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An analysis of conservation agriculture as a response to climate change in Australian dryland farming systems

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ABSTRACT

This thesis analyses the role of Conservation Agriculture in reducing greenhouse gas emissions and sequestering carbon in the Australian dryland grains sector. Australian Government policy indicates that agriculture should play a role in climate change mitigation, although the details of related policy are still evolving. Current policy relies on a market-based instrument, known as the *Carbon Farming Initiative*, to incentivise farmers to change farming practices to ones that reduce emissions and sequester carbon into soils and vegetation. Many of the farming practices being considered as part of the Carbon Farming Initiative are aligned to the concept of *Conservation Agriculture* as described by the United Nations Food Agriculture Organisation.

The Australian farming system is highly variable depending on its agro-ecological and socio-economic context. As a consequence, converting the opportunities for climate change mitigation in Australian agriculture into achievable, practical, and commercially viable farm practices is a complex challenge. Moreover, there are a number of economic and social constraints to changing farm practices in Australian agricultural enterprises. In this thesis I apply a systems-thinking and mix-methods approach to consider the issues that drive practice change. The methodology uses both quantitative and qualitative analysis methods.

This thesis considers the role of a number of Conservation Agriculture practices in climate change mitigation. These practices include; reducing tillage, maintaining full stubble retention, including legume rotations, control traffic farming, application of precision agriculture to fertiliser, recycling of organic waste and cover cropping. Review and analysis of the challenges to the adoption of these practices in the Australian broad-acre grain farming reveals that the Australian farming system is generally 'under financial stress' and there are a number of constraints to the adoption of new practices, particularly in the short-term. An examination of economic and social constraints operating on farms indicates that, under the current circumstances, a market-based instrument offering payment for carbon offsets is not a viable option to speed up the process of adoption. The main barriers are ongoing policy uncertainty, the transaction costs associated with producing a verifiable carbon offset, the rules of 'Additionality' and 'Permanence', and the current low market prices paid for carbon offsets. These factors are further complicated by the vulnerability of the Australian broad-acre farming system to carbon loss resulting from climate extremes and variability; this

presents a further commercial risk to aggregators and farmers considering carbon farming. Furthermore, given the size of the typical individual Australian broad-acre farm, offset production through Conservation Agriculture is currently not commercially feasible on an individual farm basis. It appears that currently, difficult commercial conditions in general for the farm sector means that farmers are more focussed on directly managing production issues rather than on managing environmental externalities.

The current use of a carbon market instrument to encourage farmers to reduce agricultural emissions by changing practices is not viable for some sectors such as the dryland grain farmers covering 23 million hectares of production. The current market condition and the associated compliance requirement to generate a market unit is simply not economically attractive. The CFI policy when drafted did not account for such a significant market downturn in the price of carbon and the increasing compliance requirement to meet the IPCC guidelines. There is however a real opportunity for grain farmers to reduce their emissions profile by adopting certain Conservation Agriculture practices. Although the current carbon price on its own is not a sufficient incentive for increasing adoption rates of new farming practices. Practice change in agriculture is risky and farmers change slowly as they evaluate all the implications of change. Many simply do not have sufficient investment or knowledge capacity to make the change. Ideally, adoption of practices that have mitigation benefit would also need to have a production co-benefit to be considered as feasible investments by farmers. The effectiveness of climate policy in Australian agriculture could be enhanced if it were to support the fast-tracking of existing environmentally beneficial farming practices that also have positive production outcomes. As the current carbon market is unlikely to offer sufficient incentive for individual farms, I speculate that future research might consider a specific Conservation Agriculture extension process which could be funded through the production of nominal carbon offset units aggregated and measured at an industry or sector-wide level, allowing for a degree of discounting for risk, variability and uncertainty.

Declaration by author

This thesis is composed of my original work, and contains no material previously published or written by another person except where due reference has been made in the text. I have clearly stated the contribution by others to jointly-authored works that I have included in my thesis.

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Journal Articles

Rochecouste, J. and Dargusch, P. 2011, ‘Opportunities to produce carbon offsets using conservation farming practices in developing countries’, *Annals of Tropical Research*, vol. 33, no. 1, p. 85-101.

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Bellotti, B. & Rochecouste, J-F. 2014 “The Development of Conservation Agriculture in Australia - Farmers as Innovators”, *International Soil and Water Conservation Research* (ISWCR). Special issue - Pioneers in Soil Conservation and Conservation Agriculture (Eds.) J. Dumanski, D. C. Reicosky, and R. A. Peiretti.

