Carbon Sequestration in Farming Systems

A direction for enhancing carbon sequestration and soil health in broad acre agriculture

A report for NUFFIELD AUSTRALIA FARMING SCHOLARS

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2010 Nuffield Scholar

September 2010

Nuffield Australia Project No 1003

Sponsored by: Grains Research and Development Corporation

GRDC Grains Research & Development Corporation

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Foreword

Agriculture is today facing ever increasing demands upon which the core fundamentals of farming as we know it are increasingly under review by environmentalists, policy makers and the farming community. Carbon has become a currency, a major area of interest for farmers, financiers and policy makers and its effective management is a potential source of enormous economic activity.

On a personal level, after a continual run of drier than average seasons in eastern Australia and being forced to re evaluate our land operation, our main and most important was continually up for embarking on the next great challenge in seasonal production – our soil. Understanding the characteristics of soil has become an essential component to riding out seasonal variability.

The objective of my study was to understand the principals behind carbon trade and the on-ground farming practices that may enhance soil health, increase sequestration and potentially increase greater amounts of soil carbon.

How carbon is measured and the value placed upon carbon are some of the most important factors for farmers working within a carbon constrained economy. Carbon as a component of soil and information on how to increase the effective sequestration and storage of carbon through improving soil health is becoming a more practical approach to addressing stabilisation of atmospheric carbon.

Acknowledgements

I would like to thank my family for their support in allowing me the time to travel and study in 2010. My fellow scholars who have provided an insight into their own regions and businesses. I would like to thank Jim Geltch Nuffield Australia CEO and David Brownhill Nuffield Australia Chairman for their enthusiasm, attention to detail and diligent planning in all aspects of Nuffield related activity. Thank you to GRDC for their generous support, and finally to all the people who took the time to chat, open a house or provide information for my study area.

Abbreviations & Glossary

C - Carbon

N - Nitrogen

CBOT - Chicago Board of Trade

CT - Conventional Tillage (full inversion followed by several passes)

EM - Electro magnetic

GPS - Global positioning system

Ha - Hectares

NT - No Tillage (zero tillage)

Phytolith - a rigid microscopic body that occurs in many plants

Ratooned - shoot sprouting from a plant base

RT - Reduced Tillage (several timely more specific cultivations)

Senesced - To grow old

SOC - Soil Organic Carbon

SOM - Soil Organic Matter

Executive Summary

Carbon sequestration and future carbon trade policy could very well influence future land use, changing the dynamics of agricultural production systems with ongoing ripple effects adjusting the structure of regional economies, influencing the national interest in terms of food and fibre production, export opportunities and living standards of the broader community.

Future research has a huge role to play in developing accuracy of base measurement of soil carbon in order to outline some parameters before carbon related policy in relation agriculture is set. From all aspects more information needs to be exposed on the characteristics of soil type. To date, soil test analysis revolves largely around fertiliser requirements for a particular crop, not giving a full understanding of the complexities of soil characteristics and how they may relate to production potential. There is scope for development of a scenario plan result in analysing test data, allowing for the option to manage and develop best practice land use.

A soil test outcome should include more than a fertiliser recommendation.

There is also room for cultivar development in plant breeding by combining plant characteristics conducive to accelerated carbon sequestration and store into mainstream crop varieties, giving huge potential for carbon sequestration in agricultural production systems.

Reward agricultural land management, some real incentive to initiate positive change, forget the blame game and unfair expectations, don’t let policy makers leave it to a few to correct the mistakes of many.

Accept that there is an upper limit to the amount of carbon a soil can contain. Through the very nature of carbon cycling, carbon is removed and replaced as best possible when all variability is taken into consideration.

Introduction

My Name is Alastair Starritt. I am a family partner in a mixed farming operation in the south west of New South Wales, having adopted principals of biological farming over ten years ago a strong focus has been placed on soil health. As time has progressed the soil health focus has created an interest in the role of soil carbon, and in issues related to carbon sequestration, trading and the impacts of land management on soils and the environment.

I firmly believe that agriculture has a positive role to play in carbon sequestration and although not the sole answer to reducing all CO_2 emissions farmers and farming operations deserve good information to serve them now and into the future.

I have embarked on this study with many local farmers in my region in mind. I hope to provide a greater insight into the issues I have discovered. I don't profess to have all the answers but hope at least to broaden the minds of sceptics and perhaps pave the way for a more positive understanding and approach to farming practices and land management.

Soil carbon management: A direction for agricultural systems in Australian farming, systems conducive to carbon capture and storage, understanding on going impact on soil structure health and carbon holding capacity.

The United States Department of Energy estimated that world carbon dioxide (CO_2) emissions for 2005 were around 26.33 billion metric tonnes and are projected to increase to 30.20 billion tonnes by 2010. As well as reducing atmospheric CO_2 by the introduction of low emission energy production, carbon also needs to be sequestered by as many new and innovative methods as possible. Sequestration is currently largely dependent on existing forestry or hardwood plantations broadly described as woody plants. However the land available for woody plant production has become limited due to the increasing demand for agricultural production. With this in mind a more recent approach has been to look at increasing the world's carbon stocks (Parr.J, 2009). With a growing global population and increased demand for food production, improving methods to store additional terrestrial carbon in agricultural soils and degraded landscapes is a logical approach.

Soil carbon and carbon related issues like it or not have, and will become major issues of agricultural systems worldwide.

The Australian National Climate Change Centre has adopted a policy of adapting to climate change. Before your eyes glass over, like it or not, the broader community demand answers and action.

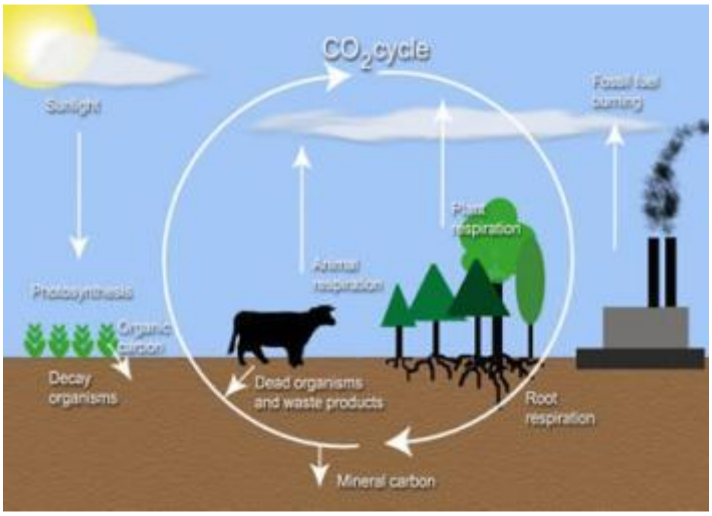
Regional communities cannot control climate variability but can understand risk and build in adaptive capability.

