Intro Pasture (G16) Sed	New Intro Pasture (G17) Sed	
Site 4	Crop (M12) G	Native pasture (M13) G	New Intro Pasture (M14) G
Site 5	No lime (H04) G	Lime (H05) G	
Site 6	Crop (J08) Sed	Native (J09) Sed	New Intro Pasture (J10) Sed
Site 7	Crop (J11) Sed	Old Intro Pasture (J15) Sed	Pine (03) Sed
Site 8	North Aspect (H06) Sed	East Aspect (H07) Sed	

Legend – Table 9 (Surnames of Trial Site Hosts, 19 trial sites)

G = granite, B = basalt, P = phosphorus, Sed = sedimentary
R01 / R02 – Rolfe sites 1 and 2
Mc18 / Mc19 – McGufficke sites 18 and 19
H06 / H07 – Horton sites 6 and 7
J11 / J15 / P03– Jeffreys sites 11 and 15 compared with Pine Plantation site 3
J08 / J09 / J10 – Jeffreys sites 8, 9 and 10
H04 / H05 – Hood sites 4 and 5
G16 / G17 – Garnock sites 16 and 17
M12 / M13 / M14 – Mitchell sites 12, 13 and 14

What we found

After averaging the carbon stock results from all trial sites in the project according to their parent materials it was clear that parent material significantly influenced the stock of soil C; with basalt- and sedimentary-derived soil having a much greater stock of C in the 0 to 0.50 m compared with granite-derived soil.

Parent material	C stock (t/C/ha)*	
	0 - 0.30 m	0 - 0.50 m
Granite derived soil	43.9	58.4
Sedimentary derived	50.7	62.9
Basalt derived	61.6	84.3

* Based on 2012 project survey data

In all the soil types the 30 to 50 cm soil layer contained a considerable proportion of the total soil carbon stock. On average basalt derived soils had 27 % in this 30 – 50 cm, while sedimentary soils showed 19 % and granite derived soils had 25 % in this subsoil (30 to 50 cm) layer.

What does it mean for the Monaro region?

Parent material significantly influences carbon stocks in the Monaro region. As well as clay content, which is most important for the retention of carbon in soils, parent materials affect fertility and thus plant production. It is important to remember this when determining the potential of a soil type in the Monaro region to increase soil carbon. A soil with low carbon levels may have little capacity to increase and maintain higher carbon levels because of the characteristics of its parent material.

In terms of building soil carbon levels; granitic-derived soils often have lower carbon levels and lower fertility levels. So it would appear that they would have greater potential to increase soil carbon if fertility is improved. However, they also have a reduced capacity to hold onto this carbon due to their characteristics of less clay and poorer water holding capacity. These features often make it more difficult to grow the plants which will add to the carbon stocks. It is unclear if the cost associated with trying to improve these soils to grow more biomass would be worth the gain in soil carbon.

The results also showed the significance of soil carbon deeper than 30 cm, highlighting the importance of considering this soil layer when investigating the implications of land management on soil C stocks. If carbon can be added into this deeper layer in the soil there may be less risk of it being lost through decomposition.

Question 3. Does 'aspect' influence carbon stocks in a system with optimum sequestration potential?

Answer: No, differences between aspects where not substantial and would probably not translate into enough of a difference to manage these slopes differently for carbon capture purposes

As most people are aware, aspect plays a big part in the productivity of any given piece of land. Aspect governs the temperature and moisture variables a soil is exposed to. This in turn greatly influences not only how well plants grow but which plants grow. MFS identified aspect (anecdotally) as having a significant influence on pasture production, type and composition. Producers felt it would be a useful exercise to compare soil and pasture parameters on contrasting aspects within the same paddock. A site was selected where an east and a north facing slope sown to an introduced perennial pasture were located in the same paddock.

In the Monaro region southerly facing slopes are generally cooler and wetter while northerly facing slopes are drier and warmer. Does this translate into a difference in soil carbon stocks?

Where?

Location: Quinburra

Caption: Ron and Mandy Horton, 'Quinburra' sheep yards

The trial took place on the property of Mandy and Rob Horton, in the Craigie district, south-east of Bombala. The paddock chosen had two slopes with the steepest gradient, desired aspect within close proximity to each other, and had exhibited an observable aspect effect in the past. At the site chosen there has been more than 20 years for the interactions between aspect and soil carbon to be in play under the same land management regime.