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List of Abbreviations

ABARES	Australian Bureau of Agricultural Economics and Science
ABS	Australian Bureau of Statistics
ACCU	Australian Carbon Credit Unit
ACTFA	Australian Control Farming Association
AGGNI	Australian Greenhouse Gas National Inventory
AUD	Australian Dollar
CA	Conservation Agriculture
CAA	Conservation Agriculture Australia
CFC	Chloroflurocarbon
CFI	Carbon Farming Initiative
CH_4	Methane
CO_2	Carbon Dioxide
CORS	Continuously Operating Reference Station
CSIRO	Commonwealth Scientific and Industry Research Organisation
CTF	Control Traffic Farming
DAP	Di-ammonium Phosphate
DOIC	Domestic Offset Integrity Commission
FAO	Food Agriculture Organisation (United Nations)
GHG	Greenhouse Gas
GPS	Global Positioning System
GRDC	Grains Research Development Corporation
HCFC	Hexa-Chlorofluorocarbons
IPCC	Intergovernmental Panel on Climate Change
LCA	Life Cycle Analysis

MBI	Market Based Instrument
N_2O	Nitrous Oxide
NH_3	Ammonia
NUE	Nitrogen Use Efficiency
RTO	Refundable Tax Offset
SOC	Soil Organic Carbon
SOM	Soil Organic Matter
SEEA	System of Environmental-Economic Accounting
UAN	Urea and Ammonium Nitrate (Liquid fertiliser)
UNFCC	United Nation Framework Convention on Climate Change
VRA	Variable Rate Applicator (fertiliser)
WUE	Water Use Efficiency (crop)

1.0 INTRODUCTION

This thesis investigates the role of Conservation Agriculture (CA) in climate change mitigation in the Australian dryland grain cropping sector. The sector is a major exporter and covers approximately 23 million hectares of cropping land, producing 40.5 million tonnes of cereals, legumes and oil crops (GRDC 2013). It is a sector that is highly exposed to climate change and is a significant contributor to emissions (Howden et al. 2010; Stokes and Howden 2010; Australian Government 2014). The thesis begins with a global perspective on the contribution of agricultural externalities to atmospheric greenhouse gases, and examines the current changes in Australian dryland cropping towards the adoption of CA and the implications of this in terms of delivering reduced emissions and sequestration opportunities. The thesis looks more closely at the Australian land climate policy context, particularly in regards to agricultural participation as a response to climate change, and considers what questions need answering to determine the potential for changing agricultural practices to reduce emissions.

1.1 The global perspective and current Australian government policy

Planetary climate change will impact on agriculture and will inevitably require a change in farming practices to reduce agricultural emissions and manage climate effects on production. The changes in the past have been predominantly for productivity reasons such as increased mechanisation; with some changes having emissions implications, such as those aimed at reversing the loss of soil organic carbon and reducing demands on energy inputs (Hughes 1980; Thomas et al. 2007c; Kassam et al. 2009; Radford and Thornton 2010).

The conundrum for the agricultural industry globally is how to deliver food security to an increasing population without further contributing to the levels of greenhouse gas emissions that are contributing to climate change (Garnett et al. 2013). The most productive form of agriculture in terms of yield per area is using industrialised agriculture typified in developed nations such as the United States, Europe, Canada and Australia. Industrialised agriculture also represents the highest emissions intensity in terms of production (Helsel 1992; Uri and Day 1992; Lal 2004b; Labreuche et al. 2011). This thesis examines the value of CA as a policy option to assist Australian dryland farmers in mitigating the impact of agricultural emissions and adapting to climate change. It considers the current evolution in farming practices to CA practices and analyses what are its emissions characteristics and the potential value of its reduced emissions in climate change policy.

The science of agricultural emissions and abatement opportunities is complex and still being developed. This thesis is orientated by a concern for the policy options that leads to the adoption of agricultural practice change. The thesis considers the development of CA practices in the Australian dryland sector in light of the Carbon Farming Initiative (CFI) Act 2011 which came into being on the 15 September 2011 as the *Carbon Credits (Carbon Farming Initiative) Act 2011* (CFI Act)[1] and the *Carbon Credits (Carbon Farming Initiative) regulations 2011* (CFI regulations)[2]. This Australian legislation is an extensive and leading effort involving agriculture in emissions reduction. The thesis looks at emerging Australian farming practices, their impact on emissions and how such policies influence the adoption of relevant changes in farming practices. The research anticipates outlining policy options that will facilitate adoption of practices to reduce agricultural emissions and adapt to climate change.

A range of possible ideas are discussed in the Carbon Farming Initiative handbook including various CA practices such as reducing tillage, retaining crop residues (stubble) and control traffic farming (DCCEE 2012). The current Liberal/National Party-led Australian Commonwealth Government (at the time of writing) has indicated support for a policy initiative towards increasing soil carbon (Australian Government 2013b; Heath 2014). The Government's Direct Action plan intends to use a 'reverse auction' as a market mechanism, wherein an 'Emissions Reductions Fund' will be established to purchase emissions reductions at the lowest price from industries including agriculture. This is outlined in the current Green Paper[3] which reflects the Government's consultation with business and the community, with a policy White Paper planned for early 2014 (Australian Government 2013b).

Globally a number of authors have alluded to the value of CA practices in terms of carbon sequestration and possible reductions in carbon dioxide emissions (Dalal et al. 2003; Lal 2004c; Ugalde et al. 2007; Gaiser et al. 2009; Stagnari et al. 2009; Boddey et al. 2010;

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[1] CFI Act 2011 - http://www.comlaw.gov.au/Details/C2012C00417
[2] CFI Regulations 2011 - http://www.comlaw.gov.au/Details/F2012C00466
[3] Refers to a policy review document in which a Green Paper is available for community consultation and a White Paper outlines the government's policy plan.

