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Soil Carbon Sequestration in Rangelands and carbon trading opportunities for Australian Agriculture

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Executive Summary

The purpose of this report is to investigate rangelands soil carbon and sequestration opportunities that farmers and graziers can exploit. This, amid an emerging, seemingly consumer driven new frontier of sustainability, lifestyle, social and moral fulfilments and economic rewards.

The rise in the awareness of soil carbon and its ability to suck carbon from the atmosphere and back into the soil is gaining momentum. There is also a legitimate and experienced few, whose thinking suggests that carbon is but one component of the agri-ecosystem and should be considered in conjunction with all soil dynamics.

To help clarify some of these issues, this report is a technical document and presents both a review of the mechanisms of carbon capture and storage in agricultural soils and an analysis of the international evolution of soil carbon and carbon commercialisation which are resulting in shifts in agricultural management.

These aspects were concurrently verified with on ground interviews and visits to farms, research facilities and universities, financiers, government officials, proprietary research, proprietary commercial technology, and stakeholders in the soil carbon and carbon trading sectors as part of a Nuffield Scholarship, supported by **Macquarie Agricultural Funds Management.**

Soil carbon is the priority theme in this report. It is used in context within the matrix that is the terrestrial mass that has sustained life for millennia and will continue to, into the future.

> Putting a value on Carbon will mean that for the first time ever, good land management will be financially rewarded. (ABC, 2013) - Terry McCosker.

Soil function, structure and its role in soil carbon sequestration

To fully understand soil, it is important to include a fundamental explanation of how soil works.

The process of soil carbon sequestration has a level of complexity that researchers, scientists and farmers are just starting to comprehend. The process of sequestration is mind-boggling; with the number of interactions and changes in biome matter inestimable. The time it takes to complete the cycle depends on a variety of factors; rainfall, temperature, seasonal changes, chemical and nutrient loads, animal impact, soil disturbance to name a few.

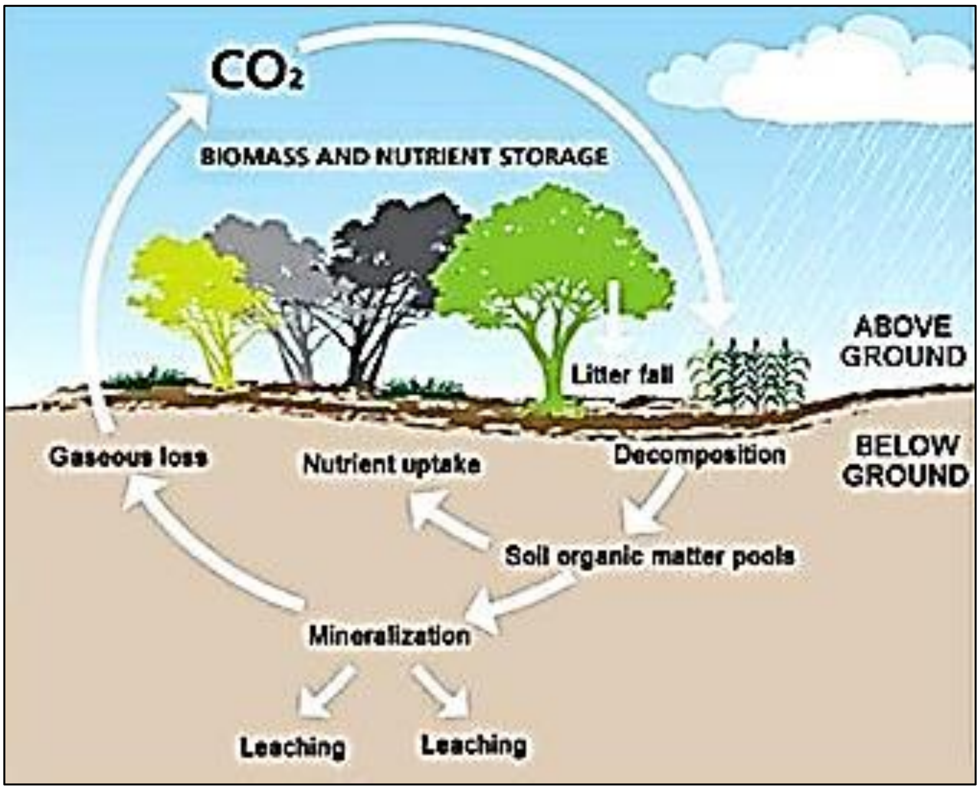

Figure 1 Carbon Cycle - terrestrial and atmospheric. Decomposition of roots and root products by soil fauna and microbes produces humus, a long-lived store of soil organic carbon. (Fortuna, 2012)

The flow of nutrients and carbon through agricultural ecosystems is a natural process which is happening for free every day. The water and carbon cycle are closely linked and one cannot function without the other. The greater the above ground biodiversity, the greater the efficiency of function below the ground. The aim is to increase water penetrability of soil, to accelerate and activate the soil micro-biome to perform their micronutrient transfer, drawdown of carbon via plant photosynthesis, root exudates and multiplying. The organic recalcitrant carbon in soils is the exoskeletons of trillions of small microbes who have bred and multiplied to perform the carbon flow processes.

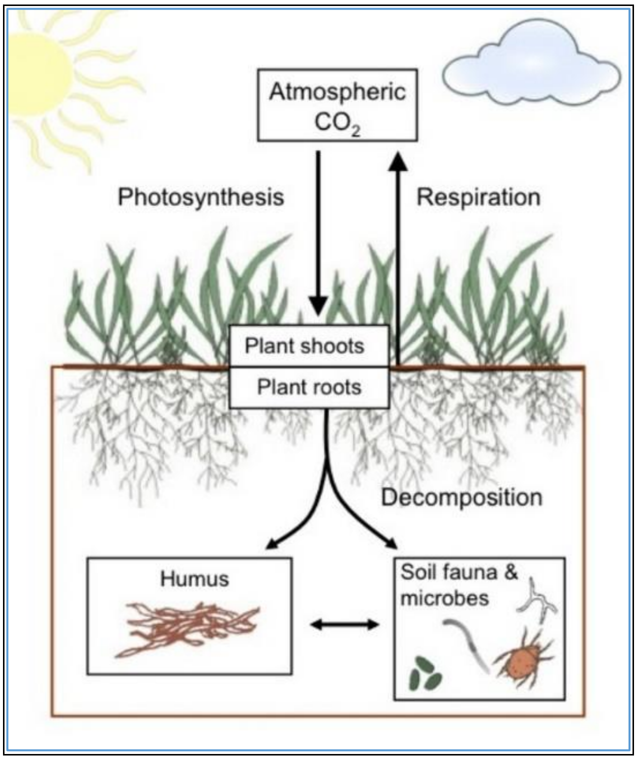

Figure 2 Live component of soils that cause soil carbon to be sequestered, for without these processes, soil is sterile and lifeless. (Fortuna, 2012)

The amount of C in soil represents a substantial portion of the carbon found in terrestrial ecosystems of the planet. Total C in terrestrial ecosystems is approximately 3170 gigatons (GT; 1 GT = 1 petagram = 1 billion metric tons). Of this amount, nearly 80% (2500 GT) is found in soil. (Lal R. , Philosophical Transactions of the Royal Society B, 2008).

Soil carbon can be either organic (1550 GT) or inorganic carbon (950 GT). The latter consists of elemental carbon and carbonate materials such as calcite, dolomite, and gypsum (Lal R. , Soil Carbon Sequestration to mitigate Climate Change, 2004)

The amount of carbon found in living plants and animals is comparatively small relative to that found in soil (560 GT). The soil carbon pool is approximately 3.1 times larger than the atmospheric pool of 800 GT (Eric H Oelkers, 2008)

Only the ocean has a larger carbon pool, at about 38,400 GT of Carbon. (Fortuna, 2012)

Soil contains 80% of all carbon on the planet excepting the ocean, which contains mostly inorganic carbon. It would suggest then, that soil and its overall health are an integral part of a healthy planet.

History of soil depletion and loss of soil carbon

Since the beginnings of recorded history, societies have understood that human activities can deplete soil productivity and the ability to produce food (J R McNeill, 2004). Food has been stored for use later in the year when seasons changed, for at least 10,000 years, (Tudge, 2006) since humans worked out how to sow seeds and harvest crops.

The game changers for soil carbon are not new; carbon extraction from the soils commenced when mass storage of preserved food formed in conjunction with the industrial revolution and world exploration requiring the need for food storage aboard ships taking long journeys across the sea.

The process of canning was pioneered in the 1790s when a French confectioner, Nicolas Appert (Nicholas Appert, 2018), discovered that the application of heat to food in sealed glass bottles preserved the food from deterioration. In about 1806 Appert's principles were successfully trailed by the French Navy on a wide range of foods including meat, vegetables, fruit and even milk. In 1842, John Kilner and Co Glass Company (Bill Lockhart , 2016) started bulk manufacturing glass jars for mass food preservation.

The 1790's signalled the start of the unbalancing of carbon flows away from soils. For the first time in history, all kinds of mass food production could truly be kept indefinitely and sold for a premium out of season. The time of industrial or extractive agriculture began and has continued unabated to today. Human health and population improved and flourished, the transfer of carbon from soils to above ground entities, (plants, and humans, atmospheric) has happily continued at an upward trajectory both literally and figuratively!

There is a growing body of evidence supporting the hypothesis that the earth's climate is rapidly changing in response to continued inputs of CO_2 and other greenhouse gases (GHGs) to the atmosphere resulting from human activities (R K Pachauri, A Reisinger, 2007).

While a suite of GHGs exist (e.g., Methane, fluorocarbons), CO_2 has the largest effect on global climate as a result of enormous increases from the preindustrial era to today. Since 1850, atmospheric CO_2 concentrations have risen from approximately 280 parts per million (ppm) prior to 1850, to 381.2 ppm in 2006 (WMO 2006), with a current annual increase of 0.88 ppm (3.5 GT C/yr.) (R K Pachauri, A Reisinger, 2007).

Approximately two-thirds of the total increase in atmospheric CO_2 is a result of the burning of fossil fuels, with the remainder coming from SOC loss due to land use change, such as the clearing of forests and the cultivation of land for food production. (Fortuna, 2012).

Soil Carbon and Climate Change correlation

Given that soil is/was the largest pool of terrestrial carbon globally, the loss of soil carbon to the atmosphere has had a creeping impact on total GHG build up in the atmosphere. While other non-agricultural emissions account for the majority of the atmospheric problem, it is agriculture that is the only industry that can reverse the flow of carbon into the atmosphere by sequestration processes. All other industries can merely decrease the rate of emissions.