The soils on the property are mainly formed from shale/slate. Both trial sites were fairly infertile with low S, acidic, poor ability to hold nutrients (CEC) and high available Al (toxic) and above 2% total carbon on the top 10cm only. Below this level the carbon levels dropped markedly.

Ron and Mandy, with their three children, own and operate a 3,300 acre (1335 ha) grazing property Quinburra. They currently manage approx. 11-12,000 sheep and join 6,000 ewes each year in a 60% wool, 40% meat sheep enterprise. They have an annual average rainfall of 650 mm.

The property was first purchased by Ron's grandfather in 1959 with Ron and Mandy taking the helm in 1997, and subsequently expanding their acreage over the years. They have implemented a gradual pasture improvement strategy sowing phalaris, sub clover and annual grasses, coupled with a regular, targeted fertiliser program.

Mandy and Rob wanted to know where carbon is more likely to accumulate on their farm. Anecdotally pastures with a northerly aspect are perceived to grow better. Does this translate into an increase in soil carbon?

Caption: View of the north and east aspect sites under an introduced pasture, near Craigie NSW.

Caption: Soil cores (Red Chromosol) from the northern aspect site, near Craigie NSW.

What we found

Although the carbon stocks in the soil with a northerly aspect were higher this difference was not great. It appears that aspect does not have a great influence on soil carbon at this site. The results were not what were expected. When the model Grassrgo was used to simulate what may happen in the longer term, it indicated that little difference would be expected in plant production between aspects here. Closer inspection of soil chemistry analysis from the site indicated that there are other limitations to plant production in the paddock. These limitations may well have concealed any difference due to aspect.

Table 10: Difference in carbon stocks between 2012 -2014 at two depths (t/ha).

Management	Soil C trend over 2 years	0 – 30 cm		0 – 50 cm	
		2012	2014	2012	2014
North	↑	46.9	49.4	55.7	58.1
East	↑ ↑	42.4	48.1	52.3	69.9

The climate data from the site revealed there was not a great deal of difference between the two aspects in term of climatic conditions. There was no significant divergence in either maximum or minimum temperatures by aspect for the period from February 2013 to February 2015. The information about rainfall is not as reliable. It appears that there was no significant difference in rainfall either during the period of the trial but the collection devices for rainfall intensity and volume had intermittent faults. Wind data collected on site for each aspect indicates that the north aspect was more exposed to wind than the east slope.

The large difference between the aspects below 30cm in 2014 reflects the spatial variability of soil carbon at the depth sampled rather than a huge across-the-board change in soil carbon below 30 cm for one year.

Table 11: Comparison *

Comparisons	0-30 cm		0-50cm	
	2012	2014	2012	2014
North vs East	4.60	1.29	3.40	-11.87

* The comparison table shows the difference in soil carbon between the two management options. A positive number indicates the first management option in the comparison is better than the second option ; a negative result means it is not as good. So in this table soils with a northerly aspect had more carbon at all depths for all years except 2014.

Compare this with other project trial sites.

What does it mean for the Monaro region?

Although it appears there may be potential to sequester more carbon on slopes with a northern aspect the difference between aspects was not substantial and would probably not translate into enough of a difference to manage these slopes differently for carbon capture purposes. The small observed difference in soil carbon levels may in part be due to pasture growing faster with a longer growing season on warmer slopes. However there may be differences in how and when these slopes are managed for use by stock based on aspect. In addition to this, given the results of the soil chemistry analysis, there may well be potential to increase carbon stocks with a soil fertility management plan for the entire paddock. Greater biomass production would be expected if phosphorus and sulfur levels were improved.

Question 4. Does liming introduced pasture increase C sequestration?

Answer: If pH is limiting plant production, then applying lime may increase soil carbon over the long term. Sampling for soil carbon after liming must take into account possible short term priming effects.

It is well documented that applying lime to most acidic soils (below 4.6 $CaCl_2$) will improve productivity of moderately sensitive plants and soil health. The influence that lime application may have on soil carbon stock is related directly to the ability of lime to improve plant growth by removing the acidic soil constraint. Liming was identified as a priority issue for some landholders on the granite-derived soils that are highly leached and poorly buffered.

MFS members were interested in investigating whether any increase in plant production ultimately leads to a measurable improvement in soil carbon stocks over a short period.

Caption: Limed and unlimed introduced pasture site included in the survey, near Bombala NSW.

Where?