Some simple facts:

- Soil is the largest source of carbon on the planet.
- The world's soils hold around three times as much carbon as the atmosphere and more than four times as much carbon as the world's vegetation.
- Soil represents the largest potential carbon sink in which mankind has control.
- Sequestering carbon in the soil has an immediate impact on reducing atmospheric CO_2, compared to planting trees which can take years to have any real impact on CO_2 levels (Jones.Dr.C, 2009)
- Degraded soils have the greatest potential to capture soil carbon
- Carbon dioxide CO_2 emissions are up 30% since 1900
- Nitros oxide NO_2 concentrations are up 60% since 1900
- Methane CH_4 concentrations up 150% since 1900
- Carbon is considered sequestered if it ends up in a stable form, i.e. wood or soil organic matter

Soil Carbon Cycle

By definition carbon is a major component of soils and cycling process of the atmosphere. Plants absorb atmospheric carbon dioxide (CO_2) which is then reduced through photosynthesis so that the carbon component is retained in soil structure and oxygen is returned to the atmosphere. The carbon that is retained by plants may be transferred to soil via roots or decomposing plant residues. Soil carbon may be returned to the atmosphere from the soil when the organic material in which it is held is oxidized by decomposition or burning. (Wikipedia, 2009).



The carbon sequestration cycle *(Susty, 1999)*

It should be noted that carbon cycling is largely a naturally occurring process so nil action will not stop some form of carbon sequestration. The challenge is to co-ordinate a more sound approach to farming system management that may increase carbon capture and storage.

Carbon Trade

Will agriculture become the pollution sink for industry players to buy credit and continue to operate with minimal adjustment to their own systems? To avoid this it is extremely important for farmers and land managers in Australia and globally to be well informed and in a position to demand the best deal for them as individual businesses and for agriculture in general.

"It's the most adaptable species that can survive." Charles Darwin.

Carbon trade is predicted to be as large in terms of value and an internationally tradeable commodity as oil. Estimates of the value of carbon emissions allowances have ranged from $15 per tonne to $348 per tonne based on early market signals (1990's) (Skees, 1999). The Chicago Board of Trade (CBOT) floated the concept among much anticipation of a buoyant tradeable commodity in mid 1990's - unfortunately trade and value diminished quickly and has remained flat ever since. Only time will tell if true carbon value and the realisation of a tradeable entity in its own right will become a reality.

In Canada, trading schemes are still in development. Blair McKlinton, executive director of Canadian soil conservation, informed me that a number of Canadian farmers are participating in a carbon trading scheme based on zero tillage cropping. The criteria is based on less than 40% soil disturbance. A formula has been derived whereby - knife point width (very few disc machines are used in western Canadian cropping systems) is multiplied by row width. Ten inch, or 250 mm between seed rows is preferred, typically 15% to 20% of soil disturbance is made in this type of seed placement. From early inception 100 fields have been monitored on carbon content until now, giving a starting point for measurement and actual data on the positive impact of zero till crop production. (McKlinton, 2010).

In Alberta carbon has been capped with the value of carbon at fifteen dollars per tonne. Some simple calculations on emissions less input derive a value of approximately one dollar per tonne per hectare for low rainfall cropping country (300 to 450mm per annum) where as the return for parkland termed country having a higher rainfall, thus greater moisture, greater naturally occurring humus through greater biomass production is valued more highly. This rangeland type country is generally used for pasture production and land use is primarily livestock grazing, due to its natural status it is graded at a higher value of two dollars per tonne per hectare.

Farmers are then able to fill out a relatively simple form that outlines previous management practices that in turn gives them a point at which they can trade carbon sequestered in that particular system. Interestingly, possibly the greatest sequester of carbon is a pasture based system (maintaining ground cover and constant cycling of carbon and other nutrients). However, the only way of deriving an income from such a system is to graze livestock thus opening another raft of issues in relation to methane emissions.

Cropping or grain production is undoubtedly the simplest method to begin in participation of carbon trade. Blair also felt the biological approach, while having merit, was missing some key issues in addressing the capture of carbon in a farming system.

Barry Rap, of Combined Grain Elevators Saskatchewan, stated carbon trade got off to a flying start, but hasn’t really been spoken of in recent years as other issues have become more paramount. Grain production and input costs have taken a far higher priority in recent times. Grant Miller, of Herbert Saskatchewan, stated the rising costs of running his business were probably his highest concern. The introduction of some irrigation has probably spread risk on production but the safety net has come with a higher cost demand on inputs associated with the higher production irrigation gives his farm. (Miller, 2010). Jim Cooper Tugaske, Saskatchewan said he has been thrilled with the change in soil condition and his ability to grow a wider range of new more profitable crops after a change to minimum tillage in 1997. His yields had probably doubled on a typical year and having eliminated his summer fallow meant that the whole farm was in production all year round. As production has increased so too have his costs in producing grain in a higher input system. The cost of equipment is huge so he needs his farming to keep up with higher financial demands being placed on his business. (Cooper, 2010) Both farmers were interested in the carbon concept but are waiting for more stability in the market and a more secure financial return.

In relation to soils research findings demonstrate healthy soils:

- Hold more water and nutrients
- Produce more per input cost
- Are able to capture and store more carbon

Therefore to gain the most from a carbon capture and trade schemes that may become part of agriculture in the future farmers need to understand the value of healthy soils for not only a greater amount of productivity but also to be able to capture, store and become prepared for a potential resource for income related to carbon trade.

Farmers need to understand the importance of their actions in a carbon trading world, by being informed agriculture should be proactive to capitalise on profits able to be made from future schemes.