Rothamsted Research Facility at Harpenden UK has been measuring ambient air temperatures since 1880. Discussions with Professor Keith Goulding (Sustainable Soils and Grassland Systems, Rothamsted Research, West Common, Harpenden, Hertfordshire) confirmed during onsite meetings, that these published figures are correct and that since the early 1990's temperatures have been rising. Using the Rothamsted long-term datasets the below graph shows that between 1991 to 2005, the annual mean air temperature (purple asterisk) has increased and is now approximately 1 degree Celsius higher than the long-term mean (1878 to 1990).

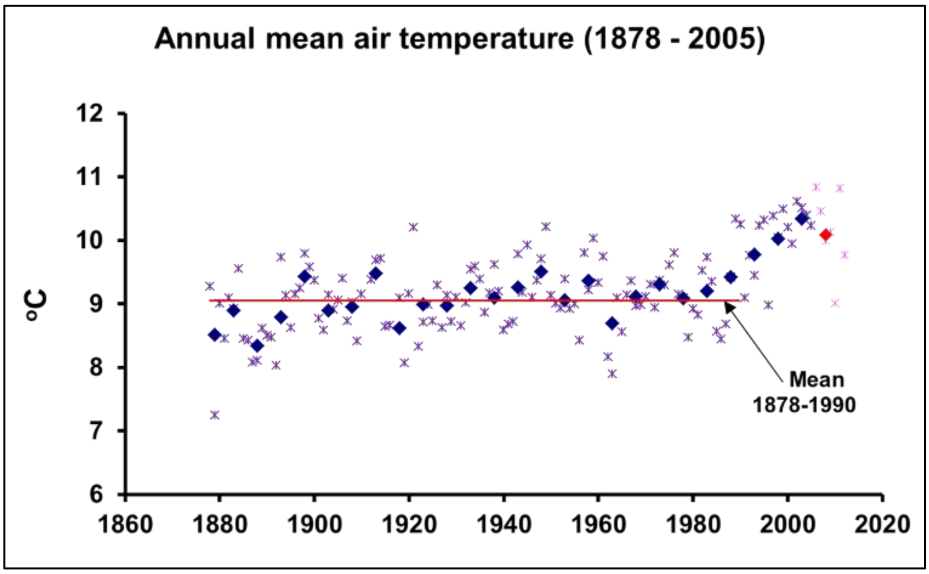

Figure 3. Temperature Recordings Rothamsted Research Facility, UK Years 1890 to present.

Without delving into the causes of this temperature rise, temperatures have increased for the past 23 years at Rothamsted. Evidence and argument as to climate change is documented and debated in copious books, research papers, websites and documentaries. To dissect it again in this report is diverting from the main thrust of the subject of soil carbon and doesn't add any significant insight by re-hashing the pros and cons.

What is important to note is the implications of temperature rises and how this can be advantageous to agriculture, as plants perform well in high levels of CO_2. Recent findings from open top chamber and free air research systems show that SOM turnover appears to accelerate under elevated CO_2 and with adequate soil moisture and nutrients, plant productivity is consistently increased. (Walthall, C.L et al, 2013).

Soil structure and Carbon Sequestration processes

Soil carbon sequestration is a process in which CO2 is removed from the atmosphere and stored in the soil carbon pool. This process is done by plants and soil micro-biome via photosynthesis and natural physiological plant and soil interactions. The result is that carbon is re-introduced and stored as soil organic carbon (SOC). The explanation below helps with describing the soil strata below the surface of the ground that research is beginning to understand.

To appreciate the complexity and best explain the process of sequestration, soil zones containing areas of activity include the:

- Drilosphere - the portion of the soil volume influenced by secretions of earthworms.
- Porosphere - the total pore space.
- Detritusphere - dead plant and soil biota.
- Aggregatusphere - the sum of soil aggregates.
- Rhizosphere – the space around the ryzomes where transfer of nutrients occurs.

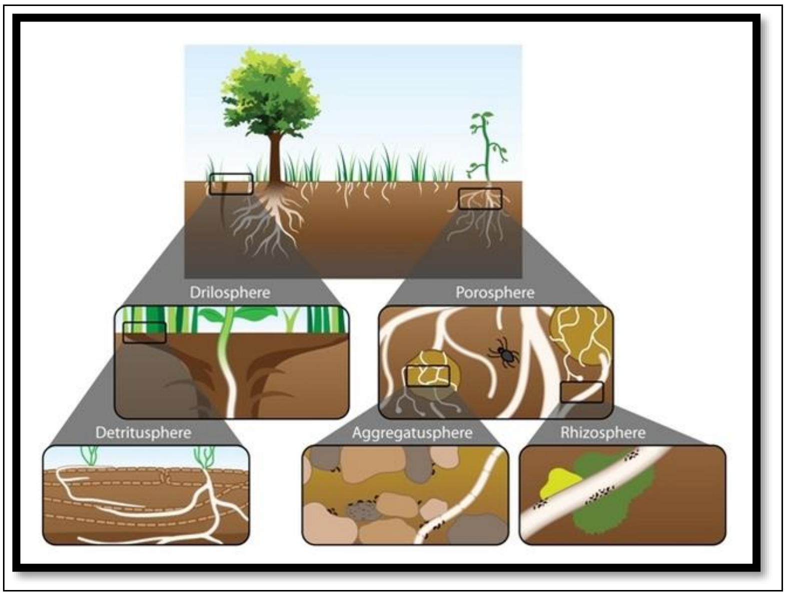

Figure 4 Pedosphere-Areas of activity in soil (Fortuna, 2012)

The Pedosphere, which is the total of spheres/strata, is an underground environment containing multiple resources in an intricate ecosystem. This underground ecosystem varies in size from the microscopic to landscape scale. The interaction of soil organisms is known as the “Soil Food Web” results in the release, transformation and relocation of elements throughout the pedosphere by bio-geochemical processes.

Soil organisms influence soil structure by physically binding soil particles together and increasing the number and size of aggregates that provide habitat for microfauna. Visualizing all the interactions of gases, water, organisms and organic and inorganic constituents in an aggregate at the "microscale" provides us with a "glimpse of the universe" in a gram of soil (Fortuna, 2012).

Soil Biota

Soil biota consist of the micro-organisms (bacteria, fungi, archaea and algae), soil animals (protozoa, nematodes, mites, springtails, spiders, insects, and earthworms) and plants living all or part of their lives in or on the soil or pedosphere. Millions of species of soil organisms exist, but only a fraction of them have been cultured and identified and studied. Microorganisms (fungi, archaea, bacteria, algae and cyanobacteria) are members of the soil biota but are not members of the soil fauna. The soil fauna is the collection of all the microscopic and macroscopic “animals” in the pedosphere. Soil animals can be conventionally grouped by size classes: macrofauna (enchytraeids, earthworms, microarthropods), mesofauna (microarthropods, mites and collembolan), and microfauna (protozoa, nematodes).

Figure 5 A soil aggregate or ped is a naturally formed assemblage of sand, silt, clay, organic matter, root hairs, microorganisms and their secretions and resulting pores. (Fortuna, 2012)

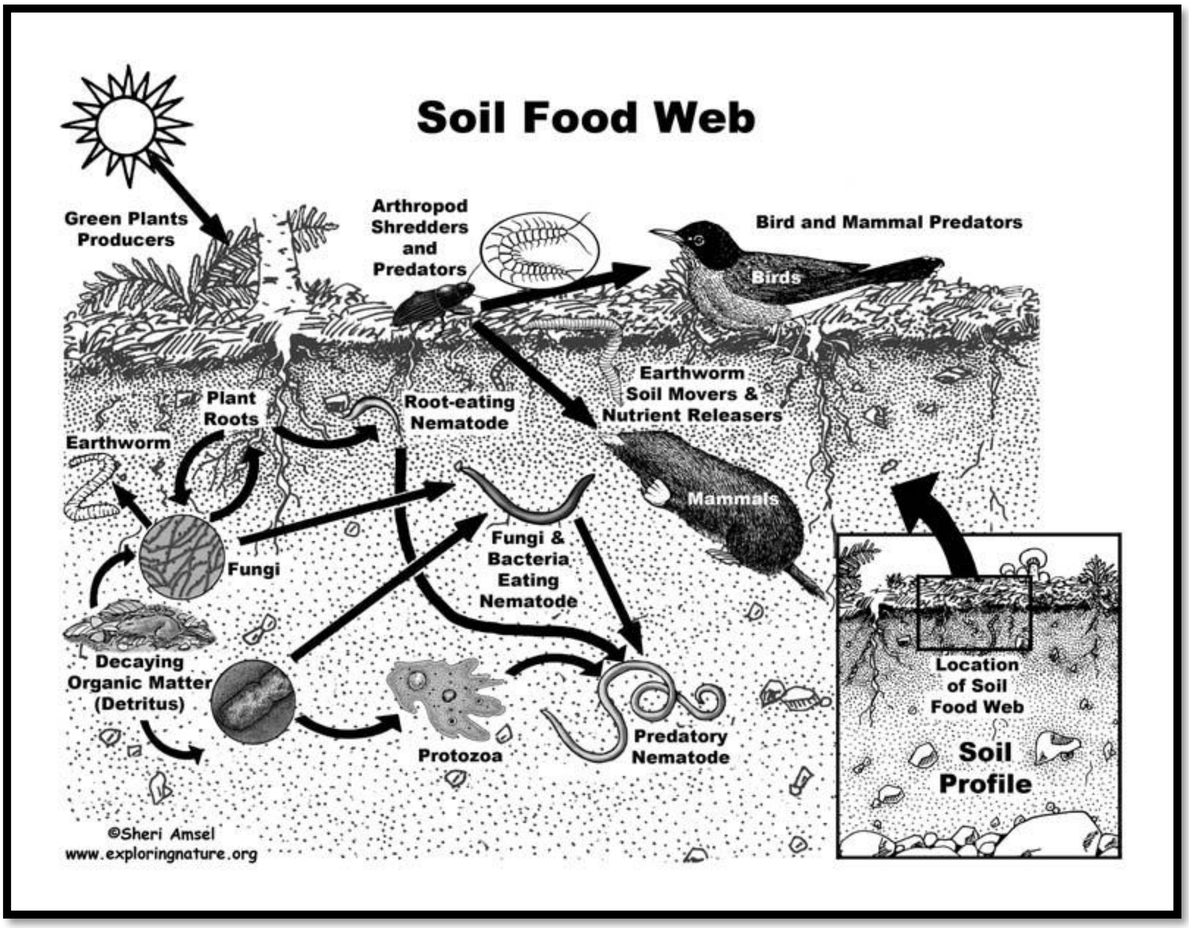

Figure 6 Soil Food Web Diagram with organic organisms responsible for optimum sequestration (Amsel, 2005)

Soil Food Web explanation

The soil food web consists of the community of organisms that live all or part of their lives in the pedosphere and facilitate the transfer of nutrients among the living (biotic) and non-living (abiotic) components of the pedosphere. This is done through a series of conversions of energy and nutrients as one organism and or substance is consumed by other organisms (Sylvia, 2005).