Location: Springvale

Caption: Charlie Hood, 'Springvale', inspecting wethers

Springvale (also known as Myamba) is a 2000ha property approx. south west of Bombala with poorer soils predominantly derived from shale and granite, i.e. Chromosols and Kandosols . The project site had a history of lime applications on a soil type (red Chromosol) that is known to respond to lime as it had previously been used in a NSW DPI liming trial (2.5t/ha in 2002). Two sites were chosen in adjacent paddocks with a phalaris, sub clover pasture (one limed and one un-limed).

Springvale has been in the Hood family since approximately 1870 and is now managed by Joe Hood and his son Charlie as part of Tintagel Pastoral Company (TPC). TPC currently manages approx. 4,250 ha, running 12,500 merino ewes, 1,600 crossbred ewes and 500 breeding cattle.

Today 90% of Springvale is improved pasture and on average it runs 12,000 merinos and 200 cows. On average, 100ha of the property is sown to a fodder crop each year.

Originally the property was timbered and most likely cleared in the 1840s. The native pasture composition following clearing was poa tussock and kangaroo grass. The first improvements to permanent perennial pasture and first cultivation of the soil were initiated in 1954 following a broadcasting of sub clover and super in the 1930s.

What we found

The carbon stock levels between limed and unlimed soils fluctuated during the period of the study. Over the time of the project carbon increased at both sites but the differences were not consistent over time. In 2014 the limed treatment under introduced perennial pasture had a lower stock of soil C compared with the unlimed site. This is consistent with other studies (Chan et al. 2011) and may indicate a priming effect. However in 2012 there was more carbon under the limed treatment than the unlimed.

It should be noted that the differences are small when related to the entire carbon stock (only around 10%) and as such the variability seen in the results is likely due to the spatial variability in soil carbon associated with perennial pastures.

Table 12: Soil carbon changes across 2012 - 2014 at two depths (t/ha).

Management	Soil C trend over 2 years	0 – 30 cm		0 – 50 cm	
		2012	2014	2012	2014
Lime	↑	45.9	52.29	58.9	67.4
No lime	↑ ↑	47.3	47.4	60.0	63.6

Table 13: Comparison between limed and unlimed soil*

Comparisons	0-30 cm		0-50cm	
	2012	2014	2012	2014
Lime vs no lime	1.43	-4.86	1.19	-3.82

* The comparison table shows the difference in soil carbon between the two management options. A positive number indicates the first management option in the comparison is better than the second option. A negative result means it is not as good. So in this table lime had more carbon than no lime in 2012 but not in 2014.

Compare this with other project trial sites.

What does it mean for the Monaro region?

In the longer term, liming can influence the composition of a pasture. If liming promotes greater legume growth, which supplies more nitrogen to the grasses in the pasture, then the resulting increase in plant production as well as the increased soil nitrogen may well lead to an increase in soil carbon levels. This is supported by the positive correlation between soil carbon levels and total nitrogen found in this project. In addition, if low soil pH is limiting plant growth, liming will remove this limitation and may therefore increase the addition of plant material to the soil and thus carbon levels. These increases could offset short term carbon losses due to the increase in soil biological activity promoted when soil pH is improved.

The higher soil carbon levels under the unlimed trial site in 2014, particularly in the surface layers, may be due to the reduced biological activity often found in acid soils. Reduced biological activity may lead to less organic matter being decomposed, a natural loss pathway for carbon. That is liming may have, in the short term, had a biological priming effect. It does this by increasing microbial decomposition of native soil C. This leads to carbon loss as carbon dioxide from microbe respiration as acidic soil constraints are removed by liming.

Question 5. What effect does soil fertility have on C stocks in the Monaro region?

Answer: Increasing biomass production by addressing soil nutrient requirements may increase SOC stocks.

- Increasing S to critical levels increased carbon but P had no effect
- Increasing soil N was associated with higher levels of C

Current research work suggests fertility has a significant effect on the carbon sequestration potential of soils. Providing better nutrition for either a crop or pasture to reach its potential production means more root and shoot growth, much of which is returned to the soil to add to carbon levels. However does this hold true for native pastures that are naturally adapted to poorer soils and are thought to not 'need' additional phosphorus?

Caption: High fertiliser trial site on a native pasture, near Bungarby NSW.

Where

Location: Idaho

1. Phosphorus levels

Caption: Mark McGufficke, weighing wool, MFS Wether Trial

A paddock of poa tussock with native grass (snowgrass, danthonia) and some legumes on the Idaho property of the McGufficke family was used. The basalt-derived soil (red Dermosol) at the site was moderately fertile although the no fertiliser site had low S, which is a natural characteristic of basalt-derived soils. Both sites had a moderate phosphorus buffering index.