Carbonell-Bojollo et al. 2011; Labreuche et al. 2011; Murphy et al. 2011; Gonzalez-Sanchez et al. 2012; Schwenke et al. 2012); however definitions of CA in practice are inconsistent (Friedrich and Kienzle 2007; Hobbs 2007; Giller et al. 2009; Govaerts et al. 2009; Heath 2011). Definitions of CA differ depending on the country concerned, climate and the farming system in which the practices are being applied. It is therefore difficult to determine the emissions intensity relating to a CA farming practice when the practices are so variable and highly dependent on its agro-ecological and social context. Policy supporting changes in farming practices such as the Australian CFI would benefit from a better understanding of what practices farmers are actually doing in Australia, the emissions intensity of these practices as we know them, and the relative merit of these practices in productivity terms.

1.2 Rationale for the inquiry into the role of Conservation Agriculture on emissions and climate change adaptation

According to updates in the Garnaut Climate Change Review 2011 commissioned by the Australian Government, the Australian climate is unequivocally changing, with most change attributed to human generated greenhouse gas emissions (Garnaut 2011). This is said to be having an ongoing impact on the nation’s agricultural production, forcing farmers to adapt to maintain production (Crimp et al. 2008; Hope and Ganter 2009; Stokes and Howden 2010). Climate change is forecasted to impact precipitation patterns and increase evapotranspiration from higher temperatures, which is likely to significantly influence available soil moisture for dryland grain production within the 250mm-600mm annual rainfall of the cereal belt (Preston and Jones 2008; Cleugh et al. 2011; Evans et al. 2011). The degree of impact to production will inevitably depend on the ongoing management responses of farmers to the nature of the changes in climate over time.

Garnaut (2008) refers to Climate Change as a ‘diabolical problem’ because it is uncertain in its impact, insidious rather than confrontational, long term, international and in the absence of effective mitigation measures, carries a risk of dangerous consequences. Other authors have pointed to the sheer complexity of the issue, the urgent need for action and the inequities of its cause and effect (Stern 2006; Pearman and Hartel 2009; Pittock 2009; Stokes and Howden 2010).

There is some community expectation that world Governments will need to manage the anthropogenic impact that greenhouse gas emissions is having on the planet’s climate. This need for action is based on the predictions of likely social and economic impacts as outlined in the five synthesis Assessment Reports in 1990, 1995, 2001, 2007, 2013 of the working groups coordinated by the Intergovernmental Panel on Climate Change (IPCC). Policy to limit anthropogenic emissions of carbon dioxide (CO_2), Nitrous Oxide (N_2O), Methane (CH_4), Chloro-fluoro chlorides (CFC & HCFC), Perfluoromethane, and Sulphur Hexa-fluoride is being considered by the IPCC through various mitigation measures such as development of renewable energy, carbon capture technology, land use, land use change and forestry. Also being considered is policy initiatives allowing for adaptation strategies given the likely slow pace of mitigation impacts on reducing current climate change trends (Parnell 2010).

The IPCC Working Group I is concerned with the physical science basis of climate change, reported in 2007 that the understanding of anthropogenic warming and cooling influences on climate has improved to the extent that they offer with "very high confidence" that the global average net effect of human activities since 1750 has been one of warming. They also report that warming of the climate system is unequivocal as evidence of increases in global average air and ocean temperatures, and predict a range of increased global average temperatures depending on the relative success of stabilising further emissions (Solomon et al. 2007).

The IPCC working Group II is concerned with the sensitivity, adaptive capacity and vulnerability of natural and human systems to climate change. The group reported a number of observable impacts to the natural systems and the likelihood of a slight crop productivity improvement at the higher latitudes, but raises concerns for some areas such as Australia where reduced precipitation and increased evaporation is likely to produce water security problems (Parry et al. 2007; Reisinger et al. 2014).

The IPCC Working Group III is concerned with mitigating the impact of climate change and indicated a high degree of agreement as to the increasing level of GHG emissions attributed mainly to anthropogenic activity in the order of 70% between 1970 and 2004 and point to substantial economic potential for the mitigation of global GHG emissions over the coming decades (Metz et al. 2007).

1.2.1 Agricultural contribution to emissions in Australia

Agricultural practices have resulted in climate change principally through land clearing, soil erosion, soil compaction and cultivation (Malinda 1995; Govaerts et al. 2007; Lal 2007b; Silva et al. 2007; Tullberg 2008; Batey 2009). But agriculture has also been regarded as having the potential to play a part in mitigating climate change and restoring atmospheric carbon to the pedosphere by increasing soil organic carbon to a new equilibrium (Schlesinger 1999; Bayer et al. 2001; Chan et al. 2003; Lal 2004c; Franzluebbers 2005; Chivenge et al. 2007; Billen et al. 2009; Boddey et al. 2010). However carbon in agricultural soils is highly cyclical and in order to act as a moderate carbon sink traditional farming practices need to change to create new soil health parameters that include higher base levels of Soil Organic Carbon (SOC) (Lal 2007a). An agricultural system with declining soil health is unsustainable in the long term as it cannot continue to produce food without continuous inputs from manufactured fertilisers which is highly dependent on fossil fuel (Addiscott 2004; Schwenke 2005; Kassam et al. 2009).