The mesofauna play a role in nutrient turnover by shredding materials into smaller pieces with higher surface area providing greater access for microfauna (bacteria, fungi, mycorrhizae) that recycle the majority of organic carbon.

All food webs contain several trophic levels or feeding positions in a food chain. The term grazing is used when organic carbon is obtained from living things. Soil organisms are part of the detrital food chain if their organic carbon is derived from dead materials.

The detrital food chain creates new soil organic matter and cycles nutrients from existing organic matter. Biological systems and organisms contain fairly constant elemental ratios of carbon:nitrogen: phosphorus: sulfur (C: N:P:S).

These ratios and mass balances (net change = input + output + internal change) allow scientists to determine biochemical shifts between organisms or ecosystems. (Sylvia, 2005)

Since the industrial revolution, the conversion of native bush and forests into agricultural landscapes has resulted in the depletion of SOC levels. This has released approximately 50 to 100 GT of carbon from soil into the atmosphere. This is the combined result of reductions in the amount of plant roots and residues returned to the soil, increased decomposition from soil tillage, and increased soil erosion (Lal R. , 2010).

Considering that the total soil carbon reserves are around 2500GT, then to replenish 50 to 100 GT's does not equate to a huge undertaking. Some Queensland soil sequestration trials have shown that up to 1 tonne per hectare per year can be sequestered over vast areas of arable soils, rangeland environs can sequester 100kg per hectare per year (Dalal R. , 2012).

Inadvertent outcomes

It was not with ill-intent that soils have been mined of the life-giving carbon resource; it demonstrates the ingenuity of humans to improve their chances of survival. The upside of the depletion of SOC stocks has created a soil carbon deficit that represents an opportunity to store carbon in soil through a variety of land management approaches.

However, various factors impact potential soil carbon change in the future, such as climatic controls, historic land use patterns, current land management strategies, and government and environmental controls.

Opportunities for agriculture

The exciting opportunity for farmers and graziers is the power of intent to reverse and significantly improve soils. This is gathering momentum and if left to innovate, the groundswell of change is set to reverse current trends. Agriculture, and in particular agricultural science, farmers, and graziers, can lead the way.

Soil carbon is the priority theme but is used in context within the matrix that is the terrestrial mass that has sustained life for millennia and will continue to do so into the future. To fully understand soil, it is important to include a fundamental explanation of how soil works.

Figure 7 contains the components required for soil carbon turnover and successful sequestration. The simplistic representation shows the interconnectedness of natural systems and ecosystem services which need to be functioning to achieve carbon back into soils.

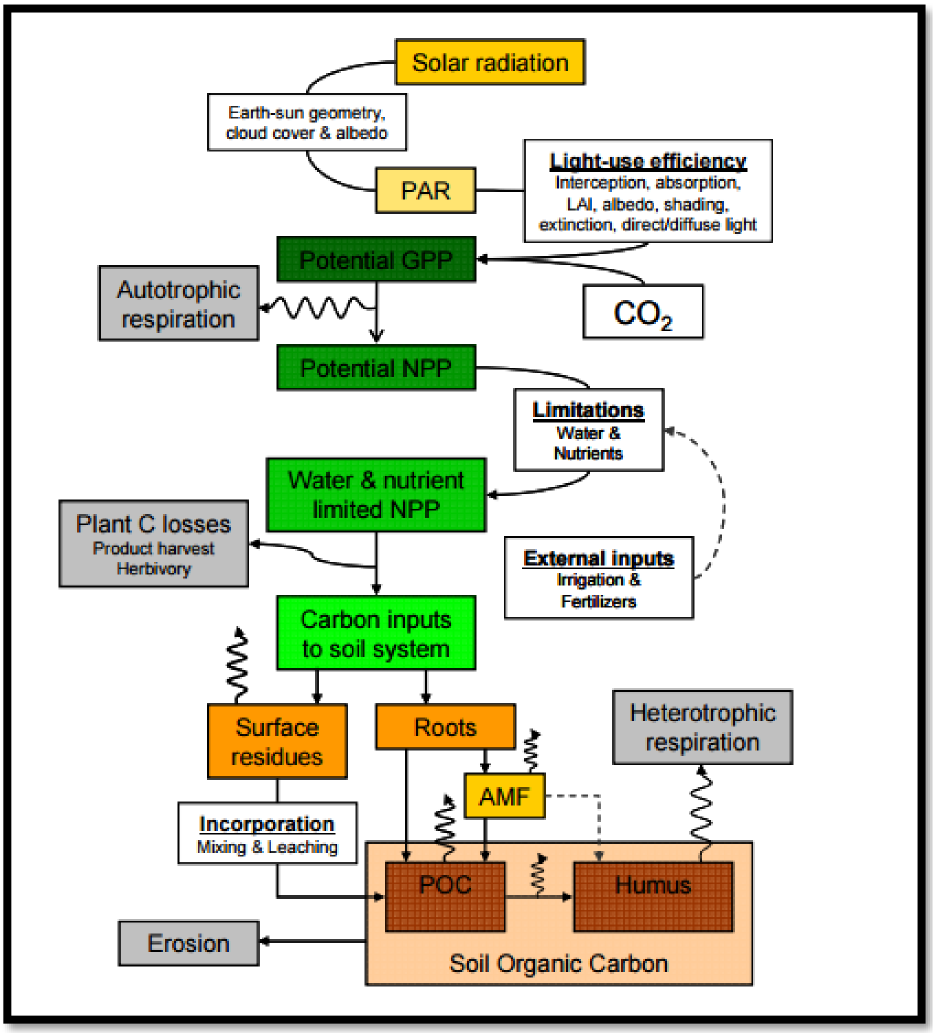

Figure 7 Carbon Flow in Eco-systems (Sanderman, Farquahson, & Baldock, 2010)

"Conversion of native land for agriculture has typically resulted in decreases in soil organic carbon (SOC) stocks on the order of 40 to 60% from pre-clearing levels" (Sanderman, Farquahson, & Baldock, 2010).

Currently there is uncertainty and debate, particularly within Australia, as to the total potential of agricultural soils to store additional carbon, the rate at which soils can accumulate carbon, the permanence of this sink, and how best to monitor changes in SOC stocks.

"Recapturing even a small fraction of these legacy emissions through improved land management would represent a significant greenhouse gas emissions reduction" (Sanderman, Farquahson, & Baldock, 2010).

"We talk about alternative energy," Crawford says. "There is no alternative soil."

"It is not to say that soil will disappear in 60 years, but when you consider the amount of topsoil lost in the past 100 years, that figure of 60 years starts not to look so daft (Lloyd, 2011).

Non-agricultural drivers of change and justifications

From the countries visited and researched, political opinion is divided, yet there is a common theme of programs and grants being available to investigate soil carbon and the impacts on food supply and climate change mitigation.

Soil carbon holds the promise of dealing with two national crises at the same time – climate change and extensively degraded soils – but it's deeply politicised, and the science not clear (Dreyfus, Wilder, McCosker, & Baldock, 2013).

Food and Water security

The global imperative for protecting and restoring the worlds soils is to ensure food and water security for future generations. Historically, wars and civil unrest stem from water and food scarcity. The importance of managing the natural resources and natural capital of agricultural landscapes has never been more crucial. The growing population needs to be fed and clothed with a finite stock of soil and water. Therefore, it is crucial that soil management activities have multiple benefits and less extractive processes now and in the future. Serendipitous co-benefits are emerging and forming the framework for drivers for transformational practice change.

Co-benefits and ecosystem service improvements

- Additional income and financial opportunities for agribusiness
- The correlation of improved soil quality and carbon sequestration is:
  - Improved drought resilience
  - Improved water quality in local and regional catchments
  - Improved yields (crop yields and livestock)
  - Increased biodiversity (above and below ground)
  - Improved water holding capacity and water cycles
  - Improved ground cover and cooling of soils and micro-climates
  - Decreased susceptibility to plant and livestock related disease
  - Decreased erosion and eutrophication
  - Faster recovery from adverse climate events such as drought, flooding

Current international considerations

Australia

Since commencement of this research in September 2011 there have been four changes to the Prime Minister in Australia and assurances to the Australian people that there would be no Carbon Tax, followed by the introduction of a Carbon Tax in July 2012.

An Emissions Trading Scheme was introduced with a fixed carbon price which when coupled with the European Union Trading Scheme, caused a significant and catastrophic change to the value of Australian Carbon Credit Units (ACCU).

A fall from a fixed $23 per ACCU to an annual average price of $6.00 per ACCU. (Eco-Business, 2013). The opportunity to trade ACCU's was quickly curtailed, due to compliance costs for trading scheme, more than the sequestration value of the ACCU.

The Carbon Tax was provocative, and the coalition government had a mandate to revoke the tax. The Carbon Farming Initiative replaced the programs from the previous labour government. The Carbon Farming Initiative commenced after legislation in 2011 was passed. The "Carbon Credits (Carbon Farming Initiative) Act 2011 (Australian Governement, 2011).

Pending future governmental policy, will be critical to how further research, development and extension will be delivered to agriculture. Soil carbon and sustainable ag practices attract bipartisan support, meaning that there will be continued development in the science and the certification of soil carbon.

USA

Interviews in Washington DC with Bruce Knight (Principal and Founder at Strategic Conservation Solutions), and visits to the Washington office of the USDA Climate Change Program Office for a meeting with team leaders, confirmed the rising awareness and subtle shift towards agriculture assisting in climate change mitigation. In fact, the climate change department was receiving the only budget increase for the entire USDA departments.