Idaho is located in the Bungarby region of the Monaro, SW of Cooma. The property is owned and managed in partnership by brothers, Alan and Mark and their families and its soils are predominantly basalt derived. The historic average, annual rainfall is approximately 585mm.

This part of the soil carbon project trial was carried out on a paddock used in a DPI/Southern Rivers Catchment Management Authority trial. This previous project (2005-2010) assessed the use of fertiliser and legume additions to achieve productivity gains in native grasslands, comparing a low fertiliser application of 19kg/ha/yr sulfur and zero phosphorus with a high fertiliser treatment of 11kg/ha/ yr of phosphorus and 33kg/ha/yr sulfur. Between 2005 and 2010 annual fertiliser applications were made on both paddocks in the autumn. The rates were:

- low 125kg gypsum
- high 125kg gypsum + 125kg superphosphate.

Caption: Soil cores (Red Dermosol) from the high fertiliser trial site on a native pasture, near Bungarby NSW.

2. Nutrient correlations

Soil chemical data in 10 cm increments was collected from all 19 sites in the project. This information was used to examine the relationship between soil carbon and other soil chemical characteristics. The chemical properties used in the correlation included total carbon (TC), total nitrogen (TN), particulate organic carbon (POC), resistant organic carbon (ROC), humus (HUM), pH, cation exchange capacity (CEC), available sulfur and phosphorus (Colwell)

What we found

1. Phosphorus levels

There was an increase in carbon stocks between 2012 and 2014 under the low phosphorus fertiliser treatment so that by 2014 soil carbon levels in the high phosphorus site were no longer better than the low phosphorus site. Given that they were much better in 2012 this is a large drop. At this site this could be due to a couple of things. It could be that:

- in higher fertility sites the available sulfur and phosphorus allows more rapid decomposition of more labile forms of carbon leading to lower soil carbon levels
- the soil preparation associated with the new pasture (sown 2014 to a Lucerne mix) may also have had a priming effect.

The difference in C stocks between the sampling times reflects not only possible spatial variability in soil carbon associated with pastures (as previously discussed), but also the influence of soil preparation, sowing and the newly emergent pasture.

Table 14: Change in soil carbon from 20-12 – 2014 at two depths (t/ha).

Management	Soil C trend over 2 years	0 – 30 cm		0 – 50 cm	
		2012	2014	2012	2014
Nil P (low)	↑↑↑	61.4	77.1	75.9	101.5
125kg/ha P (high P)	↓↓	78.8	73.5	108.7	101.1

Table 15: Comparison between high and low Phosphorus sites*

Comparisons	0-30 cm		0-50cm	
	2012	2014	2012	2014
High v low P	17.44	-3.62	32.78	-0.34

* The comparison table shows the difference in soil carbon between the two management options. A positive number indicates the first management option in the comparison is better than the second option in the comparison. A negative result means it is not as good. So in this table the high P management option had more carbon than the low in 2012 but not in 2014.

Compare this with other project trial sites.

2. Nutrient correlations

Variability in soil carbon content between all the sites decreased with depth, which indicates the increased influence of management on the top layers. However correlation of chemical properties is also strongly affected by parent material so this was taken into account when estimating correlations.

Soil type seems to play a large part in determining whether the correlation between soil carbon and an attribute is positive or negative. Correlations are described as either negative or positive. That means, if total carbon increases along with another soil chemical attribute the correlation is 'positive' and if one attribute decreases as carbon increases it is 'negatively' correlated. However it is difficult to determine causation: Is it environmental or management? Is it because of the case study nature of this project, with little replication?

This project supports previous findings (Orgill et al. 2014), that total carbon concentrations in the soil are highly positively correlated with total nitrogen, and the various carbon fractions (POC, ROC and HUM). There is also a strong positive correlation between these attributes i.e. total N and the carbon fractions (POC, ROC, HUM) with pH, CEC and available nutrients S and P. So what does this mean? Largely, it may indicate that if soil conditions (N, pH, POC etc) are adequate for biomass production (that is, ultimately, the supply of organic matter) then soil organic carbon may increase. Remembering that, this increase in organic matter supply also needs to feed the microbial community which responds favourably to the same conditions as plants.

The correlation between other soil chemical attributes and soil carbon was not detected in both years of sampling, which indicated that the relationship between these is influenced by other variables such as climatic conditions and or variability across the landscape. Examples of these are the correlation between available phosphorus and POC.