Thomas Jefferson famously said "*Cultivators of the earth are the most valuable citizens. They are the most virtuous and they are tied to their country and wedded to its liberty and interests by the most lasting bands"*

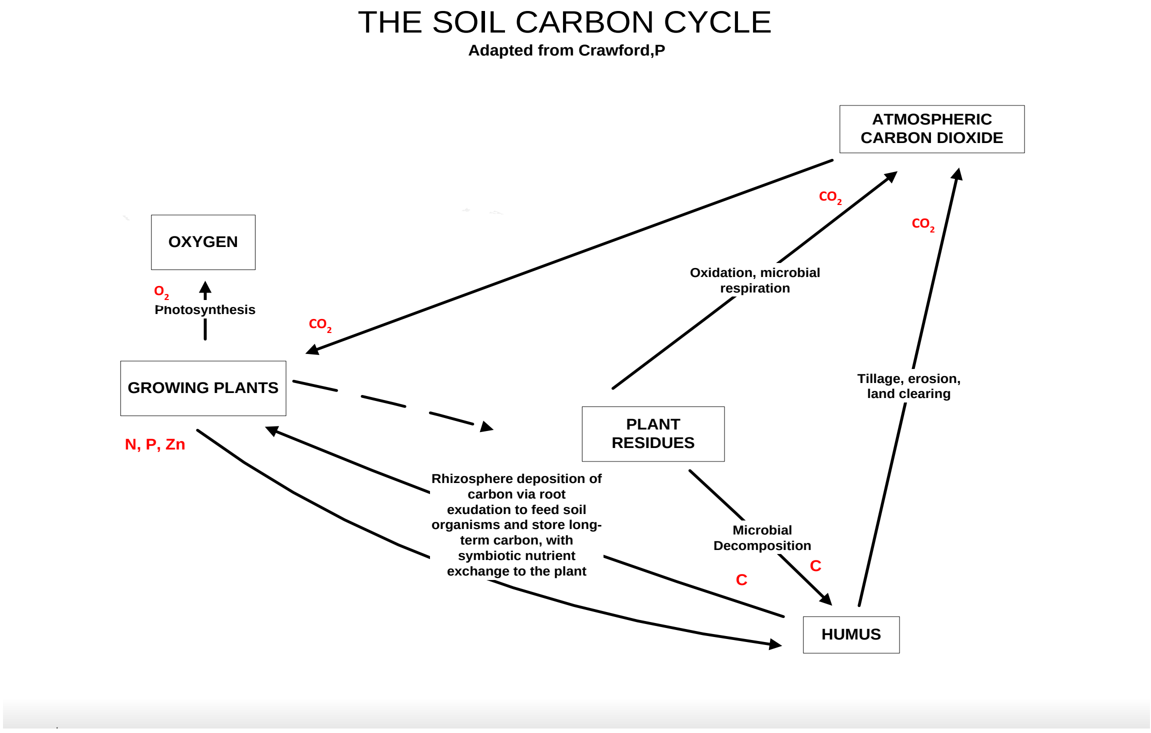
It is quotes such as these that stir the core of those living and working on the land, be all that it may we should not be blinded by our self pride but look modestly to learn and continuously re evaluate our position as soil managers and global food and fibre producers.

By the very nature of agriculture challenge is apparent and change is constant, so in relative terms the face of farming is under constant review, with this in mind farming needs to seek and adapt to change.

Tim Richer of Lime Springs Iowa USA (when referring to the length of his farming career)

"*I've only got forty chances at this; I need to get it right every time"*

Farmers or land managers prepared to take the initiative to change their farming system need to be encouraged and rewarded for sound land management. It is hard to see how any operators would radically change a farming principal or method on a whim, risking business stability unless they could see a form of productivity or financial security. The uncertainty in relation to carbon trade raises many questions, and there are many components to consider. The model below illustrates elements and the process of the soil carbon cycle.



The soil carbon cycle *(Crawford P)*

Plant cultivars conducive to carbon capture

Literature would suggest the carbon cycling process of plant growth and sequestration via photosynthesis is a sound basis for carbon capture and storage. To reach the full potential of this theory, results of studies conducted on both corn and sugar cane varieties have demonstrated their value as converters of atmospheric CO_2 into plant structure and in turn to soil profile.

Research has investigated a process of carbon capture and long term storage using silica phytoliths. The findings of this process on newly planted ratooned sugarcane varieties indicated there was significant variation in the phytolith occluded carbon (PhyOC) content of different varieties. This did not appear to be directly related to the quantity of silica in the plant but rather the efficiency of carbon encapsulation by individual varieties.

This PhyOC process provides an approach which reduces emissions from agriculture for the long term (millennia) as opposed to many other soil organic carbon fractions that may decompose over a much shorter time. Importantly the ability to quantify PhyOC prior to its incorporation into the soil will provide a distinct advantage for the quantification of this carbon form over other soil carbon fractions in emerging emissions trading and offsets markets. (Parr.J, 2009)

Wales UK Athol Marshall pasture plant breeder stated the focus on pasture species had been on nitrogen fixation and digestibility with little change in focus for the last twenty years. However, Aberyswyth University Bangor campus has recently begun a pilot project to explore carbon capture of plant varieties for sequestration purposes.

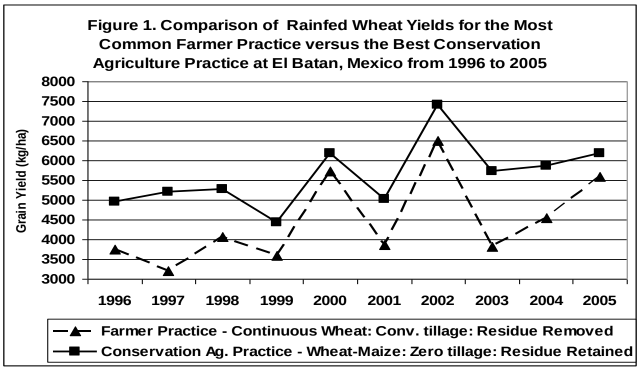
Michael Norriss of PGG Wrightson Seeds New Zealand, also acknowledged that little emphasis had been placed on the ability of carbon capture in breeding of pasture species until now but this may change over time. He also made mention of a clover species *trifolium ambiguum* that had been primarily used on reclamation work sites. The plant had a massive root structure which would suggest an increased ability to sequester carbon. This clover is unpopular with mainstream grassland production systems because it takes a full year to establish. Yet it may have desirable characteristics that could be drawn upon in future plant breeding. (Norriss, 2010)

There is much scope for future plant breeding or gene technology to use some of these traits to breed plant species that have a greater ability to sequester atmospheric carbon into soil structure.