The Australian National Greenhouse National Inventory Report attributes Australian agriculture as producing an estimated 79.5 million tonnes CO_2e emissions or 14.64% of net national emissions in 2010 (Australian Government 2014). The report indicated that enteric fermentation was actually the main source of agriculture emissions contributing 67.8% (53.9 million tonnes CO_2e) of the sector's emissions. The next largest source was agricultural soils (16.7%) and field burning of agricultural residues contributed less than 1% of the sector's emissions. The agriculture sector is the dominant national source of both CH_4 and N_2O, accounting for 57.0% and 72.6% respectively of the net national emissions for these two gases. The impact for the cropping industry is much less; about 13.5 million tonnes CO_2e including soil emissions and residue burning. Agricultural soils emissions have decreased by 1.3% (0.2 million tonnes CO_2e) between 1990 and 2010, and emissions from field burning of agricultural residues have increased by 13.9% (0.04 million tonnes CO_2e) between 1990 and 2010. This needs to be balanced by the sector's role as a grain exporter which is significant to global food security (ABARES 2010). If these grain products were not grown in Australia, would the emissions be shifted to another jurisdiction? This might solve a national reporting issue but does not solve a problem that exists in a global common; the planet's atmosphere.

Much of the emissions attributed to agriculture is bio-chemical in nature and has no single point source of emissions and is not easily measurable coming from grazing animals, soil, manure breakdown and crop residue decay (McGinn 2006; Sanderman and Baldock 2010; Browne et al. 2011; Whittle et al. 2013). Historical soil carbon loss from cropping is not accounted for in the national accounts and the use of on-farm diesel is not included in agricultural emissions, being reported under the transport sector where the majority of diesel is used (Sanderman et al. 2010; Australian Government 2014).

1.2.2 Balancing food security and adapting to climate change

Policy to manage Greenhouse Gas (GHG) emissions at a national level should take into account the impact of its policy on international food demand. Shifting one nation's liability to other nations is unproductive when dealing with atmospheric pollution which is a 'global common'. Global crop production is susceptible to potential changes in climatic conditions, although the magnitude of the impact is uncertain (Lobell 2010). Australia is an important supplier to the world grain market and in the coming decades grain producers and policy makers will need to consider how the country will adapt to climate change and what role agriculture will play in providing food security in a low carbon economy (Parnell 2010; Stokes and Howden 2010; World Bank 2010). The dryland cropping sector includes Australia's largest agricultural commodity exports with wheat, coarse grains and oilseeds valued at approximately $AUD10 billion (Australian Government 2013a). The average rainfall in the production areas lies between 250 to 600mm per year, but this can fluctuate with drought and flood years, which according to the Australian Bureau of Meteorology depends on the various climatic patterns of the Indian and Pacific oceans[4]. While the production areas are familiar with drought and flood years, they are nevertheless economically vulnerable to future climate change impacts on rainfall patterns, evaporation, carbon dioxide concentration and temperature (Crimp et al. 2008; Howden et al. 2010). A factor that is of particular concern to crop yield in the short term outlook, are reductions in net rainfall and the timing of that rainfall, with the possibility of a trend to increases in rainfall intensity going to run-off and limiting infiltration required to recharge soil moisture (Stephens and Lyons 1998; van Herwaarden et al. 1998; Hope and Ganter 2009).

The marginal rainfall of the cereal belt exposes future crop yield to potential losses from climate changes of reduced rainfall and higher temperatures (Crimp et al. 2008; Hennessy et al. 2010). Potential changes in rainfall will vary across regions but on the whole the trend is towards reduced rainfall across the cereal belt (variability of -30% to +20%). With increasing temperatures from climate change in the range 0 to 4°centigrade this will also impact on the soil's vapour pressure deficit reducing microbial activity and affecting soil fertility (Crimp et

[4] Bureau of meteorology. www.bom.gov.au

al. 2008; Pittock 2009). Cropping as a farming enterprise generally yields better profit than livestock production, but it is also more economically vulnerable to climate risk in dry years due to grain yield sensitivity to moisture loss (van Herwaarden et al. 1998; Day et al. 2010). Both risk conditions of exposure to reduce rainfall and crop sensitivity to that change is likely to have a significant impact on the future of farm profit if those risks are realized (Stephens and Lyons 1998). Farming practices not only need to consider the impact it is having on the environment but also the impact the changing environment will have on its future viability. These influences are illustrated in Figure 1. The degree of impact is highly variable and farming is only one of many contributing factors to greenhouse gas emissions but is itself in turn affected by climate change in various ways; some positive, some negative. There is a threefold objective in considering practice changes at farm level. Apart from reducing its emissions liability it needs to remain productive in yield terms and adapt to future climate outlook.