Charles Walthall (Deputy Administrator, Natural Resources and Sustainable Agricultural Systems Research, USDA Ag Research Service) confirmed the shift in relevance of soils when he spoke at an agriculture, soil health and climate change forum in Sydney in July 2013, hosted by the US Studies Centre, in partnership with the Australian Government DIICCSRTE. His departments' mission: to improve the quality of atmosphere and soil resources affected by, and having an effect on agriculture, and to understand the effects of, and prepare agriculture for, adaptation to climate change.

Figure 8 Charles Walthall, National Resources, Sustainable Ag Systems Research ASDA. Agriculture, Soil Health and Climate Change Forum. 2013 Sydney. Photo: Author

Charles team is taking a different approach to agricultural systems, and the need to investigate why systems such as bio dynamics, compost teas, and biological soil enhancers work, despite not fitting into scientific frameworks. To harness the intuitive successes and life experience of farmers and graziers and why these systems work instead of trying to prove why they don't, was a breakthrough moment for the future of soil and Agriculture in general.

> The person who says it cannot be done should not interrupt the person doing it.
>
> – Chinese Proverb

The American Farm Bureau Federation are supporting market-based incentives, such as pollutant trading, and emphasize these are preferable to government mandates (carrot versus stick). As part of their resolutions on national issues, they adopted the following:

1. A voluntary market-based carbon credit trading system that is not detrimental to other agricultural producers.
2. Compensation to farmers for planting crops or adopting farming practices that keep carbon in the soil or plant material.
3. The inclusion of the agricultural community as a full partner in the development of any policy or legislation (American Farm Bureau, 2012).

Canada

The Guelph University in Ontario has created a role exclusively dealing with the changing social licence/climate change potential of agriculture. Ralph Martin is now the Loblaw Chair in Sustainable Food Production. This is a privately funded position to enhance R&D between private and governmental sectors. Ralph's tactic for sustainable food production is to produce enough food to meet dietary needs today, while preserving productive capacity for future generations of people and other species. This is within the context of healthy soil, clean air and water, and renewable energy to support resilient farming and fishing communities.

The OMAFRA/University of Guelph partnership is mandated to support strong rural communities, keeping food safe and developing a prosperous, environmentally sustainable agri-food sector in Ontario. It aims to balance the needs of people and the agri-food industry with environmental priorities to achieve sustainable agriculture and food production.

Factors affecting Australian agriculture

The Carbon Farming Initiative (CFI) is a carbon offsets scheme that provides new economic opportunities for farmers, forest growers and land managers while helping the environment by reducing carbon pollution. Farmers and land managers are able to generate credits that can then be sold to other businesses wanting to offset their own carbon pollution. The Australian Carbon Farming Initiative has bipartisan support in federal parliament, so should continue under the newly formed coalition government. At the time of this report, there have been no documented or definitive changes to the program, but early indications in newspapers and website commentary suggests the shelving of some projects. It is understood that grant funding will change with the Landcare groups taking a much larger role in project roll outs, with on ground dialogue from grass roots organizations (Hunt G. , 2013).

Kyoto 2

The Kyoto Protocol is an international agreement linked to the United Nations Framework Convention on Climate Change, which commits its parties by setting internationally binding emission reduction targets. The Protocol was adopted in Kyoto, Japan, on 11 December 1997 and enacted on 16 February 2005. The detailed rules for the implementation of the Protocol were adopted at COP 7 in Marrakesh, Morocco, in 2001, and are referred to as the "Marrakesh Accords." The Kyoto Protocol is important as it was the first global treaty to set binding obligations on countries to cut GHGs.

Developed countries are accepting responsibility for current high levels of GHGs in the atmosphere due to more than 150 years of industrial activity. The Protocol places a heavier burden on developed nations under the principle of "common but differentiated responsibilities."

The Minister for Climate Change and Energy Efficiency Greg Combet and Parliamentary Secretary for Climate Change and Energy Efficiency Mark Dreyfus announced that Australia signed up to a second commitment period under the Kyoto Protocol at the United Nations climate change conference in Doha (Doha Climate Change Conference).

Australia's ratification of Kyoto was one of the first acts of the Labour Government in 2007. The willingness to join a second commitment period was widely welcomed at the Doha conference and provided impetus for progress at the talks.

<u>Commercialisation and financial incentives</u>

Ducks Unlimited

As part of the Oklahoma Conservation Districts Conference, Ducks Unlimited, a 70-year-old conservation organization, has worked with thousands of landowners on projects covering 11 million acres of land. They have aggregated this land for CO_2 sequestration projects. It is a natural evolution of its services. President George W. Bush 2002 challenged heavy emitting industries to reduce carbon dioxide emissions voluntarily or face possible mandatory emission-reduction legislation, Ducks Unlimited were quick to capitalize on the opportunity. It aggregates land credits, matching groups of private landowners with energy companies seeking to offset their GHGs. They acquired rights to sell the carbon that the restored forests sequestered to energy companies, thereby gaining locations and income to protect waterfowl. Energy companies took credit for sequestering carbon without reducing their industry emissions. "We regard CO_2 trading as a huge part of our future. Industries developing proactive strategies will stay ahead of the curve while those ignoring the issue will lag behind," (Steadman, 2006).

Qantas

The Australian airline signed a deal to buy 1.5 million offset credits over five years to meet part of its liabilities under Australia's carbon pricing scheme and offer voluntary offsets to passengers. Henbury Station, a 500,000-acre cattle property in Northern Territory, was purchased in July 2011 in a hurry to capitalise on the program by RM Williams. The offsets were to be generated from management changes based on sequestration values. It was hoped that Henbury would store up to 1.5 million tonnes of carbon dioxide equivalent per year.

"We have typically purchased around 300,000 tonnes of carbon credits per year under the voluntary program and we'd expect to be able to source a majority of this from Henbury in future" (Munoz, 2012).

Whilst honourable in theory, the demise of the Henbury Station project and subsequent shelving due to government funding being pulled and very poor uptake of the program by passengers' choosing to offset their carbon footprint. It seems that consumers want fewer emissions but when it comes to paying for their own footprint, they are happy for someone else to pick up the tab.

Brief History of Carbon Trading, Cap and Trade and Voluntary Markets

Carbon trading and sequestration seems to be a discretionary activity that is intrinsically coupled to a company's or country's profitability.

An explanation of 'Cap and Trade' is pertinent to understand the link between agriculture and GHGs. Soil Carbon sequestration is the cheapest and easiest process of removing carbon from the atmosphere. Whilst agricultural activities produce GHG's, these activities can be balanced by sequestration pursuits. Due to the scale of farming in Australia, sequestration via the soils provides carbon positive capacity on farms but must be coupled with changed management practices. This excess carbon capacity can be traded as additional income for farmers.

Cap and trade mechanism's function when countries (as well as companies or individuals) are given an allowance of how much GHG they may emit, known as the cap.

An easy example is Country A easily reduced its emissions and emitted 10 percent fewer GHGs than its cap permitted. Country B, though, didn't meet its cap. Country A can sell the unused 10 percent of its allowance to Country B and help Country B offset its emission excess called the "trade".

Australia has been a leader in market-based policies to reduce GHGs and increase the use of renewable energy. The 2001 national Mandatory Renewable Energy Target (MRET) and its associated markets was the first scheme of its kind globally (Renewable Energy (Electricity) Act , 2000).

In 2003, the New South Wales Government introduced the world's first carbon trading scheme, the NSW Greenhouse Gas Abatement Scheme. Other schemes in operation include the Queensland 13% gas scheme, Victorian Renewable Energy Target, National Green Power Accreditation Programme and the Victorian Energy Efficiency Target Because Australian carbon regulations evolved concurrently at the State and Federal level, a number of existing schemes overlap.

The Chicago Climate Exchange (CCX) opened in 2000. It was the USA's first experiment in carbon emissions cap and trade markets. Exchange trading in the allowances the system generated, known as Carbon Financial Instruments (CFIs), was to assist countries and companies to meet emission reduction commitments. Whilst it still operates, its cap-and-trade system ended in 2010. CFI generation will continue as strictly voluntary greenhouse gas emissions offset system (Smith, 2010).

The CCX was the first in the world when it launched, quickly followed by affiliated exchanges in other countries. These include the European Climate Exchange (ECX), Chicago Climate Futures Exchange (CCFE), Montréal Climate Exchange (MCeX) and Tianjin Climate Exchange.

The CCX system soothed climate activists when it launched, but was quickly plagued by a flood of cheap and dubious credits from offset project generators which collapsed the CFI market, sending exchange prices as low as cents per unit. Many factors manifested the demise of CCX. The failed climate legislation in US Congress, a fiasco at international climate change negotiations in Copenhagen, Denmark (at which Australian Kevin Rudd was chairman), and the collapsing prices associated with the Regional Greenhouse Gas Initiative (RGGI), combined to cause the closure of the CCX and threatened the survival of the concept of cap and trade in totality. Nevertheless, CCX's aligned exchanges, the European Climate Exchange and the Chicago Climate Futures Exchange, continue as long as there is corporate and government interest in fighting climate change, despite the failure of Cap and Trade in the US Congress. The rising validity of Corporate Social Responsibility (CSR) with indexes now tracking environmental footprints of individual companies has reinvigorated voluntary schemes globally.

Voluntary Markets

The Californian legislature has moved to mandatory emissions trading and is resurrecting the carbon trading market. CCX has moved its focus from a contractually binding trading platform to an offset trading one. The aims of leveraging relationships with large emitting companies to revitalize the voluntary carbon market, will maintain their position as the largest trader of environmental commodities. Traders can participate through the offset's registry.

The underlying problem that has hurt mandatory carbon markets globally, has been an abundance of units issued at the start of the programs, usually in the face of weak demand. Prices at the European Union's Emission Trading System nearly fell through the floor after political negotiations led governments to be overgenerous with allowances to influential industries. EU allowance prices have recovered since the first commitment period but still face downward pressure from a weak economy, carbon trading and sequestration is deemed a discretionary activity that is intrinsically coupled to a company's or country's profitability. It could be assumed that if a country is performing poorly, their emissions will also be lowered. The conundrum of industrial and capitalistic growth!

Carbon Offsets

A carbon offset is a reduction in emissions of carbon dioxide or greenhouse gases made in order to compensate for or to offset an emission made elsewhere. One carbon offset represents the reduction of one metric ton of carbon dioxide or its equivalent in other CO2 equivalent gases. There are two markets for carbon offsets. In the larger, compliance market, companies, governments, or other entities buy carbon offsets in order to comply with Caps on the total amount of carbon dioxide they are allowed to emit. This market exists in order to achieve compliance with obligations of the Kyoto Protocol.