Soils and land management

If some of the least disturbed soils in the world contain 6% carbon and the most cultivated contain 1% (or less), the carbon capacity of soils is relatively low to begin with. The recent adoption of zero till crop production is well placed to begin sequestration of greater amounts of atmospheric carbon into soil structure.

Records kept on soil carbon content in zero soil disturbance crop production and retaining all crop residue (in an ideal situation) conducted By CIMMYT Obregon Mexico for the period 1996 to 2005 showed an increase of 1% to 1.6% in nine years and although minor in terms of individual measurement the overall picture is positive.



(T.Goddard, 1996-2005)

Production gain by adopting conservation agriculture

This table demonstrates the overall production gain to be made by adopting a policy of full stubble retention and in all situations yields were improved, demonstrating an overall productivity gain justifying a complete change to a core principal of crop production. Zero till agriculture is becoming increasingly popular and is complimentary to soil carbon sequestration - it is no quick fix but more a mindset toward a principal for soil management.

Using this information as an example, participation in future carbon sequestering production systems would be unlikely to occur without a financial reward as an incentive.

Measurement of carbon in soils

Soil profile *(Starritt 2010)*

Perhaps the greatest hurdle to setting real goals and objectives in the great soil carbon debate is that major inconsistencies have evolved in the measurement of carbon content when soil type and profile depth are considered. Measurement of carbon content will change over a given field area and will vary according to soil depth.

Current research suggests that there are as many variations in carbon content as there are soil types and textures. Establishment of carbon related policy needs to be based on proven consistent science. It is hard to run a marathon if you don't know who has started or where the finish line is.

Development of a proximal sensing technique used to predict root density and soil organic carbon has recently been extensively trialled by scientists at New Zealand's Massey University. A portable field spectrometer with a modified soil probe was used to acquire reflectance spectra (350-2500nm) from horizontal surfaces of soil cores. Calibration models developed using partial least regression between the first derivative of soil reflectance and the reflectance data were able to predict the soil profile root density and soil Carbon and Nitrogen content for all soils. This research has identified a potential method for assessing root densities in field soils enabling study of their role in soil organic matter synthesis (Tuohy, 2010). This research may help to eliminate soil variability giving misleading soil carbon content measurement results.

Cultivation

Moulboard ploughed *(Starritt 2010)*

Reduced tillage will reduce carbon emission but will not increase storage capability.

Methods from previously published experiments that recorded the response of Soil Organic Carbon (SOC) to changes in tillage or crop rotation and that were greater than five years in duration did not go far enough to base carbon sequestration policy upon. Measurements were recorded as mass per unit area (eg. m-^{2} 30 -cm depth) and many cases little or no change in SOC was found to occur between 20cm and 30 cm. It means extrapolating SOC measurements from higher in the soil profile to represent SOC changes in the lower profile would incorrectly inflate carbon sequestration estimates. Therefore when experimental results indicated SOC measurements (for example to a depth of 15 cm) they were not necessarily an accurate view of the entire profile. It is vital to consider this as well as particulate size and clay content when making such estimates (West, 2002).

There is a distinct difference between carbon cycling and carbon store. This is perhaps better distinguished as ‘new’ and ‘old’ carbon. Consequently policies derived from the results of experiments and studies such as these may not ultimately be workable.

Soil Composting and Microbes

Early stages of composting *(Starritt 2010)*

Soil fungi is a key indicator of soil health, although it seems there are as many interpretations of soil health and status as there are soil types. Due to the complex nature of soil testing and interpretation, it is difficult to set a hard and fast rule on data entry and a one size fits all solution. Hence there is a value in understanding the specific needs of a particular soil type or more to the point, understanding the soils that you are farming. It is crucial to understand the importance of testing as near to possible to previous test sites in order to pick up the variation of soil conditions from season to season. Carbon content in soils can vary according to soil depth. Improvements made by the adoption of conservation tillage may only enhance the top layer of disturbed soil by inversion of crop reside with seeding process. Interestingly the fastest way to incorporate crop residue into soil is by full inversion (ploughing), however the damage caused by this action would most likely counteract the benefit of enhanced residue incorporation by damaging the fragile nature of fungi and beneficial bacteria broadly referred to as soil biology within the soil structure. (Williams, 2010).

It is said that one handful of soil contains more soil biology than number of beings on earth. That's greater than seven billion. To get a gauge of the size of a billion, one billion seconds ago it was 1959, so if you use that kind of analogy many could rightly ask 'How well do we really know soils and how they work?'

Soil structure

Loss of SOC can also be reversed by using less intensive cultivation practices or by changing from monoculture to rotation cropping. In an analysis of 17 experiments Kern and Johnson (1993) concluded that a change from conventional tillage (CT) to no tillage (NT) sequesters the greatest amount of carbon in the top 8cm of soil a lesser amount in the 8 to 15 cm depth and no significant amount below 15 cm. It was also concluded that unlike NT, no significant change in SOC was realised in response to reduced tillage (RT) (West, 2002).

A distinct advantage for agriculture is the great 'zero till, full stubble retention' revolution (70% in Australian broad acre crop production systems and growing). Importantly, not all soils are suitable for no till practices, however, with technology gains in seeding equipment, new varieties and cropping systems overcoming some obstacles and embracing change, there is good news for improving soil structure and therefore carbon sequestration and carbon holding capacity.

According to Dr Christine Jones, any farming practice that improves soil structure will build soil carbon. Soil microbes play a very important role in building and maintaining soil structure. Glues and gums form fungal hyphae in the soil rizosphere and enable formation of peds or lumps. The presence of these aggregates creates macro pores (spaces between aggregates) which markedly improves the infiltration of water (Jones.Dr.C, 2009).

So how does agriculture get recognition for the silent revolution that is changing the face of worldwide soil management? Again this is the very crust of all issues related to working within an insular environment with less and less farmers forced to produce more for less cost for a growing world population (9 billion people by 2050). The answer is communication, and although the "paddock to plate" type slogan has been rolled out time after time it best contains the essence of what is required by communicating the relevance of agriculture to the greater population. As the food and fibre producers, we also now potentially hold the added responsibility of carbon capture

Soil Carbon's impact on water retention

Changes to groundcover management can have significant effects on levels of SOC influencing soil surface condition, soil structure, porosity, aeration, bulk density, infiltration rates, water storage potential and the amount of plant available water. An improvement of any of these factors increases the effectiveness of the rain that falls which enhances productivity as well as reducing rates of erosion, dispersion water logging and dry land salinity.