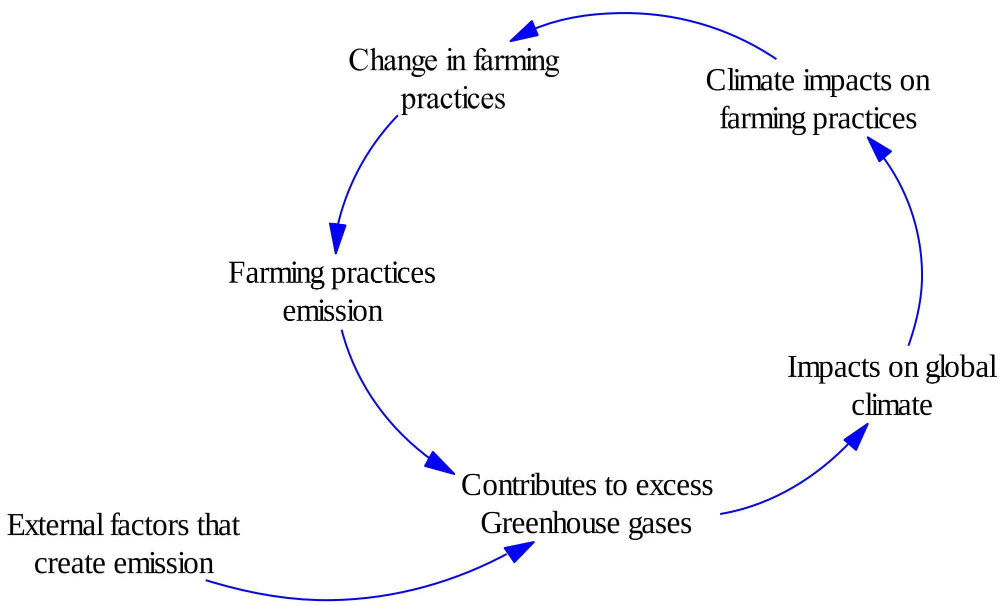

Figure 1 Causal loop relationship of farming practices and climate change.

1.2.3 Production practices and emissions

With agriculture as a sector featuring so prominently in national emissions and being a major commodity exporter, there is some degree of interest in the details of the carbon footprint of agricultural produce and whether such emissions could be altered without compromising food production (Harris and Nerayanaswamy 2009). I postulate that there is a need to have an understanding of the main variables that account for the farm's greenhouse gas emissions in order to consider policy options to minimise those emissions. When considering farm policy that is seeking to influence the behaviour of farmers, the boundaries affecting emissions from the sector relates to those areas under the direct control of the farm business. Some leakage factors such as the manufacture of herbicides and fertilisers can be given consideration, however changes as part of the manufacturing process that might affect the carbon footprint of the product is outside the control of farmers. In many cases the energy requirements of production of farm inputs (e.g. herbicides) is not publicly available.

The major factors that impact on farm GHG emissions and operate under the control of a farm manager include:

1. The type and amount of nitrogenous fertiliser applied and how it is applied. This relates to the embodied energy of the product, the energy of application and the N_2O emissions resulting from application
2. The amount of tillage required and the subsequent mineralisation of organic matter
3. The amount of fuel and electricity required
4. The removal of crop residues by either burning or grazing
5. The application of chemicals, predominantly herbicides

1.2.4 Conservation Agriculture and its relationship to emissions

Conservation Agriculture is a set of principles that relate to farming practices that aims to maximise the soil health parameters and water use efficiency in crop production within an economically acceptable framework over the long term (Hughes 1980; Allmaras and Dowdy 1985; Uri 2000; Hobbs 2007; Reicosky and Saxton 2007; Hobbs et al. 2008; Kassam et al. 2009). This concept is offered as an adaptation of the Food Agriculture Organisation (FAO) definition which states that farmers should minimize soil disturbance by minimizing mechanical tillage, enhance and maintain a protective organic cover and cultivate a wider range of plant species (Collette et al. 2011). The FAO definition of 'Conservation Agriculture' deals primarily with reducing tillage, stubble retention and crop rotation. This is primarily targeted at smallholder crop producers globally, but has long been in use by the majority of Australian grain farmers. Many Australian grain farmers are looking beyond these three main principles to managing soil compaction problems presented by their use of heavy machinery, nutrient management efficiency by incorporating legumes, cover crops, recycled organics and application of precision agriculture techniques to efficiently deliver fertiliser and pesticides (Thomas et al. 2007c; Tullberg et al. 2007; Butler 2008; Rochecouste 2009). They are applying a range of new farm practices but the objective is still targeted towards long term soil health and improved water use efficiency (Branson 2011). This extended definition has implications for policy management of GHG emissions looking to change farm practices.

Conservation Agriculture involving reduced tillage, stubble retention and crop rotations has played a key role in maintaining the productivity of farms in the marginal grain production areas of Australia helping to manage the risk of drought periods over the last 30 years (Strong et al. 1996; Armstrong et al. 2003; Turner and Asseng 2005; Thomas et al. 2007c; Thomas et al. 2011). The compelling benefits of CA in increasing crop yield by managing soil moisture and fertility has encouraged a change of practices to meet the economic realities of increases in production costs and a reductions in the relative price of grains (Turner 2004; Mullen 2007). These gains are being further challenged by the risk of climate change (Howden et al. 2010). Available soil moisture will be a key driving factor for farmers in managing future risk (Acuna and Wade 2005; Branson 2011). Given that farmers have already widely adopted reduced tillage, stubble retention and crop rotation according to Llewellyn et al. (2009), are there more efficiencies to be gained? The question for consideration is whether Australian grain farmers can further reduce their GHG emissions by adopting a range of other CA farming practices such as Control Traffic Farming (CTF) and Precision Agriculture (PA). If so, what impact would this have on farm productivity and how likely are we to get ready adoption, given that adoption of new farming practices such as reduced tillage (illustrated in Figure 1 in book chapter under section 2.1) can take decades (Pannell et al. 2006; Knowler and Bradshaw 2007; Tullberg et al. 2007; Llewellyn et al. 2009; Rochecouste and Crabtree 2014).