What does it mean for the Monaro region?

The granite-derived soils of the Monaro region are inherently low in P, while the basalt soils are inherently low in S. Addressing the P and S requirements of pastures can increase above and below ground plant matter and therefore OM supply to the soil (Chan et al. 2010) and can also increase the stability of soil C (Kirkby et al. 2011). The GrassGro model outputs for this project suggest addressing critical soil nutrient levels may increase herbage mass production (OM supply) which may lead to an increase in soil carbon stocks.

While the exact process(es) leading to the differences in soil carbon between the phosphorus treatments cannot be identified in this project, it is known that changing vegetation species in the paddock, disturbing the soil and applying nutrients can facilitate a priming effect and result in a decline in the labile more vulnerable forms of organic matter.

It should also be noted that improving the nutrient status of a soil where this lack has been limiting soil biological activity will have a priming effect. In the short term this can decrease soil carbon levels as biological activity surges. Adequate C, POC in particular, and nutrients will enhance priming. However, this is usually short-lived and rarely negates the long term benefits of improved nutrient status for improved plant production and thus long term addition of carbon to the soil. It may, in fact 'kick start' other processes that further improve plant growth. Much like an engine that runs better and more efficiently after it has been tuned.

It is important to remember that correlation between attributes does not imply causation. High phosphorus content in a soil may not lead to an increase in soil carbon, especially if the nutrient is not limiting plant growth. Addressing the limitation(s) to plant growth, whatever they may be, to increase production may lead to increased soil carbon levels.

Question 6. What effect does pasture age have on the potential for perennial pasture to sequester carbon?

Answer: Age of pasture is not the only factor important for carbon build up. If carbon stocks can rapidly increase at a site, it should be assumed that they could decrease just as rapidly.

Using pasture has been touted as a good way to capture carbon in cropping systems that are depleted of carbon. But in a perennial pasture system the soil is little disturbed after initial sowing, if at all. Research seems to suggest that the best soil C system in a grazing enterprise is a diverse and healthy perennial pasture system due to its deep rooted species, effective water holding capacities and pasture production potential. Thus losses are minimised and theoretically carbon can accumulate in the soil. However there may be an upper limit of carbon that a particular soil in a particular environment can store. Does pasture age create a 'ceiling' on sequestration potential? Do older pastures that have essentially reached equilibrium have less capacity to increase carbon stocks than newly established pastures?

Caption: New introduced pasture site included in the survey, near Bombala NSW.

Where

Location: South Bukalong

Caption: Bryce Garnock, South Bukalong

This trial was carried out on the 2,180 ha grazing property of Bryce and Sarah Garnock, with predominantly basalt / slate derived soils and an average annual rainfall of 499mm.

Two introduced perennial pasture sites adjacent to each other with the same brown Chromosol soil were chosen for the project. The oldest introduced pasture was sown over 40 years ago in 1974 and the newest pasture under 10 years ago(sown in 2003). The trial also included native perennial pastures which are the oldest pasture; having never been significantly altered since first white settlement.

Since taking on the property from his parents Murray and Carol Garnock in 2005, Bryce and Sarah have made a quantum shift towards cattle trading rather than a whiteface bull breeding enterprise and 4,000 self-replacing ultrafine Merino Ewes the property used to produce.

Historically the property was managed in a slow grazing rotation alternating with stud breeding stock at 7-8 DSE/ha followed by the sheep with superphosphate added every two years. Before the 1970s the large paddocks on the property were set-stocked with both sheep and cattle. The majority of the property is improved country, of a dominant phalaris and cocksfoot base with some clover appearing if the season is favourable.

In 2005 Bryce and Sarah initiated a timed rotational grazing system (50% sheep, 50% cattle) with advice from Bruce Ward, an Alan Savory Holistic Educator. Since the stud's dispersal in 2007, the drought continued and reluctantly they had to sell their entire merino flock.

After rain later in the season, Bryce used agistment for cash flow and then traded cattle so their stock numbers and type vary significantly from year to year, following the carrying capacity which depends on the rainfall pattern. By not breeding they can fully destock without any emotional attachments and purchase without the dilemma of introducing diseases to their base herd or flock.

New improved

Old improved

What we found

The carbon stocks in both the old introduced pasture and the new introduced pasture decreased over the life of the project. The decline in carbon levels is hard to explain given the favourable conditions for plant growth during the period of the study. Perhaps these conditions also led to greater decomposition of organic matter or maybe the nutrient levels in the soil were not adequate for optimal plant growth and thus limited soil carbon accumulation. The sampling methodology may also have contributed to differences in carbon stocks between the two sampling periods.