The majority of Australian topsoils have bulk densities in the range 1.2 to 1.8g/cm^3. Within the soil matrix, stable forms of organic carbon such as humus can hold up to seven times their own weight in water - assuming one part of soil organic carbon can retain four parts of soil water.

How will water storage in the top 30cm of soil be influenced by changes in the level of soil organic carbon?

1% OC = 3.6 kg/m^2 = 14.4 litres/m^2 = 144,000 litres/ ha

The above calculation shows that an increase of 14.4 litres of extra plant available water could be stored per square metre in the top 30cm of soil with a bulk density of 1.2g/m^3, for every 1% increase in the level of soil organic carbon in addition to the current water holding capacity of the soil itself. (Jones C. , 2006)

The importance of soil carbon to soil water holding capacity

The water use efficiency of wheat varies from 5kg to 20 kg/ha of grain per 1 mm of rainfall (depending on soil type) as an example; base of 15kg/ha/mm of rainfall.

A wheat crop Yielding 2.5 tonnes per ha would require 170mm of stored and in crop rainfall 1.7 million litres / ha (1.7 megalitres)

A heavy clay soil with 1% organic carbon with a bulk density of 1.2g/m^3 would be able to store 100mm of rainfall before runoff (depending on groundcover soil structure and slope). With no in-crop rainfall this soil should be able to produce a crop yielding 1.5 tonnes per ha. If, however this soil had an average soil carbon content of 3% to a depth of 30cm it could store an extra 288,000 litres per ha or the equivalent of 28 mm of rainfall - a total of 128mm of stored water. With no in-crop rainfall this soil should produce 1.9 tonnes per ha (an increase of 400kg/ha). Assuming an average wheat price of $200/ tonne the soil with 3%

carbon is able to produce $80 per ha more than the soil with 1% carbon. In a marginal season this could be the difference between profit and loss. (Jones.Dr.C, 2009)

Farming methods and their impact on soil structure

In terms of building a healthy soil, aggregates held in a ball or cluster reduce the surface area to exposure to decay and possible loss of beneficial soil biology. If thought of in terms of a large ball made up of small aggregate as opposed to the same size ball filled with large aggregate as you can imagine the larger aggregate allows light air and water to pass through, having greater potential to erode beneficial components of good soil structure. In other words a fine soil is a good sign of healthy structure and a positive direction when looking to enhance characteristics conducive to carbon and other nutrient holding capacity. The challenge is to be aware of how fragile a fine soil can be to wind and water erosion as well as compaction from excessive wheel tracking. The single worst practice to degrade soil structure is ploughing or conducting tillage or other practices to a wet soil. It reduces the air component of the soil unleashing a raft of issues that severely reduce healthy characteristics of soil and should be avoided where ever possible.

Negative impacts on stored soil carbon

Practices that have been defined to lead to loss in SOC from soils include:

- Cultivation, exposing soil carbon and organic matter, leading to the accelerated organic matter decomposition and soil structure decline.
- Burning of stubble and removal of plant residues, such as hay (reduces the amount of organic matter returning to the soil)
- Removal of native vegetation, ‘cleaning up’ can reduce and remove vast amounts of carbon from any natural areas.
- Extended fallowing, traditional long fallowing leaves the soil bare and exposed; there is also a chance of increased cultivation used for weed control.
- Ground loss maintenance, any activity that leaves soil bare results in decreased root biomass beneath the soil, as the volume of root biomass is directly related to the biomass above the ground. (Johnstone, 2010)

In New Zealand, The Lincoln Millennium Tillage trial was established to determine if the use of less intensive tillage practices could help to sustain soil quality and arable crop performance following improvements under grass pasture.

In the short term (first 4 years), tillage intensity had no significant effect on main crop yields. In the longer term (greater than five years), no tillage and to a lesser extent, minimum tillage practices produced higher yielding crops that may have been attributed to higher water use efficiency and greater top soil nitrogen availability. In this trial environment, effective slug control is important for crop establishment under no tillage practice for autumn sown cover crops known to be susceptible to slug damage such as peas. (Poole, 2009)

This trial demonstrates agriculture must retain flexibility in recognising and adapting to land management. With the growth of chemical resistance in recent years farmers need a raft of strategies to combat such problems. This would most definitely include grazing, burning and cultivation in the ‘tool box’ of options. By using these means of rogue pest and weed control measures, a farming system may run the risk of being viewed as a non sound ‘carbon sequesterer’ through a pre-conceived system for soil management ‘best practice’. Nothing would fall from favour faster than a structure of regulation that in effect dictates land use, or prevents farmers from having the ability to farm their land.

Characteristics of healthy soils

- The level of organic matter is maintained
- Soil fertility is optimised
- Optimised water entry storage and supply
- Enhanced soil biological function
- Supports productive land uses
- Enhances environmental and community health and well being (GRDC, 2009)

Soil Profile *(Starritt 2010)*

Soil organic carbon

Soil organic carbon (SOC) refers to the carbon associated with soil organic matter (SOM). Soil organic matter is the organic fraction of the soil and is made up of decomposed plant and animal materials as well as microbial organisms, but does not include fresh and undecomposed plant materials like straw and litter lying on the soil surface. Soil carbon can also be present in inorganic form as carbonates such as limestone.

Soil carbon pools

Chemically SOC is very complex, containing organic materials at all stages of decomposition. SOC is made up of the following:

- Partly decomposed organic matter, organic materials at an early stage of decomposition
- Microbial biomass, microscopic living organisms
- Humus, old organic material (the original form is no longer recognisable)
- Charcoal, burnt organic material in varying states of oxidisation.

Fresh organic materials (stubble, senesced roots and dung) are technically not part of SOC because much of their carbon is likely to be lost as carbon dioxide in a process of decomposition with only a relatively small portion entering the soil. In addition, if these materials are not removed prior to laboratory analysis they can become a large source of error when soil carbon content measurements are taken over time. (NSW I. &., 2010)

Agronomic Benefits of Co2 in soil structure

Carbon as part of a naturally occurring cycle obviously has a place in the health of soil systems and the plants that grow in them. Carbon in soil helps to release nitrogen for plant development and potentially to increase yield.