The process of improving efficiency by reducing inputs compared to older traditional agricultural methods of forty years ago, also reduces net energy requirement (per hectare of crop production) and other fugitive emissions that comes from cultivating the soil (Phillips and Young 1973; Wittmuss et al. 1975; Percival 1979; Hughes 1980). This outcome has become particularly relevant when considering the need to change the standard agricultural production paradigm to suit the emerging carbon economy (Uri 2000; Kimble et al. 2002; Sanderman et al. 2010). The adoption of CA practices have been slow to evolve in other parts of the world occupying only 8% of the total crop land globally compared to approximately 80% of Australia's dryland cropping area, excluding sugar cane and cotton (Derpsch et al. 2010b). The reasons for the lack of global acceptance has in part been attributed to a lack of suitable education on practices, cultural issues and economic investment in practice change (Dent and McGregor 1994; Alroe and Kristensen 2002; Garcıa-Torres et al. 2003; Knowler and Bradshaw 2007; Llewellyn et al. 2009). In Australia the need to reduce agricultural GHG emissions and the potential establishment of carbon trading markets via the Australian CFI is being suggested as an opportunity for uptake of new agricultural practices to provide carbon credits to polluting industries (Martens et al. 2005; Benwell 2009; Miller 2009; Sanderman et al. 2010). In this thesis, I consider if this idea is feasible in dryland grain production given current farming circumstances in Australia.

The potential of atmospheric carbon removal by total cropped land (38 million hectares including cane cotton and horticulture) in Australia using conservation tillage[5] was estimated by the Garnaut review (2008) to be about 60 million tonnes CO_2e per year for 20-50 years. For grain production to play its role in climate change mitigation, it needs to develop a detailed understanding of the greenhouse gas emissions profile of its current farming practices and establish the practices that are most effective in abating those emissions. Also, what might be some of the policy initiatives that could assist those changes in farm practices?

An important consideration in farmers changing practices is the economic benefit that is achieved by the farmer, and the cost of investment required on their part to make that change (Nicholson et al. 2003; Vanclay 2004; D'Emden et al. 2008). Farmers may wish to take up a practice but they may lack the initial investment capacity. As an example, a survey of 29 farmers attending Control Traffic workshops delivered by the company CTF Solutions over the 2008-2009 seasons indicated that the vast majority (>90%) were interested in the practices for their farm, but 58% indicated financing machinery and set-up technology as an issue in taking up the practice, and they were not ready to go forward with adoption[6]. The importance of financial benefits as a driver of practice change was also highlighted in an Australian government survey of farmers into 'Drivers of Practice Change' (Ecker et al.

[5] Conservation Tillage as referred to in the report is a sub-category of Conservation Agriculture which applies solely to tillage practice reductions
[6] Internal survey conducted by the author for CTF Solutions in 2009. Used with permission.

2012). Another factor that also needs consideration in policy framing is the capacity of farmers to manage change, especially when those changes involve the use of digital technology which many older farmers may not be familiar with and would thereby involve a considerable investment of time and effort in training (Wilkinson 2011; Robertson et al. 2012).

1.2.5 Rural policies and impacts on abatement strategies

Under the Australian Government Emissions Reductions Fund program the Government is intending for agriculture to play a role in reducing emissions and sequestering carbon (Australian Government 2013b). Previously the role of agriculture in carbon trading has been reviewed in Australia by the Government of Australia in which they highlighted the problematic issues of verifying a carbon offset in practice change (Walcott et al. 2009). In November 2010 the Financial Times announced the closure of the Chicago Climate Exchange after the final carbon credit price per metric ton in November 2010 was between 10 and 5 US Cents, down from its highest value of 750 US Cents in May 2008. The times indicated that trading reached zero monthly volume in February 2010 and remained at zero for the next 9 months before a decision was made to close the exchange. The FAO, in a submission to the United Nations Framework Convention on Climate Change (UNFCCC), outlined that a number of countries have indicated an interest in pursuing their mitigation outcomes through agriculture (FAO 2010, FAO 2013). Foremost amongst those interested in agriculture as part of their climate change strategy includes the USA (Young et al. 2007). Despite this interest, a clear verifiable abatement role for agriculture at an international level still appears some way off.

This thesis explores the potential role that CA can play in mitigating GHG emissions and adapting to climate change in dryland agriculture in Australia. CA farming practices are being increasingly adopted by Australian farmers mostly as an adaptation to improve production under limited soil moisture which is likely to be further impacted by climate change (Dalgliesh and Foale 1998; Hope and Ganter 2009; Llewellyn et al. 2009). In addition it is apparent that CA farming practices have already delivered some reductions in GHG emissions in terms of reduced energy demands (Chivenge et al. 2007; Kassam et al. 2009; Young et al. 2009a; Derpsch et al. 2010a; Lam et al. 2013). Over the last twenty years a number of CA farming practices such as reducing tillage, stubble retention, control traffic farming and legume in crop rotations have evolved to improve crop production efficiency through improved soil health and water use efficiency (Phillips and Young 1973; Percival 1979; Allmaras and Dowdy 1985; Malinda 1995; Unger and Jones 1998; Li et al. 2001; Swift 2001; Valzano et al. 2001; Gajri et al. 2002; Roldán et al. 2003; Hamza and Anderson 2005; Chivenge et al. 2007; Govaerts et al. 2007; Thomas et al. 2007a; Thomas et al. 2007c; Tullberg 2008; Young et al. 2009a; Olson 2010; Iqbal et al. 2011).