In the much smaller, voluntary market, individuals, companies, or governments purchase carbon offsets to mitigate their own GHGs from transportation, electricity use, and other emitting activities.

Example: An individual might purchase carbon offsets to compensate for the GHGs caused by their personal consumption. Many companies offer carbon offsets as a "feel good up-sell" during the sales process so that customers can mitigate the emissions related with their product or service purchase.

The voluntary market transacted market-wide volumes of 95 MtCO2e to the value of $576 million via Over the Counter (OTC) transactions (not futures or options trading). After the end of the CCX, 97% of offset transactions were conducted in the voluntary market for 2011. Different programs had widely variable pricing between $0.1/tCO2e to $100/tCO2e. The greater the allure of the programs; correlated with higher demand and values. This is very much a legitimate market by value and volume with increasing demand year on year. Average credits traded in 2 bands: $1.00 - $2.00 and $5.00 - $10.00 (Peters-Stanley & Hamilton, 2012).

Common project types are renewable energy, such as wind and solar farms, biomass energy, or hydroelectric dams. Others include energy efficiency projects, the destruction of industrial pollutants or agricultural by-products, capture of landfill methane, and forestry projects. Most popular carbon offset projects from a corporate perspective are energy efficiency and wind turbine projects. Sequestration projects are smaller and almost pioneering compared to the more acceptable abatement projects.

Carbon offsetting has gained appeal and momentum among consumers in western countries where there is rising awareness of the negative environmental effects of energy-intensive lifestyles and economies. The Kyoto Protocol has sanctioned offsets as a way for governments and private companies to earn carbon credits from changed management practices. The Clean Development Mechanism (CDM), validates and measures projects to ensure they produce authentic benefits and are genuinely "additional" activities that would not otherwise have been undertaken.

Whilst it was short lived (7 years), the CCX cap and trade system achieved 700 million tonnes of GHG reduction, 88 percent through direct industrial emission cuts and 12 percent through offsetting. It provided cost-effective and market-based flexibility for reducing GHGs through an exchange platform with price transparency and independently verified reductions. The CCX has not been matched since.

Carbon needs to be treated like any other commodity, when value is assigned, it becomes marketable and tradeable. Additional income can be an important incentive for small (low economy of scale) and financially constrained farmers to invest in soil restoration and adopt regenerative management practies (RMPs). Measuring and monitoring protocols of change in carbon pools at the landscape, farm, and regional scales are becoming available to facilitate carbon trading.

The greatest potential for sequestration is in the soils of those regions where most soil carbon has been lost. Regions where soils are severely degraded and have been used with extractive farming practices over a long time.

<u>The Science of Soil Carbon - Technical Advances</u>

Carbon sequestration into soils and plants is the only low-cost strategy that can remove and stabilize carbon from the atmosphere. The technical potential of carbon sequestration in world soils may be 2 billion to 3 billion MT per year for the next 50 years. Most soils have a technical or maximum sink capacity of 20 to 50 MT of carbon per hectare that can be sequestered over a 20-to-50-year period Thus, the potential of carbon sequestration in soils and vegetation together is equivalent to a draw-down of about 50 parts per million of atmospheric CO2 by 2100 (Stockman, 2011).

Deep SOC is more stable and in greater quantities than previously analysed. This has major implications for estimates of global carbon storage and modelling of the potential global impacts of climate change and land-use change on carbon cycles. The research paper by Harper and Tibbett suggests that deep SOC has been underestimated by between 2 and 5 times the levels that have been recently measured. It is crucial that reassessment of the current arbitrary shallow soil sampling depths for assessing carbon stocks is revised, and a recalibration of global SOC estimates is made (Harper & Tibbett, July 2013).

Figure 9 Shayleen Thompson, Head of Division, Land, DIICCSRTE Agriculture, Soil Health and Climate Change Forum. July 2013, Sydney

<u>The hundred years rule…. the biggest stumbling block of all</u>

Shayleen Thompson, Head of Division, Land, and DIICCSRTE explained at the Agriculture, Soil Health and Climate Change Forum in Sydney (2013) that the department is aware of the problem of the 100-year permanence rulings, and given the poor uptake by farmers in projects, the permanence time has been revised down to 25 years. As the Carbon Farming Initiative has bipartisan support, the change to time frames should not be blocked from passing through the senate. Greg Hunt confirmed this on a Radio National interview prior to the Federal Election, speaking in his role as Shadow Minister for Climate Action, Environment and Heritage.

The coalition's direct-action plan, published three years ago states that "the single largest opportunity for CO2 emissions reduction in Australia is through bio-sequestration in general, and in particular, the replenishment of our soil carbons."

The policy also states "We will support up to 85 million tonnes per annum of CO2 abatement through soil carbon by 2020 - and reserve the right to increase this, subject to progress and evaluation."

Greg Hunt says he still believes "bio-sequestration remains the largest single opportunity" for reducing carbon emissions (Hunt G. M., 2013).

Soil sequestration modelling approaches

Soil Sequestration Modelling is categorized as either process-orientated or organism-orientated. See Appendix 1, where the list shows the process-orientated and organism-orientated models that are in use currently.

Figure 10 shows how science and agriculture currently assess the technical and scientific advancements for SOC. Farmers operate in the organism-orientated frameworks, as this appeals to their hands on and anecdotal sensibilities. Much of the proprietary on- farm research examined is in this realm.

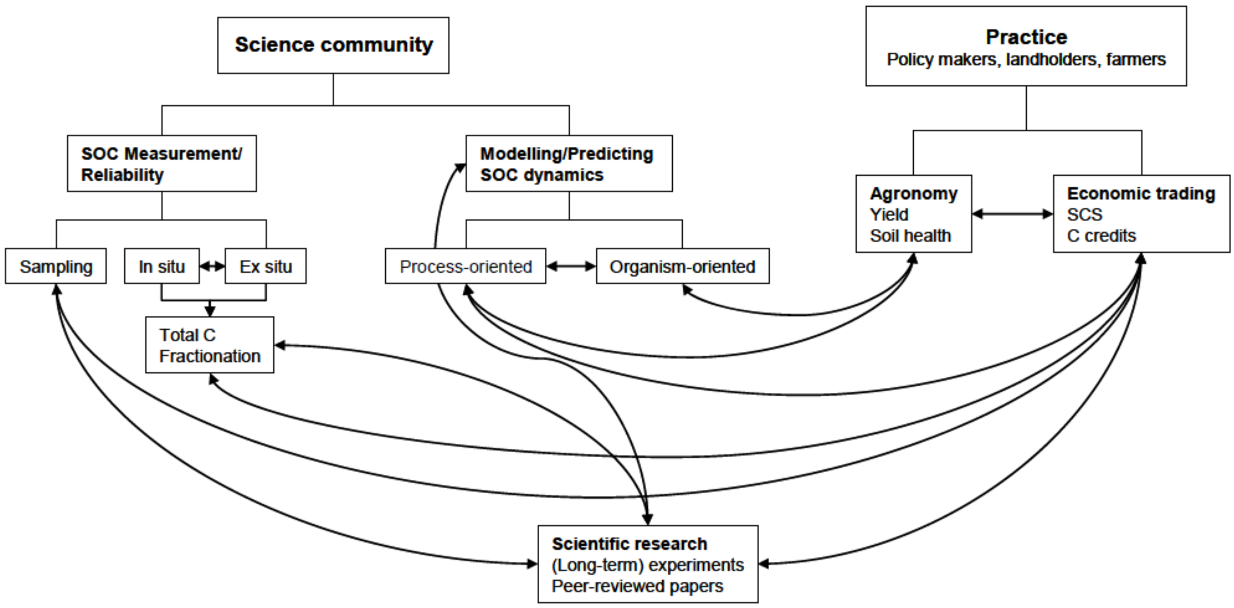

Figure 10 Interdisciplinary Research Model (Stockman, 2011)

Globally accepted methodologies

Soil Carbon Methodologies were developed since the 1980's with the main three used today the RothC, CENTURY version 5 and HadCM3.

RothC-26.3 Model

The Rothc-26.3 measures organic carbon turnover in non-waterlogged soils which allows for the effects of soil type, temperature, moisture content and plant cover on the turnover process. It has been extended to model turnover in temperate grassland and forest sites. It should be used cautiously outside this range.

RothC-26.3 uses a monthly time step to calculate total organic carbon (t/ha -1), microbial biomass carbon (t/ha -1) and above 14C (from which the radiocarbon age of the soil can be calculated) on "years to centuries" timescale. (Coleman & Jenkinson, RothC - A Model for the Turnover of Carbon in Soil. Model Description and Users Guide., 2014). It needs few inputs and those it needs are easily obtainable.

Kevin Coleman's role as the main developer and programmer of the Rothamsted carbon model (RothC) explained changes to the model over time to improve its input parameters and decrease variability factors. Mr Coleman is world leader in modelling the turnover of organic carbon in the soil at plot, field, regional, national and global scales and using models to assess the impact of land use, management and climate change on the levels of soil organic matter.

He is currently working on the RothC to incorporate the model into the HadCM3, which would enable simulation of feedbacks and interactions between soil, vegetation and atmosphere under a changing climate – essential for an integrated, holistic assessment. A blueprint for the inclusion of RothC in HadCM3 (see below) is being developed in a joint venture between Rothamsted Research Facility and the Hadley Centre (Coleman, RothC model development at Rothamsted Research Facility. Interview., 2014).

The Roth C model is used extensively for soil carbon projects worldwide, and in particular, for the extensive Kenyan Sustainable Ag Land Management Project. This project is a Bio-carbon Fund project financed via the World Bank to assist 60 000 farmers in two regions in Kenya to convert to sustainable soil management systems.

Neeta Hooda, Senior Carbon Finance Specialist, Carbon Finance Unit, World Bank, explained the program was a trial to see if farmers could change practices, improve their financial positions and continue sustainable and sequestering practices. The project encompasses average farm size is small; around half an acre with 60,000 farmers demonstrating management change and aiding sequestration for a nominal payment which is proof that management change can occur within the broader global agriculture community. Education and on-ground training is integral for change to occur, and this part of the project is embedded in its structure and seems essential for success.