Soil Fertility	Effects of SOC	C pools
Chemical Fertility provides nutrient available to plants	Microbial decomposition of SOM releases nitrogen, phosphorous and a range of other nutrients for use by plant roots.	Liable, slow
Physical fertility improves soil structure and water holding capacity	In the process of decomposition microbes produce resins and gums that help bind soil particles together into stable aggregates. The improved soil structure holds more plant available water, allows air and plants to move easily through the soil, and makes soil friable	Liable, slow
Biological fertility Provides food for Soil organisms	Organic carbon is a food source for soil organisms and micro-organisms. Its availability controls the number and types of soil inhabitants and their activities which include recycling nutrients, improving soil structure and even suppressing crop diseases	Liable
Buffers toxic and harmful Substances	SOC can lessen the effect of harmful substances by absorption of toxins heavy metals and degradation of harmful pesticides.	Slow and Recalcitrant

Importance of SOC to soil health and the carbon pools responsible. (NSW I. &., 2010)

The creation of soil carbon is a complex biological process and as CSIRO Plant Industry researcher Clive Kirkby says, “It is not as simple as stubble equals carbon”.

An understanding of the components needed to create the carbon would help people understand why retaining stubble doesn’t always lead to increased soil organic matter an important consideration in the development of a long term approach to reducing agricultural carbon emissions. Heavy Crop Stubble looks like the start to healthy soil composition, but only if the soil is also rich in nitrogen, phosphorous and sulphur needed by soil microbes to turn into carbon. (Kirkby, 2010)

Wheat Crop emerging heavy stubble *(Starritt 2010)*

Crop residue is perhaps not new to many Australian farmers already using full stubble retention in a zero till cropping situation. This however is well recognised as the first of many steps to improve the characteristics of soil composition.

Soil carbon sequestration should be pursued after soil health and production capacity, according to Dr Geoff Baldock, Head of Soil Carbon Research CSIRO based in Adelaide. The first real gain to be made from farmers when considering carbon farming is that by having a healthy soil structure, the ongoing benefits of potential carbon trade will only flow later in time and should not be something viewed as a new an upcoming reliable income source. (Baldock, 2010)

Cover crops and the green bridge

Cover crop species mix *(Starritt 2010)*

Dakota Lakes Research Farm USA director Dwayne Beck has been conducting trials on the method of rotating crops full stubble retention and zero tillage for over twenty years and the science is working. Where one time crops were only grown on a two-year rotation with an extended fallow period between, there is now a raft of regional and use practices that allow continuous cropping of a range of crop species with varying growth periods. The introduction of a "cover crop" disc-seeded into a standing wheat stubble or the residue from a recently grown crop means the remaining moisture supports a temporary crop. The mix is made up of legumes and cereal varieties to enhance microbial activity, nutrient cycling and process of carbon sequestration - the crop is allowed to run full cycle prior to being killed off by frost and ice late in the season prior to winter dormancy (Northern Hemisphere).

If this principal was to be adopted by Australian cropping systems the cultivar species mix would have to be changed to suit the warmer soil temperatures. The thought is to mix about seven or so crop species together, perhaps a minimal graze followed by a 'brown off' through the application of herbicide prior to planting of the intended winter crop. The remaining residue becomes available for soil microbial activity as well as a groundcover to assist in the establishment of the following crop. Concern may well be raised in regard to extracting stored soil moisture for the intended following winter crop as well as harbouring diseases from season to season (referred to as the green bridge). The potential moisture loss, versus the gain to be made from continuing the cycle of microbial activity, nutrient cycling, carbon capture and moisture retention (through above ground shading loss from evaporation), should be carefully considered. It seems minimal surface disturbance would be most beneficial to this type of system as moisture at seeding in order to achieve an acceptable germination is essential for any chance of success with such a proposal.

Bio char as a sequester of carbon

This process is thought to have been discovered by accident. It was a practice carried out in ancient times where natural bio mass plant material was covered with soil and left to smoulder. The original intention was to produce charcoal as an early fuel source. The pits that remained contained dark soil which then was placed around plants, rapid growth followed and the product was discovered to be rich in nutrient. This was also spread across crops as a source of fertiliser. Further analysis has uncovered, treated sites are able to hold greater amounts of water and nutrient.

Commercial production involves a process of controlled heating of plant and or animal material at temperatures of 350-600^o Celsius in a low oxygen environment. The technique is known as pyrolosis. (NSW I. a., 2009) If only the enthusiasm behind the theory could match the development and practicality on ground this could be viewed as a real option for mainstream agriculture. The scientific community see the process of bio char as being the most effective model for sequestering carbon and placing into soil structure for millennia. It is debateable as to the practicality of such a system for the following reasons:

Biochar requires a volume of plant material that may have had an otherwise destined use i.e. in livestock industry or direct human consumption. The plant residue may have had a role as a soil conditioner, (as naturally occurring humus) or creating an environment for zero till crop establishment. Reducing wind, water erosion and increasing moisture retention. Vital components in crop production in marginal volatile environments (something we are likely to see more of apparently).

In addition there is a specific process of burning the material in a low oxygen environment which is quite site specific. The volumes of bulk material required are huge and the practicality and cost of moving such large volumes of bulk while not beyond the realms of possibility have to be borne by someone.

Is debateable as to whether this is ‘new’ carbon as it is a combination of previously sequestered carbon being moved from one form to another through plant development and growth. Not actually a greater volume of carbon being drawn directly from the atmosphere in order to install to soil profile.

Mechanised energy in Farming

Since the turn of 1900 agriculture has faced massive changes in terms of efficiency through mechanisation and the introduction of more and larger farm equipment the efficiencies made by such changes have created huge labour savings and increased the efficiency of agricultural producers across the world many times over. But size and compaction has become a limiting factor and the problems of huge horsepower reached a head in the late 1970’s when North American manufacturer Versatile developed “Big Roy” a 22 tonne 600 horsepower tractor. The tractor was subjected to extensive field tests all of which it passed well, however, at the time there was no commercially available implements robust enough withstand the horsepower. Not to mention the impact of such a heavy tractor combination would make on soil structure. Consequently commercial production of the concept tractor was abandoned. From this point on tractor efficiencies have been re addressed constantly. The Caterpillar machine below develops the same horse power while the rubber tracks provide ample traction and deliver half the weight spread over a greater footprint

Caterpillar Rubber Tracks *(Starritt 2010)*

Recent development of Rubber track Tractors have significantly reduced soil compaction benefiting soil condition while still providing large horsepower.