In 2012 the difference in carbon levels showed the younger pasture (10 years old) had more carbon than the older pasture in the top 30 cm but over-all the older pasture had very similar total carbon, indicating that in the soil with the older pasture is storing more carbon in the 30 – 50cm section of the soil profile. In comparison in 2014 the older pasture seems to have lost less carbon in total. Perhaps this is due to the greater proportion of carbon the older pasture soil has below 30 cm where it is more protected from losses.

The new pasture in this comparison was sown in 2003 and it would be expected that the rapid increase often observed with newly established pastures is beginning to wane.

Table 16: Soil carbon changes for 2012 – 2014 at two depths (t/ha).

Management	Soil C trend over 2 years	0 – 30 cm		0 – 50 cm	
		2012	2014	2012	2014
Old introduced pasture	↓	46.7	44.9	66.3	61.3
New Introduced pasture	↓ ↓	50.8	40.8	65.9	54.6

Table 17: Comparison between old and new introduced pastures *

Comparisons	0-30 cm		0-50cm	
	2012	2014	2012	2014
Old vs new	-4.15	4.20	0.35	6.67

* The comparison table shows the difference in soil carbon between the two management options. A positive number indicates the first management option in the comparison is better than the second option, A negative result means it is not as good. In this table the old pasture had less carbon than the new pasture in 2012 in the 0-30 cm depth but for all other years and depth the new pasture had more carbon.

Compare this with other project trial sites.

Interestingly, in other project pasture sites there was a greater stock of soil C under two of the three younger (<10 years old) perennial pastures compared with older introduced or native perennial pastures. The pasture that was <5 years old and sown on a soil derived from low grade metamorphics had 23.8 t/C/ha/30 cm more soil carbon in 2012 compared with the native pasture pair and 28.0 t/C/ha/30 cm in 2014. This new introduced pasture was sown in 2010 and had been cropped for the previous 6 years. This greater stock of soil C may be explained by continued fertiliser (N,P,S) application during both the cropping and pasture phase and the three years of above average rainfall since pasture establishment in 2010.

What does it mean for the Monaro region?

The results from the pasture age comparison were unexpected and did not follow the typical trend of a new pasture system. We expected that soil carbon would increase rapidly initially and over time the rate of the increase would slow. Other studies have shown newly established pasture can increase soil carbon in the first 5-10years. After this the rate of carbon build-up slows for up to 30 years, so a greater stock is built up earlier. Although not reflected in these small scale trial results, a perennial pasture system is still understood to be the best agricultural system for building soil carbon. To maximise the potential of a pasture to gather carbon it is important to ensure optimal growing conditions such as supplying all the required nutrients. It would seem the results seen here are most likely due to a spatial sampling incongruence.

Despite the new pasture results, the result for the older pastures highlight the importance of time in building up lasting stores of carbon. Most importantly, **the soils with older perennial pastures and native perennial pastures have a greater percentage of the carbon stock below 30 cm where it is more protected from loss than those with younger pastures.** Over time, as undisturbed perennial pasture grows, it produces more roots and soil processes move these and the products of their decomposition around the soil.

Caption: Old introduced pasture site included in the survey, near Bombala NSW.

Table of results

Table 18: The 2012 carbon stocks were calculated to a depth standard and the 2014 carbon stocks were calculated based on an equivalent soil mass (with the 2012 soil as the reference soil mass).