The CENTURY version 5

The CENTURY Version 5 Agri-ecosystem model is the latest version of the soil organic model. This model simulates C, N, P, and S dynamics through an annual cycle over time scales of centuries and millennia. A sub-model may be used in grassland/crop, forest or savannah system, with the flexibility of specifying potential primary production curves representing the site-specific plant community. Version 5 seems to be the best and has evolved to include a layered soil physical structure, and new erosion and soil deposition sub-models.

The HadCM3

The HadCM3 (Hadley Centre Coupled Model, version 3) is a coupled atmosphere-ocean general circulation model (AOGCM) developed at the Hadley Centre in the United Kingdom. It was one of the major models used in the IPCC Third Assessment Report.

These models are evolving towards a whole of atmospheric model that can only be good for soil carbon data predictability.

Mr Coleman was interested in the Australian modelling, as he suggested that it could be used in extensive situations, more suited to Australian conditions. When questioned about the purpose of measuring to 30cms and not deeper, he clarified that it was initially developed for arable systems recognising that root depths of plants in those environs at that time being shallow. Rothamsted was also restricted in terms of research funds, and to keep costs within limits, it was concluded to measure to a depth of 30cm (Coleman, RothC model development at Rothamsted Research Facility. Interview., 2014).

New modelling methods

The new and outlier sequestration models are addressing the complex and multifaceted "agri-ecosystem as a whole" concept. Carbonlink's Cell Grazing Methodology (McCosker, 2013) factors in soil emission and sequestration potential, animal emissions, chemical and fuel inputs.

CFI Cell Grazing Model

An outlier model by Carbonlink captures data in a dynamic matrix has been developed in Australia. This CFI Cell Grazing Model is the most definitive found during research for beef cattle production and grazing. This model is different to other modelling in that it allows for seasonal variation and has significantly reduced variance in baseline modelling, due to the analysis tools used. It has also been tested on the largest trial site available. A 3,000-hectare research project has tested soil carbon in 5cm depth increments to a depth of 1m across the entire of 3,000ha site.

The Cell Grazing Methodology calculates livestock emissions (CLS) and livestock leakage (CLSL). CLS is calculated separately for project and baseline data over the reporting periods. The net livestock emissions during the reporting period are calculated as the difference between the project and baseline estimates. The livestock leakage CLSL adjusts the livestock emission estimates, to account for differences in the livestock numbers between the project and baseline. It also calculates GHG baselines. Carbon Link has identified a range of algorithms and methods for estimating tradable soil carbon stocks including Linear statistics, geo-statistics modelling, hybrid measurement modelling systems and use of satellites as well as proximal sensors. These approaches coupled with site scanning and soil sampling methods are expected to lead to improvements in the capacity and costs to estimate tradable soil carbon.

The models listed in Appendix 2 typically only use site estimates calculated from inventory values using statistical estimates and are typically constrained to 300mm depth and with high uncertainty. Carbon Link methodology produces detailed 3D maps of soil carbon data and site scanning optimises stratification with much reduced variance adjustment.

The livestock emissions estimation module of the Carbon Link Cell Grazing methodology is also a breakthrough in base lining emissions, it allows for seasonal variance and the different ways in which cattle produce emissions.

Livestock emissions occur from three sources; enteric emissions, nitrogen excretion in urine and manure and methane emission from manure. While livestock emissions may be significant it doesn't necessarily mean that livestock emissions will make a significant contribution to overall project emissions. In accordance with CFI legislation and guidelines, livestock emissions are determined as the difference between the project and baseline emissions. If the baseline and project livestock feed intake, stocking rate and herd structure are essentially the same, it can be expected that baseline and project emissions are similar and cancel each other out. In such cases it is not necessary to make detailed emissions estimates because net livestock emissions do not make a material impact to the project emissions.

However, if there are significant differences between baseline and project livestock feed, stocking rate and herd structure and, in particular if the difference in emissions from baseline and project are material to overall project emissions, then more detailed estimation methods are utilized.

To account for these differences this module provides three tiers of estimation. If minimal differences between livestock emission between baseline and project are expected, then a simplified Tier 1 method is used. If the difference is significant than a Tier 2 method is used. Alternatively, the proponent can choose a custom Tier 3 method that meets the quality and requirements of the CFI and is supported by appropriate documentation and justification (McCosker, 2013).

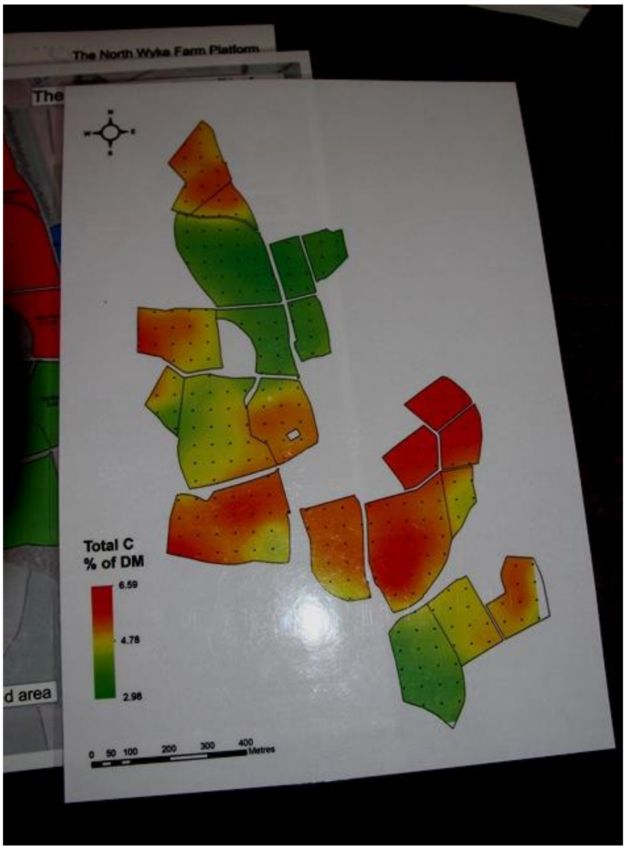

Figure 11 Soil Organic Carbon mapping of North Wyke Research Facility trial paddocks ready for start of 30-year trial on Life Cycle Analysis and sequestration. North Wyke Research Facility, part of the Rothamsted Research Facility UK. Photo: Author

Life Cycle Analysis

The use of Life Cycle Analysis (LCI) and a national inventory for emissions and sequestration (AusLCI, 2014) become essential in analysing and reporting. An examination of the production matrix behind a food article from conception, growing to post farm gate and manufacturing and packaging is important for branding and CSR statements. It has been difficult for agriculture to make sustainability efforts measurable, and how to embed the benefits quantitatively into daily operations. It is also difficult to declare products as sustainable or having regenerative Ag benefits for product differentiation or competitive advantage.

LCI is now globally recognized as the leading method to measure sustainable processes. It is superseding the carbon foot-printing models that give an indication of the emissions produced say, in a kilo of beef produced. It takes into account the community/social issues, animal welfare issues and upstream carbon emissions. Whilst ISO 14025 accreditation gives some assurance, it doesn't provide adequate quantitative records for producers or further down the supply chain.

LCI of 1 kilo of beef produced in a feedlot is vastly different to 1 kilo of beef produced in grass-fed rangeland environs.

"On a per-kilogram basis of live weight production, impacts in all four categories were highest in the pasture-based system and the lowest in the feedlot system. It should be noted, however, that the analysis did not consider potential differences in carbon sequestration – SOC that can be tied up in the soil under certain types of production" (Pelletier, Pirog, & Rasmussan, 2010).

Organism-orientated modelling is evolving to highlight the need for whole eco-system integration in life cycle inventories. Anecdotal projects suggest that intensive grazing practices harness sequestration potential and other ecosystem services which are not fully captured in the current models. Carbon Link modelling comes closest to putting values on dynamic variables. "In pasture-based grazing systems, moving to intensive grazing could result in reductions in GHGs because of increased carbon sequestration and lower inputs for maintaining productive pastures. Managed grazing systems may increase pasture utilization beyond the assumed 60 percent rate (as much as 90 percent may be possible, according to research in Missouri) and improve environmental performance. All beef production systems could be improved with greater feed efficiency and, in the case of the feedlot systems, use of fewer inputs that rely on fossil fuels (gasoline, fertilizer, electricity). Selecting animals with superior genetics that are better suited to each system also could improve performance and thus reduce environmental impacts. Substantial reductions in greenhouse gas emissions also may be possible in both feedlot and pasture-based systems through genetic selection, forage selection, various methods of methane inhibition and animal management. Several studies show that forage performance could be improved by adding certain legumes" (Pelletier, Pirog, & Rasmussan, 2010).

Commercial compliance obligations emerging

A clear example of commercial reality and the impact from downstream compliance requirements is highlighted by Joe Delves, 2012 UK Nuffield Scholar in the dairy industry. Discussions focused on the requirement by Tesco supermarket chain that UK suppliers now require carbon footprint documentation as part of the contractual agreement to supply them with raw milk.

After reviewing the Tesco measurement matrix, there is no allowance for soil carbon sequestration, and is therefore significantly deficient and inaccurate with a negative outcome to farmers. While this would not have been done in malice, but purely a function of not enough scientific evidence or accurate soil carbon parameters in their modelling, it is an oversight that needs rectification, to change the outcomes to the affirmative for dairy farmers. This highlights the need for farmers to be on the front foot, in terms of the imminent sustainability requirements that will be rolled out in the next five years or so. There is a need for agriculture to be informed and ensure that their good practices are included, and not just their emissions footprint. Since highlighting this oversight, Joe has taken up the issue with Tesco, who are looking into adjusting their sustainability/footprint matrix to include soil carbon (Delves, 2014).

<u>The existential imperative of soil carbon sequestration and climate adaptation</u>

The IPCC Fourth Assessment report concluded that Australia has significant vulnerability to the changes in temperature and rainfall projected under climate change (Hennessey, 2007). Agriculture is likely to be radically affected, along with the natural resources sector.

Extensive grazing is by far the most widespread agricultural land use in Australia. Most rangeland country is unsuitable for intensive agricultural production and is best used instead, for low intensity or simulated migratory production (rotational grazing) of beef and sheep for meat and wool. The grazing industry has been an important contributor to the overall economic growth of Australia but is vulnerable to the impacts of a variable climate.

In developing robust climate change adaptation strategies, it will be important to continually assess that strategy responses are positive in achieving intended benefits while minimizing unintended consequences to landscape functionality, food and water security.