Carbon consumption in Agriculture

Another approach to carbon related issues in agriculture would be to avoid excessive emissions from the onset. There is raft of new technology in relation to precision agriculture (PA) whereby satellite technology can accurately place equipment pass after pass eliminating operator error. The main driver of adopting this technology is efficiency gains in all field operations especially over or under applying crop nutrition, namely fertilisers. This, combined with harvest yield monitoring and satellite mapping, can identify deficiencies in field production and allow the same data to be transferred to seeding equipment which then adjusts input rates depending on a pre-determined target yield. This approach greatly reduces overall fertiliser consumption.

Some 'out of the square thinking' would be to consider aim for less carbon consumption rather than focusing on greater carbon sequestration. US Congress adopted a policy of addressing diesel engine emissions in five stages or Tiers.

Tier one and two basically focus on fuel efficiency accounting more greatly for the fuel consumed to direct horsepower. Stage three is far more specified to particulate expulsion from engine exhaust system. Tier Three and Tier Four engines use a combination of previously developed greater injection efficiency of fuel to the engines combustion system then an added stage where exhaust gases are forced through a catalytic converter similar to that used on petrol engines in the motor car industry. A series of porcelain honeycomb type filters designed to capture carbon particulates. Tier five extracts this gas then forces it into another chamber where liquid nitrogen is mixed to neutralise carbon monoxide prior to expulsion into the atmosphere. A distinct disadvantage is that two forms of fuelling are required, one tank for distillate and another for liquid nitrogen for the de-toxification process. It is rumoured the engines are so advanced in clean burning technology that they exhaust cleaner air than they originally drew for combustion! Cleaner burning more environmentally friendly engines but with two forms of fuel may consider this proposal impractical. Also, as technology developed cleaner engines with less toxic emissions a greater volume of fossil fuel was required to run them, thus questioning the overall environmental benefit of the development of this phase of technology.

Andrew Ransley of Caterpillar Illinois, believes the future is in development of bio fuelled engines. Northern hemisphere users of large diesel powered engines have access to alternative bio fuel sources. The sheer volume of material required for large scale bio fuel production suits regions that in the beginning have huge volumes of reliable agricultural crop production to sustain development of such an industry.

In addition to bio fuelled solutions, Caterpillar has recently released a midsized bulldozer onto the market. The new machine uses a diesel powered generator to transfer energy to the rear main drivers on the tractor. This use of electricity over oil hydraulic and geared system is thought to save 20% to 30% of fuel when compared to the same size conventional type machine. (Ransley, 2010). As this type of technology develops it could be widely adapted to mainstream agriculture through modification of a raft of machines currently in use. Although this aspect is not directly sequestering carbon the approach to reduce fossil fuel consumption has to be a positive step for agricultural systems.

Irrigation- the pros and cons

If ever there were a more emotional debate to encounter in Australia within the Murray Darling Basin Catchment over the last ten years (almost all other irrigation regions in Australia have suffered the same fate in recent times) it’s the angst and uncertainty of the volume of water extraction and now calls for new sustainable levels of diversion or diversion limits are being thrown around. There is increasing pressure on farmers, regional communities and the national economy. Somewhere along the line the message has been lost that the portion of extracted water sustains a massive proportion of the global economy. Humans need water and food to survive. It cannot be described in more simple terms. After reading a report that was all too ready to condemn irrigation from carbon conducive management as it wet and dried the profile and accentuated the rotting of leaf matter and organic content within the soil profile, greater enhancing carbon loss. (Zhongkui.l, 2009) I felt there needed to be a balance in the argument.

Irrigation when used to enhance a seasonal crop (which may otherwise be restricted from meeting its full potential through a lack of moisture), overcomes this restricted growth. Application of water enhances plant growth, root development, plant health and subsequent yield. Undoubtedly this plant vigour allows greater sequestration of atmospheric carbon into the soil through photosynthesis. Not to mention the ability for the crop to reach a full yield potential reducing the risk of wasting pre applied inputs (time, fuel, seed, fertiliser and area commitment) as made in earlier crop growth stages and again providing the result to which the crop was originally intended.

Agriculture needs to be prepared to jostle into a positive position to argue the merits of sound land management. Farmers need to objectively draw upon all resources available to minimise risk and maximise positive economical, social and environmental outcomes.

Reward for Sound Land Management

Organic Oat Crop, Will Scale and Peter Storrow, Alastair Srarritt *(Starritt 2010)*

Reward for land management has been adopted by custodians of native bushland and the principal could be easily adapted to mainstream agriculture. As an example a program developed by State of NSW Department of Environment and Climate Change, known as Bio-banking. Biodiversity banking and offsets scheme improves biodiversity and provides funds for landowners who take care for bushland forever and pays them to do it. Bio banking is a market based scheme that brings together landowners who create biodiversity credits by establishing a bio bank site and purchasers who buy credits created. Purchasers may be developers wanting to ‘offset’ biodiversity loss from a new development site or conservation groups, philanthropists and government departments interested in conserving biodiversity in perpetuity. There are two types of biodiversity credits, species credits and ecosystem credits. Landowners who enter into a bio banking agreement and sell their credits can receive an annual payment in return for actively managing their land's biodiversity. (NSW D. e., 2009)

After meeting with Peter Storrow, South West Wales (UK), he appeared unperturbed at the idea of a structure of soil monitoring and perhaps future recognition of sound land management. I feel it important to recognise that he was also receptive of the idea of major business change having adopted Organic farming over ten years ago. Stringent models of monitoring of inputs and activity associated organic farming criteria may perhaps place him in good stead to place protocols for system of monitoring soil carbon increments in order to establish a reward structure giving birth to the possibility of a future payment scheme for sound land management.

Some or a greater majority of more mainstream operators may not receive such an idea with the same degree of enthusiasm.