In order to determine how CA farming practices can further reduce GHG emissions we need to consider some form of classifying the various CA sub-systems in a way that is recognised by the agricultural industry. There is limited systematic operational definition of 'Conservation Agriculture' in Australia that can be readily used for comparison of GHG emissions. This lack of definition is likely to create potential confusion in supporting practice change policy. By applying various definitions of related farming practices, I include the terminologies already employed by the Australian industry in farm literature as outlined in Table 1. It is important to note that terminology such as 'Tillage' is often prefaced with other words such as '*Reduced* tillage'; '*Minimum*-till', '*No*-till' or '*Zero*-till' that are interpreted differently by farmers. There are degrees of tillage of which 'zero-Till' is the least soil disruptive, referring to a one pass tillage operation with a disc planter. There are similar variable interpretations regarding stubble retention, control traffic farming, crop rotation, cover cropping and the use of precision agriculture. The process over time should also be considered. Farmers often take a step process to adopting a practice moving through stages of adoption. It is this variability in addition to the natural variability of a bio-chemical process that creates an issue in linking a *farm practice* with a *unit of carbon offset* with any measurable accuracy, as indicated in a review by Walcott et al. (2009). A range of farming practices operating on Australian farms is proposed under the term 'Conservation Agriculture', these are included in Table 1.

Table 1 Conservation Agriculture practices as communicated by the industry and its resulting environmental impacts

Conservation Agriculture Farm practice	**Broad Environmental Impact**

Zero-till (*reducing tillage to one pass operation less than 12% soil disturbance*)	Higher OM/ reduced erosion/ improved WUE/ reduced emissions (Bayer et al. 2001; Roldán et al. 2003; Wang and Dalal 2006; Ashworth et al. 2010)
Stubble retention (*100% retention of crop residue after harvest*)	Higher OM/reduced erosion/reduced chemical run-off (Baker and Mickelson 1994; Yadav et al. 1994; Malinda 1995; Uri 2000)
Control traffic farming (*All machinery set for one lane pass*)	Higher OM/improved WUE/ reduced erosion/ reduced emissions (Li et al. 2001; Tullberg et al. 2007; Batey 2009; Tullberg 2009)
Legume/crop rotation (*not specifically defined in industry terms, issue of time dimension*)	Higher OM/ Reduced emissions (N fertiliser) (Roldán et al. 2003; Addiscott 2004; Boddey et al. 2010; Huth et al. 2010)
Cover cropping (*Non-harvested crop grown for organic matter and as ground cover*)	Higher OM/ carbon sequestration/ improved WUE (Uri 2000; Dabney et al. 2001; Veenstra et al. 2007)
Precision Ag technologies (*not specifically defined as one practice at this point*)	Reduced emissions/ reduced pesticides & fertilisers (Butler 2008; Mayfield and Trengrove 2009)
Application of recycled organics (*just emerging*)	Higher OM/ improved WUE (Gibson et al. 2002)

OM = Organic Matter (all components) WUE = Water Use efficiency mm/ha/kg product

The CA Practices listed in Table 1 are primarily adopted by farmers for production benefits but they also have environmental benefits such as increasing soil organic matter, reducing fuel use, reducing wind or water erosion and run-off pollution into waterways. In this thesis I examine the grains cropping industry as a 'system' and the various CA practices as 'sub-system activities' for their general emissions profile and the drivers that influence their adoption.

The practices as described by the industry in Table 1 are at different stages and extents of adoption in Australia (Thomas et al. 2007c; Llewellyn et al. 2009; Walcott 2010; Edwards et al. 2012; Robertson et al. 2012). The use of reduced tillage and stubble retention for example, has been evolving for 30 years and is well recognised by grain producers (Llewellyn et al. 2009). Control traffic farming is reasonably well known by farmers but not yet strongly adopted; data available from an Australian Bureau of Statistics survey indicates that Control Traffic Farming (CTF) is now being implemented by about 25% of farmers[7]. The area sown to legume rotations have decreased slightly in the last 25 years, but the number of hectares are not large (about 1.37 million hectares in the 2013 Grain Year book), mainly because the returns are less than cereals (Malcolm et al. 2009). Precision agriculture is a complex mix of technologies relying on connectivity with Global Positioning Systems (GPS) to more efficiently deliver inputs such as fertilisers and chemicals. The levels of use by farmers for the purpose of more efficiently delivering inputs such as fertiliser using variable rate systems is limited to about 20% of dryland farmers (Robertson et al. 2012). A survey of 33 dryland farmers in south western Queensland[8] indicated 85% of participating farms used a GPS tool. It is not apparent that if these functions extended to precision placement of fertiliser and chemicals or whether they were simply used for auto-steer. There are other practices such as cover cropping and the use of recycled organics that are only just emerging in the farming discourse, but as yet there is little information on the extent of adoption in Australia (Gibson et al. 2002; Butler 2008; Pritchard et al. 2010).