There are several foreseeable risks of poor consequence outcomes, where trade-offs will need to be carefully evaluated. An example would be introducing legumes into native pastures to offset declines in forage quality, which could then incur risks of soil acidification and impacts on biodiversity.

Current carbon trading schemes may create short-term opportunities for earning carbon credits from increases in woody plant biomass, but this has to be weighed against the ongoing costs of possible losses in pasture production, erosion related sediment movement, increased fire/fuel load risk or reduced water yields from catchments.

Existential imperative of soil sequestration management practices will require:

- Cultural shifts by farmers and graziers that climate change adaption is required and is separated from the natural year-to-year climate variability inherent in current production systems.
- Financial and motivational incentives for change, based on risk and reward outcomes which provide direct benefit on ground and for farmers themselves.

- Agtech that is demonstrably verified and pertinent.
- Safeguarding against revised land management failure of new practices during less favourable climate periods.
- Marketing infrastructure and support by media-at-large for farmers and graziers changing to climate adapted food production systems.
- Price point premiums for food produced in climate adaptive (sustainable and regenerative) systems as opposed to existing soil carbon extractive agricultural systems.
- Consumer education and awareness of adaptive farming and grazing practices by agricultural lobbyists, membership organisations and media.
- Development and modification of government policies and institutions to support adoption and implementation of the required changes. Adaptation strategies that incorporate the above considerations are more likely to be of value, as they will be more readily incorporated into existing on-farm management strategies (Stafford Smith, McKeon, & Watson, 2007).

The importance of Soil Carbon and its role in agricultural food production

Figure 12 Micoryzal Fungi and humus in healthy soil, Roma, Queensland, Australia. (Williams)

Soil fertility and thus soil carbon is the underlying foundation to the building blocks of all layers of food production. The capacity to receive, store and transmit energy to support plant growth underpins plant yield and therefore the overall viability of all food production businesses.

The process of fertile soils – living, self-organising systems with physical, chemical and biological components all functioning and in balance (Stapper, 2006) cannot be exploited for profit long term, if only short term profit targets persist. When the delicate balance of healthy soils is interrupted by use of acidic or salty synthetic petrochemicals, and continuous grazing and overgrazing, then the ultimate outcome is rapidly degrading soils and rapidly decreasing profit (Stapper, 2006).

Organic farming has recognised this but needs to follow the leaders of sustainable agri-ecosystems and actively focus on soil fertility management. During this research, it became obvious that although commendable for their cessation of fertilizer use, organic farmers can improve their practices by changing their focus to building soil carbon and thus soil fertility. This is a change of emphasis beyond the persistent and sometimes fanatical opposition to chemical inputs and animal health products and vaccines.

New technologies and genetics

Switchgrass in the USA was considered a commercially viable crop for use in the biofuels industry. A visit to the early breeding programs at the Nobel foundation's genetics laboratory disclosed that some preliminary work with Switchgrass seedlings in a laboratory environment has shown that by selectively breeding for increased tillers, it has concurrently shortened the stem length and decreased the lignification, therefore making the grass more palatable for livestock in its mature stages (stages 3&4). Benefits of switchgrass with regards to soil carbon is that it has a root system that can reach over four metres in depth. This type of plant breeding would create carbon sequestration potential along with the co-benefits of erosion control and deep transfer of carbon from shallow soil strata to deep strata making it recalcitrant for an indefinite time horizon.

Figure 13 Switchgrass trialled at Nobel foundation, Ardmore Texas USA for biofuels production was modified for increased tillers.

Seed Coatings

Seed coatings with biota to enhance germination and early growth success is in its infancy, and much more work is needed to understand the symbiotic nature and interactions of soil biota (Mastouri, 2010) . Current thinking is that biological seed coatings are to enhance plant growth and strong germination, but this concept could further be trialled as a pathway to accelerating the re-introduction of biota that has been lost during extractive land management and nitrogenous fertiliser use. Processes currently used for pesticide and fungicide seed coatings could be repurposed to apply soil and plant friendly applications. Coating in trace elements which are lacking in soils could also form the basis of biological expediency of soil profiles.

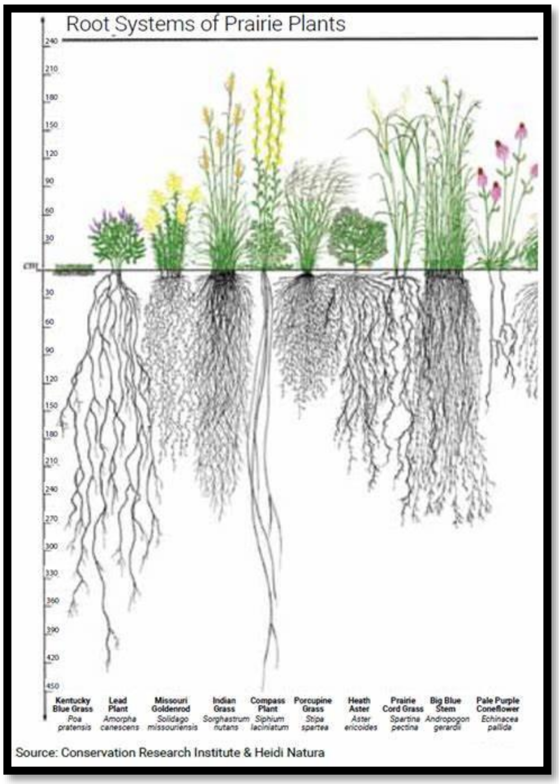

Figure 14 Root depth of perennial rangeland and prairie ecosystems reach depths of over 4 metres. This needs to be considered when modelling soil carbon at depth.

<u>Soil carbon modelling techniques – error potential</u>

There is a bifurcation of soil carbon methodology measuring depths and plant root depth in agricultural ecosystems. Most soil carbon methods base their modelling on established soil carbon to 30cm depth with the top 10cms disregarded as labile carbon which is not permanent. This labile layer is due to the exposure to natural elements such as sunlight, temperature, animal predation on plants and other ground surface activities.

The Roth C soil carbon turnover methodology forms the foundation of all subsequent modelling calculations globally. Given the description in the Roth C model description in this document, the modelling was initially only calculated for sequestration to 30cms.

Soil carbon below 30cms is considered recalcitrant (permanent and hard to release back into the atmosphere). Given that rangeland ecosystems have plant species with root systems of up to 4 metres or greater, there is room for significant modelling error. These errors could be extrapolated over vast areas when considering rangeland and large land holdings in Australia.

During brief discussions with Dr Jeff Baldock (at the United States Study Centre Conference, Sydney, July 2013) in relation to the establishment of the Australian Soils Database, the testing was undertaken to 30cms only. The author was not able to achieve further meetings to discuss observations with Dr Baldock.

The latest research paper and literature review for Australian soils published 28 May 2012 (Baldock, 2012) was at time of reporting the most up to date document for refence. It is cited in this document that the Roth C method underpins the modelling approaches. Whilst there is reference made to testing to 100cms within the Namoi Valley and Liverpool plains, it does not address the Roth C modelling calibrations to 30cms. No reference was made to testing done at depth outside of cropping systems and so relevance to rangeland ecosystems is not clear.

Given the sampling regimes and processes that are available for future use, it is pertinent that testing of soils be done to more than 30cms and calibration of models to reflect soil carbon at depth to decrease the soil carbon variability and causing potentially huge margins of error.

Methodologies need to consider adjusting calculations to greater depths, particularly in rangelands, which reflect land use, plant species types and prevalence and soil types for accurate reporting. The propensity for large modelling errors could see farmers and graziers miss opportunities to convert land management change to financial benefits and cost recovery in relation to infrastructure and improvements.

Conclusion and Recommendations

Soil carbon and its potential to reverse climate associated risks to agriculture needs copious research and funding resources with a sense of urgency, unlike ever seen before. The Rothamsted temperature recordings over the past century do not lie. The rate of temperature increase is unprecedented. This is having a direct impact on climate change and effects on agricultural ecosystems with longer hotter and drier cycles, interspersed with wetter, wilder rainfall events.

Sequestration of carbon back into soils by natural processes, nurtured by competent agricultural practitioners (farmers and graziers) is the most efficient means to reverse atmospheric CO2 and climate change.

To improve agri-ecosystems, it is vital to understand why they are the way they are, and then how science and practice can help to actively manage soil biology to improve and maintain soil fertility, and achieve more sustainable, healthy and productive farming systems – even on fragile Australian soils in a highly variable and changing climate. Hence the intricate detail of soil in earlier in this document.

Soil is the foundation for greater eco-system function and so what is under the ground needs to by synergistic with the biodiversity above the ground. Natural ecosystems need to be in balance, managed in non-extractive management processes with a long horizon for positive change.

A greater focus on drivers of change on farm and incentive-based practice change will ensure accelerated uptake of new research findings and innovative management practices which move focus from traditional farming and grazing to carbon and soils focused farming and grazing.

Research related to super sequestering plant species and soil biota is paramount in accelerating sequestration potential; is difficult to find and even harder to see demonstrated. This component of soil research is in its infancy and should be prioritised.

Caution should be taken when using modelling for sequestration potential. Measuring soil at depths greater than 30cms is very important to understand the Australian rangeland soil carbon potential.

The global carbon trading schemes have been decimated by various economic drivers which have forced carbon prices down to unviable ranges internationally. The rebuilding of carbon markets and incentivised participation in carbon projects is what is needed to restore confidence in carbon as a financial opportunity for farmers and graziers.

Semi-arid rangelands hold the key to unprecedented sequestration opportunities. Whilst rates of soil sequestration may be smaller increments, the economy of scale on Australia's large land holdings make it viable to pursue carbon farming as an additional revenue stream for farmers and graziers.

Acknowledgements

I would like to thank Nuffield Australia for the opportunity to be involved in this groundbreaking area of agriculture.

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A special thankyou to my Global Focus Program Group (2012). You made life pleasant and easy for me being many months pregnant when I did most of my travel. Chivalry is alive and well!!