	0-30 cm			0-50 cm		
Management	2012	2014	Difference	2012	2014	Difference
Basalt derived soil						
Crop (R01)	46.39	50.12	3.74	71.72	77.09	5.37
Native pasture (R02)	59.98	64.94	4.97	80.80	87.10	6.30
# Native pasture - Crop	13.59	14.82	1.23	9.08	10.01	0.93
Low P (Mc18)	61.38	77.10	15.72	75.87	101.45	25.58
High P (Mc19)	78.82	73.48	-5.34	108.65	101.11	-7.54
# High - Low P	13.44	-3.62	-21.06	32.78	-0.34	-33.12
Low grade metamorphics						
North Aspect (H06)	46.97	49.38	2.41	55.69	58.09	2.40
East Aspect (H07)	42.37	48.09	5.72	52.29	69.96	17.67
# North-east Aspect	4.60	1.29	-3.31	3.40	-11.87	-15.27
Crop (J08)	47.65	45.36	-2.29	55.69	52.43	-3.26
Native (J09)	45.15	55.91	10.76	56.76	70.34	13.59
# Native pasture - New intro pasture	-23.81	-13.99	9.81	-28.00	-16.38	11.62
# Native pasture - Crop	-2.50	10.55	13.05	1.07	17.91	16.84
Pine (03)	66.83	93.87	27.04	85.06	125.14	40.07
Crop (j11)	40.37	46.53	4.16	53.82	57.72	3.90
Old intro pasture (J15)	44.93	43.63	-1.30	59.33	55.80	-3.53
# Old intro pasture - Crop	2.56	-2.90	-5.46	5.51	-1.92	-7.43
# Old intro pasture - Pine	-21.90	-50.24	-28.34	-25.73	-69.73	-43.61
Granite derived soil						
Unlimed (H04)	45.87	52.29	6.42	58.85	67.43	8.57
Lime (H05)	47.30	47.43	0.13	60.04	63.61	3.57
# Lime - unlimed	1.43	-4.86	-6.29	1.19	-3.82	-5.00
Crop (M12)	40.21	53.19	12.98	54.92	67.26	12.34
Native pasture (M13)	39.94	46.80	6.86	54.88	62.45	7.57
New intro pasture (M14)	36.66	42.79	6.13	47.64	54.69	7.05
# Native pasture - New intro pasture	3.28	4.01	0.73	7.23	7.76	0.52
# Native pasture - Crop	-0.27	-6.39	-6.12	-0.04	-4.81	-4.77
Old intro pasture (G16)	46.66	44.99	-1.67	66.27	61.29	-4.98
New intro pasture (G17)	50.80	40.79	-10.02	65.91	54.62	-11.29
# Old intro pasture - New intro pasture	-4.15	4.20	8.35	0.35	6.67	6.31

Background information on the trials

Site selection

Land use and soil type combinations were decided upon by members of the Monaro Farming Systems group. Sites were selected based on their parent material, vegetation and management class and proximity to comparison, as well as landholder cooperation and agreement. Sites were selected following a field trip by Nancy Spoljaric (Project Officer, MFS), Luke Pope (formerly District Agronomist, NSW DPI) and Lachlan Ingram (Lecturer, University of Sydney). Comparisons are listed in Table 19.

Table 19: Summary of the comparison with parent material class (IPP: Introduced Perennial Pasture, NPP: Native Perennial Pasture). All pasture paddocks were grazed.

Parent material	Comparison	Treatment
Basalt	Crop (R01) vs NPP (R02)	Short term cropping (since 2012, previously NPP) paddock (barley in 2012) compared with a native perennial pasture.
	Low fertiliser (Mc18) vs High fertiliser (Mc19)	Low compared with high P,S input (since 2005) on a native perennial pasture.
Low grade metamorphics	IPP: Aspect North (H06) vs East (H07)	North aspect compared with east aspect within the same paddock under an introduced perennial pasture (sown 1989).
	Crop (J11) vs >35 yr old IPP (J15) vs Pine Plantation (P03)	Long-term cropping (since 1998) paddock (oats 2012) compared with an old introduced perennial pasture (sown 1960) and commercial pine plantation (established 2002).
	Crop (J08) vs NPP (J09) vs <5 yr old IPP (J10)	Short term cropping (since 2009, previously native perennial pasture) paddock (wheat 2012) compared with a native perennial pasture and a new introduced perennial pasture (sown 2010, previously crop since 2004).
Granite	IPP: Unlimed (H04) vs Limed (H05)	Unlimed compared with limed paddock (2.5t/ha lime broadcast in 2002) under introduced perennial pasture (sown 1970).
	IPP: >35 yr old (G16) vs <10 yr old (G17)	Old (sown 1974) compared with new (sown 2003) introduced perennial pasture.
	Crop (M12) vs NPP (M13) vs <5 yr old IPP (M14)	Short term cropping (since 2011, previously introduced perennial pasture) paddock (wheat 2012) compared with a native perennial pasture and new introduced perennial pasture (sown 2012, previously crop since 2009).