For Consideration in carbon farming

SOIL TYPE MANAGEMENT CULTIVARS LAND USE BUISNESS CONTROL CLIMATIC CONDITIONS SEASONAL VARIABILITY INSECT PRESSURES ZERO TILL IMPUT COSTS LAND VALUE GEOGRAPHIC LOCATION EXISTING EQUIPMENT MAINTAINANCE COSTS MINIMAL COMPACTION SUCCESSION PLANNING APPROPRIATE NUTRITION BIODIVERSITY COMMUNITY EXPECTATION RETURN ON INVESTMENT WATER USE EFFICENCY MARKETING PRESSURE PRODUCT TRACABILITY PROFIT

Forestry and its role in Carbon capture

Pine Forest log dump *(Starritt 2010)*

In the South West of Scotland pockets of forestry are very well adapted to the local environment as an introduced species from native northern hemisphere pine forests of Canada. Tree species have been continually selected and re selected for growth rate and mill ability (strait logs less wastage). Plantations are operated on a 35 year rotation producing around 500 tonnes of millable product to the hectare. As a converter of carbon these plantations are most efficient, however are restricted in their sites as fear of losing native upland grass and pastures to a different land use may alter the environment from what is deemed a natural state. Again as an efficient adapter of carbon to soil plantations similar to this are a positive measure however are much slower in growth and sequestration than mainstream agricultural pursuits. Constraints over dedicated land use will restrict this type of approach being more widely adapted than already so.

What the future may hold

Enquiries were made regarding the capabilities of electromagnetic soil reading (EM). Until now this technology has been used to take images of underground water aquifers and more recently being used to map soil types. With further development and a combination of overlaying presently used mapping technology perhaps a more sensitive soil probing test may be used. If this were to be combined with harvesting operations whereby the harvester utilising global positioning system (GPS) used for steering accuracy, and in built yield monitoring that measures crop volume as it enters the bin or hopper on the machine. This then gives the farmer an accurate view of yield variation across a whole field.

The idea is to tune fertiliser or nutrition or perhaps even land management practices to either compensate or correct an underlying problem for following crops on the same paddock. By adding EM technology to the same machine the radar could read soil condition, or even carbon content and then be accurately cross referenced over any given area. Accuracy of reading the same area (vital in recording accuracy or variation over a select period to ensure a base control is achieved by utilising the same wheel track as previous harvesting operations (also complimentary for soil condition).

The nature of the operation ensures that the entire paddock is covered. Select points could be flagged, (a term used by GPS technology when referring to a specific place in any given field). Therefore the machine could still approach the desired position from any angle and give an ongoing reading of soil carbon content according to land management. (If not using constant wheel track). By reading into the soil profile data from the exact same spot from season to season would give an accurate overall picture of soil carbon content and change. Depending on how the data is translated the grain from that particular bin load typically eight to ten tonnes (depending on harvester capacity) could be categorised, although larger tonnages would be more practical. In any case this gives farmers the ability to directly relate paddock yield to soil management. Some simple data entry the marketed grain perhaps accompanied by a recognisable logo would then give a direct conduit for payment based on land or more particularly soil management.

Recommendations

Management practices (grazing)

Some primary examples of land management practices that can be utilised and have been defined as leading to developing an increased soil carbon level include:

- Converting or promoting areas from annual to perennial pasture.
- Maximising species diversity and encouraging all-round seasonal growth to maximise groundcover. A minimum of 70% groundcover (up to 90% on steep or fragile land).
- Matching perennial species to soil types and conditions.
- Improving production from existing native pastures by identifying native species and developing appropriate nutrition.

- Improving the sustainable use of nitrogenous and phosphorous based fertilisers including more timely application.
- Using intensive rotational grazing can increase the cover of pastures generating increased carrying capacity potential profitability and increasing soil carbon (Johnstone, 2010).

Management practices (Cropping)

To get the best from a zero tillage farming system;

- Farmers should consider putting standing stubble on the ground, using a roller prickle chain or slasher.
- Rotating crops and including grain legumes in the rotation.
- Introducing livestock into the farming system and incorporating a pasture phase where practical.
- Above all it is imperative good farm records are kept.

  The likelihood of retrospective payment for prior land management practices appears very low. However as schemes are developed it may be a handy tool to roll out well structured documentation of production that may help place a farm business in good stead to counter argue participation in a rewards-based scheme for 'carbon smart' farming.

Conclusion

The perfect system for soil carbon sequestration - is it achievable? Possibly, if we are able to recognise that there is a perfect season, a perfect amount of cost input and of course a perfect return on investment. The reality is that a system of reward for land management runs very close to dictating land use, which in turn could influence commodity volumes in turn supply demand and of course threaten market stability. And although a potential disaster for free market it would only make an impact if there were a massive uptake across all regions - the likelihood of which I would perceive as being very low. It appears scientific community have a specific view of carbon sequestration, yet the agricultural community seek far wider, more practical methods for carbon sequestration. This is a major issue hindering further development of this approach.

Governments, even with best environmental intentions, have done little more than to propose a new tax structure rather than a real pathway to a solution. I believe the scientific world views carbon related issues as an industry and area for ongoing research. While the agricultural community sees the carbon industry as a new threat to production stability. Meanwhile agriculture has production and financial commitments to meet from the land, be it modified or an existing system. The gap needs to be bridged between all parties to have any chance for progress in meeting some real and positive impact on carbon sequestration. Whether or not this happens is up to the view of the individuals that are prepared to step forward and accept that change is inevitable, participation is optional. Agriculture needs to be viewed equally as part of the solution rather than part of the problem.

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Plain English Compendium Summary

Project Title:	Carbon Sequestration in Farming Systems
Nuffield Australia Project No.:	1003
Scholar: Organisation: Phone: Fax: Email:	Alastair Starritt Womboota Pastoral Co 03 5489 3252 03 5489 3200 alastair@wombootapastoral.com
Objectives	The objective of my study was to understand the principals behind carbon trade and the on-ground farming practices that may enhance soil health and store soil carbon.
Background	Recent media has given conflicting reports on the potential value of a carbon trading world. The impact on agriculture could be huge. Agriculture has a real and valuable role to play. It is essential to be well informed before taking action based on unrealistic assumptions which could jeopardise the stability of agricultural production systems.
Research	My research has been conducted over eleven months and eight countries as well as in Australia. I have collated data from Industry Meetings, Seminars, Research organisations, Farmers and the Scientific community as well as documents related to my study area.
Outcomes	The contents of this report cover a raft of issues related to the study area - many concepts are not new. However, the overall objective is to collate data in a form that may broaden the thought process in understanding where carbon management adds to the complexity of future farming systems.
Implications	The implications of my findings do not hold a single answer but may help to pave the way for future clarity in development of concepts required when considering the impact and complexity of carbon capture trade and storage in farming systems.
Publications	