Appendix 1

Main characteristics of processes-oriented versus organism-oriented models (based on (Lindsay, 2008, Brussaard, 1998, Krull et al., 2003, Post et al., 2007, Smith et al., 1998, Dokuchaev, 1899))

Process-oriented models		Organism-oriented models
Model type	mechanistic predictive value	mechanistic explanatory value
Aim	simulate processes involved in SOM migration and transformation	simulate SOM using functional/taxonomic groups of the soil
Examples	CANDY, CENTURY, DAISY, DNDC, ITE, NCSOIL, RothC, Socrates, SOILN, SOMM, Struc-C and the Verbene model	Fungal-growth models Models of decomposition of OM that incorporate functional groups of microbial biomass Food web models based on taxonomic groups (mostly detrital models)
Representation of SOM	different conceptual carbon pools with similar chemical or physical characteristics differ by decomposition rates, stabilization mechanisms generally soil biota only included in form of microbial biomass (exception: SOMM) Generally, more than one compartment of SOM degradation: a) active pool (fresh plant material, root exudates, microbial biomass) with MRT of 1 year b) slow pool (SOC that decomposes at intermediate rate) with MRT of 100 years c) passive or inert pool (SOC with physical or chemical stability) with MRT of 1000 years	SOC dynamics represented through different pools of soil biota (classified according to their taxonomy or metabolism) i.e. representation of soil biota by functional groups (food web models): microorganisms (bacteria, mycorrhizal and saprotrophic fungi) SOM and litter (represented in form of roots, detritus)
Mechanism	SOC decomposition based on first-order kinetic rates	C and N fluxes simulated through functional groups based on their specific death rates and consumption rates,

		applying energy conversion efficiencies and C:N ratios of the organisms
Time-step	weekly or monthly	daily
Scale	include top 30 cm of the soil small-plot to regional-scale	small-plot
Application	have been applied to a range of ecosystems (grassland, arable land, grass-arable rotations, forest)	have been applied to arable land and grassland
Others	successfully coupled with GIS software (CANDY, CENTURY, RothC)	include changes of soil biota communities in the modelling of SOM dynamics (i.e. simulating feedback mechanisms due to changes in biota activity or characteristics)

Appendix 2

Model	**Main characteristics**	**Reference**
CANDY	modular system combined with data base system for model parameters, measurement values, initial values, weather data, soil management data simulates soil N, temperature and water to predict N uptake, leaching, water quality uses proportion of soil particles to separate IOM (<6 µm)	(i.e. Franko, 1996)
CENTURY	designed for long-term (up to centuries) SOM dynamics, plant growth and N, P and S cycling developed for grassland, but extended to agricultural crops, forests and savanna systems monthly time step implements two forms of litter: metabolic and structural implements three SOM compartments: active (MRT 1-5 yr), slow (MRT 25 yr, 30-60 % of SOC) and passive (MRT 1000 yr, 30-50 % of SOC) soil texture (clay content) determines separation of C from active OM pool into CO2 or slow pool basic ideas similar to RothC biomass included	(i.e. Parton, 1996)
DAISY	simulates crop production and soil water and nitrogen dynamics developed as field management tool for agricultural systems	(i.e. Mueller et al., 1996)

	portioned into hydrological model, soil nitrogen model with a SOM submodel and a crop model with a nitrogen uptake model clay content influences rate constants semi-cohort accounting system used for litter decay biomass included	
DNDC	couple's denitrification and decomposition processes 4 sub models: soil climate, decomposition, denitrification, plant growth clay absorption of humads biomass included	(i.e. Li et al., 1992)
ITE	developed for grassland environments aims to simulate N cycling 3 sub models: grazing-animal intake model, vegetative grass-growth model, SOM model decomposition rates are function of quantity of microbial biomass	(i.e. Thornley and Verbene, 1989)
NCSOIL	simulates N and C through soil microbes and organic components 4 organic compartments: plant residues, microbial biomass, humads, stable organic matter (stability of SOM results from metabolism) decomposition independent of microbial biomass /biomass included	(i.e. Molina, 1996)
RothC	developed for arable land, but also applied to temperate grasslands and forest soils monthly time step 5 compartments: decomposable plants, resistant plant material, microbial biomass, humified organic matter (MRT 50 yr 80-90 % of SOC), inert organic matter (MRT up to 10000 yr, 5-15 % of SOC) decomposition rate, and ratio of humus, microbial biomass and CO2 dependent on soil clay content basic ideas similar to CENTURY biomass included	(i.e. Jenkinson and Coleman, 1994)
Socrates	weekly time step 5 compartments: decomposable plant material, resistant plant material, unprotected microbial biomass, protected microbial biomass, humus (stabilised pool)	(Grace et al., 2006)

	decomposition rate (into humus, microbial materials and CO_2) dependent on soil CEC /biomass included	
SOMM	developed for forest systems	(i.e. Chertov

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Table of Diagrams

Glossary of Terms

Soil Carbon - Soil organic carbon is a measurable component of soil organic matter. Organic matter makes up just 2–10% of most soil's mass and has an important role in the physical, chemical and biological function of agricultural soils.

Sequestration - a natural or artificial process by which carbon dioxide is removed from the atmosphere and held in solid or liquid form.

Agri-ecosystem - an ecosystem on agricultural land.

Carbon Trading - Carbon trade is the sale of credits that permit a certain level of carbon dioxide emission with the goal of reducing overall emissions over time.

Sustainability - avoidance of the depletion of natural resources in order to maintain an ecological balance.

Micronutrients - a chemical element or substance required in trace amounts for the normal growth and development of living organisms.

Drawdown - Climate drawdown refers to the future point in time when levels of greenhouse gas concentrations in the atmosphere stop climbing and start to steadily decline.

Photosynthesis - the process by which green plants and some other organisms use sunlight to synthesize nutrients from carbon dioxide and water. Photosynthesis in plants generally involves the green pigment chlorophyll and generates oxygen as a by-product.

Exoskeletons - a rigid external covering for the body in some invertebrate animals, especially arthropods. Consists of carbonates.

Inorganic carbon - Inorganic carbon compounds are carbon-based compounds that are not organic. The primary element in inorganic carbon compounds is carbon, as the name suggests. The carbon-based inorganic compounds can contain other elements like oxygen, nitrogen, sulphur, sodium, and other metals.

Labile Carbon - Labile carbon is the fraction of soil organic carbon with most rapid turnover times and its oxidation drives the flux of CO2 between soils and atmosphere. Available chemical and physical fractionation methods for estimating soil labile organic carbon are indirect and lack a clear biological definition.

Recalcitrant Carbon - Recalcitrant organic carbon – is organic material resistant to decomposition and, in Australian soils, is dominated by charcoal. Recalcitrant organic carbon can take centuries to thousands of years to decompose and is largely unavailable to microorganisms.

Methane - a colourless, odourless flammable gas which is the main constituent of natural gas. It is the simplest member of the alkane series of hydrocarbons.

Fluorocarbons - a compound formed by replacing one or more of the hydrogen atoms in a hydrocarbon with fluorine atoms.

Green House Gases - are gases in the earth's atmosphere that trap heat. During the day, the sun shines through the atmosphere, warming the earth's surface. At night the earth's surface cools, releasing heat back into the air. But some of the heat is trapped by the greenhouse gases in the atmosphere.

Emissions - Carbon dioxide emissions or CO_2 emissions are emissions stemming from the burning of fossil fuels and the manufacture of cement; they include carbon dioxide produced during consumption of solid, liquid, and gas fuels as well as gas flaring.

Soil biota - Soil biota: Consists of the micro-organisms (bacteria, fungi, and algae), soil animals (protozoa, nematodes, mites, springtails, spiders, insects, and earthworms) and plants living all or part of their lives in or on the soil or pedosphere.

Arable - Arable land is land worked (ploughed or tilled) regularly, generally under a system of crop rotation.

Soil carbon turnover - Turnover time: In soil science and biogeochemistry, the lifespan of soil C is often described as its turnover time, mathematically defined as the ratio of the total carbon stock in a particular soil pool to the output flux.

Natural Ecosystems - Examples of natural ecosystems are forests, mountains, rivers, grasslands etc. Human-made or Artificial Ecosystem – When human beings modify the already existing ecosystem to meet their purpose or create an ecosystem of their own that mimics the natural condition, those are called artificial ecosystems.

Mandatory Renewable Energy Target - Mandatory renewable energy targets are part of government legislated schemes which require electricity merchandisers to source-specific amounts of aggregate electricity sales from renewable energy sources according to a fixed timeframe.

Chicago Climate Exchange - The Chicago Climate Exchange was a voluntary, legally binding greenhouse gas reduction and trading system for emission sources and offset projects in North America and Brazil. CCX employed independent verification, included six greenhouse gases, and traded greenhouse gas emission allowances from 2003 to 2010.

Corporate Social Responsibility - Corporate Social Responsibility is a management concept whereby companies integrate social and environmental concerns in their business operations and interactions with their stakeholders.

Carbon Offsets - an action intended to compensate for the emission of carbon dioxide into the atmosphere because of industrial or other human activity, especially when quantified and traded as part of a commercial scheme.

Rangelands - Rangelands are grasslands, shrublands, woodlands, wetlands, and deserts that are grazed by domestic livestock or wild animals. Types of rangelands include tallgrass and shortgrass prairies, desert grasslands and shrublands, woodlands, savannas, chaparrals, steppes, and tundras.

Life Cycle Analysis - Life cycle assessment or LCA is a methodology for assessing environmental impacts associated with all the stages of the life cycle of a commercial product, process, or service.

Kyoto Protocol - The Kyoto Protocol was an international treaty which extended the 1992 United Nations Framework Convention on Climate Change that commits state parties to reduce greenhouse gas emissions, based on the scientific consensus that global warming is occurring and that human-made CO_2 emissions are driving it.

Kyoto 2 - The Kyoto Protocol implemented the objective of the UNFCCC to reduce the onset of global warming by reducing greenhouse gas concentrations in the atmosphere to "a level that would prevent dangerous anthropogenic interference with the climate system.

Organic Farming - also known as ecological farming or biological farming, is an agricultural system that uses fertilizers of organic origin such as compost manure, green manure, and bone meal and places emphasis on techniques such as crop rotation and companion planting.

Switchgrass - a tall North American panic grass which forms large clumps.

Seed Coating - Seed coating is a technique in which an active ingredient (e.g., microbial inoculant) is applied to the surface of the seed with the help of a binder and in some cases a filler that can act as a carrier.

Cap and Trade - a system for controlling carbon emissions and other forms of atmospheric pollution by which an upper limit is set on the amount a given business or other organization may produce but which allows further capacity to be bought from other organizations that have not used their full allowance.

Carbon methodology - A carbon market methodology defines a standard set of parameters, criteria, and operations required for the calculation of emission reductions or removals from a carbon project during its lifetime. Carbon project developers can either use pre-existing methodologies or develop new ones.