Table 19 Legend - Trial Sites (names of Site Hosts, 19 trial sites)

R01 / R02 – Rolfe sites 1 and 2
Mc18 / Mc19 – McGufficke sites 18 and 19
H06 / H07 – Horton sites 6 and 7
J11 / J15 / P03– Jeffreys sites 11 and 15 compared with Pine plantation site 3
J08 / J09 / J10 – Jeffreys sites 8,9 and 10
H04 / H05 – Hood sites 4 and 5
G16 / G17 – Garnock sites 16 and 17
M12 / M13 / M14 – Mitchell sites 12, 13 and 14

Testing and sampling

All sites were sampled in late spring in 2012 and 2014. For the field survey, 19 sites were sampled, with a total of 266 soil samples collected and analysed in both 2012 and 2014. For the spatial variability investigations, five sites were sampled, with a total of 441 soil samples collected to 0.3 m.

Sample collection

As per requirements that field sampling was carried out to comply with existing SCaRP protocols. Samples were collected using a hydraulic corer and split into depth increments of 0-0.10, 0.10-0.20, 0.20-0.30, 0.30-0.40 and 0.40-0.50 bulked and subsampled for analysis.

At each site four cores were carefully collected to 0.50 m using an 80 mm diameter core (40 mm diameter core in 2014) and a hydraulically driven core sampler for bulk density (BD) measurements (McKenzie et al., 2000). Bulk density was determined on whole soil samples dried at 105°C as described by Dane and Topp (2002) and results were calculated as BD in mg/m^3 (equivalent to g/cm^3) on an oven-dry basis to the nearest 0.01 mg/m^3.

At five of the monitoring sites, the spatial variability of soil carbon across the paddock was investigated. The location of each core was recorded using a GPS.

Sample analysis

Analysis was carried out at NATA accredited laboratories. The analyses carried out were as follows:

- Total carbon
- Total nitrogen
- Carbon fractions (as predicted by Mid Infrared Spectroscopy)
- Phosphorous (Colwell)
- Sulfur (KCl40)
- Cation exchange capacity
- Soil pH (CaCl2)

Protocols

Following are the basic protocols that were followed for sample collection and preparation.

Field sampling:

- Use an appropriate core diameter
- Use an appropriate coring tip (wet/dry) and record tip diameter
- Do not use any coring tube lubricant
- Avoid atypical areas (for example, manure patches, plant crowns)
- Note and discard where necessary atypical samples unless relevant to study
- Record core length and hole depth
- Carefully cut core into appropriate intervals (that is, 0.10 m)
- Scratch a reference depth onto core before cutting to prevent core creeping
- Record actual core length where length differs from regular sampling interval
- Note presence of gravel by depth. If appropriate, note depth where soil boundaries occur
- Store soils in an esky whilst in the field, and refrigerate until able to be dried
- Transfer to oven @ 40°C as soon as possible

Processing: Stage 1 – Sample drying and preparation:

- Ensure preparation area and oven are free of potential organic matter contamination
- Set oven at 40°C
- Roll down bags and push in corners of bags to facilitate drying
- Disturb/mix soils after 24hrs to facilitate drying
- Oven dry (40°C) to constant weight (c. 3 days)
- Sieve samples to 2 mm, record gravel content

Processing: Stage 2 - Sample dispatch:

- Advise receiving lab that soils have been sampled
- Robustly package samples for transit to receiving lab
- Send soils to the NSW DPI Wollongbar Analytical Laboratory (NATA accredited) notifying receiving lab of dispatch.

Further resources

Final report from the Soil Carbon Project

www.monarofarmingsystems.com.au/projects/soil-carbon-project/

Federal government information

Carbon farming futures

www.agriculture.gov.au/ag-farm-food/climatechange/carbonfarmingfutures

CSIRO soil carbon information

Adrian Chappell, Jeff Baldock, Raphael Viscarra Rossel 2013. *Sampling soil organic carbonto detect change over time.*

publications.csiro.au/rpr/download?pid=csiro:EP136498&dsid=DS4

Jonathan Sanderman, Jeffrey Baldock, Bruce Hawke, Lynne Macdonald, Athina Massis-Puccini and Steve Szarvas 2011. *National soil carbon research programme: field and laboratory methodologies*

www.clw.csiro.au/publications/science/2011/SAF-SCaRP-methods.pdf

Jonathan Sanderman, Ryan Farquharson and Jeffrey Baldock, 2010. *Soil Carbon Sequestration Potential: A review for Australian agriculture*

Soil Carbon in Australia's Agricultural Lands. *Soil Research Special Issue* Volume 51, Numbers 7 & 8 www.publish.csiro.au/pid/7314.htm

Media about this project

ABC interview: Farming practices can improve soil carbon stocks May 2015 www.abc.net.au/news/2015-05-11/farmers-to-increase-soil-carbon-stocks/6460698

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