The environmental impacts listed in Table 1 are general in nature, not restricted to climate change impacts only. They are included in the table as they may have an indirect effect on the GHG budget of the farm. For example increased organic matter through stubble retention, cover cropping or applying recycled organics can lead to increased soil organic carbon but it is only of value in a climate change mitigation capacity if it can be retained in the soil (Bayer et al. 2001; Dalal and Chan 2001). Clearly there is a need to have better information on these practices and their potential climate change implications if farmers are to adopt them as part of a climate and land use policy such as that outlined in the Carbon Farming Initiative.

There is considerable amount of research underway looking into the emissions profile and sequestration potential of agriculture under the 2009-2012 Government's "Filling the Research Gap" program. Policy makers are aware that measuring gases and decay in biological systems are inherently complex and variable. There is a reliance on the use of

[7] Data source: ABS ARMS survey. Number of agricultural businesses using controlled traffic farming. Supplied by Dr Michele Barson Dept., Agriculture Fisheries and Forestry (personal Communication)
[8] Survey conducted by the author for Conservation Farmers Incorporated in 2005-2007 unpublished (used with permission). Data has been reanalysed as part of this study.

proxy measurements and models to determine likely trends (Browne et al. 2011). Research may determine that an agricultural practice (e.g. stubble retention) is beneficial to increasing soil organic carbon but it does not tell us whether promoting or developing a market around such a practice is going to be taken up by farmers. A farmer's objectives are determined by a range of other considerations such as markets, production economics and social capacity. These potentially disparate goals may undermine a policy initiative to create practice change. In this study I rely on the scientific literature to determine the extent of the emissions reductions or sequestration possibilities associated with a CA practice and examine the drivers within the farming system based on interviews with farmers and farming experts and the analysis of various sector and regional-wide data collated from various sources. I will also consider policy initiatives that can support the drivers for change.

1.3 Linking practices with a credit unit

The extent of GHG reductions and the means of measuring emissions from a farm practice in Australia is still uncertain (Sanderman et al. 2010). The determination of an accepted methodology for international markets is currently determined by agreements within the United Nations Framework Convention on Climate Change (Hodgkinson and Garner 2008). In Australia there is research underway in methodologies that can produce an Australian Carbon Credit Unit. The Domestic Offsets Integrity Committee (DOIC) has endorsed twenty methodologies covered under four basic themes (capture and combustion of landfill gas, destruction of methane generated from manure, environmental plantings and savannah burning) and these were recently approved by the Parliamentary Secretary for Climate Change and Energy Efficiency (De Wit et al. 2013). At the time of writing, the potential for biochar or fertiliser management is still to be listed as an approved methodology.

As farming provides a critical service in terms of food production, it is important that emissions reductions on farms should not be at the cost of food security. In order to be considered sustainable in the long term, farming should produce the equivalent amount of food using alternative systems rather than relying on finite resources of fossil fuel (Diouf 2009). The relative benefits of CA farming practices to sustainable food production is recognised in the literature (Garcıa-Torres et al. 2003; Friedrich and Kienzle 2007; Hobbs 2007; Knowler and Bradshaw 2007; Butler 2008; Hobbs et al. 2008; Kassam et al. 2009;

Collette et al. 2011). The adoption of new farming practices by Australian farmers is based on economic and social factors which need to be clearly considered when setting policy agendas for promoting change (Vanclay 2004; Pannell et al. 2006).

If CA practices already have economic benefits, could the government seek emissions reductions practices that do not produce a carbon credit unit for the market? Given the difficulty of measuring offset units from such a diffuse pollution source it is not inconceivable that satisfying the requirement for a credit unit is simply not viable on an individual farm level. Any measurement of abatement required to meet market requirements is likely to have significant auditing processes involved to verify the validity of the unit. Experiences from a Canadian agricultural farm carbon offset program suggest that these difficulties are quite likely. McClinton (2008) from the Saskatchewan Soil Conservation Association discussed the Canadian Saskatchewan farmer's perspective on agricultural soil offsets and concludes the 'permanence' and 'additionality' test as applied to offset generation are the largest constraints to creating an agricultural carbon credit unit in Canada (McClinton 2008).

In the context of climate policy, *permanence* refers to the durability of an emissions reductions activity. Carbon in vegetation or soils can only really offset emissions from vehicles and industrial processes if it is stored permanently. If the carbon was subsequently released back into the atmosphere, for example because vegetation was cleared, it could not offset emissions. For this reason, sequestration projects are subject to *permanence obligations*. Emissions reductions projects are not subject to permanence requirements because they stop emissions from entering the atmosphere in the first place. The internationally accepted timeframe to ensure sequestration is equivalent to emissions is 100 years, based on the estimated life of one ton of carbon pollution in the atmosphere (Locatelli and Pedroni 2004; De Wit et al. 2013).

The concept of *additionality* is also an important integrity principle for all offset schemes, including the CFI. Only emissions reductions that go beyond business as usual can be considered to be a genuine offset. The CFI additionality test ensures this by assessing whether the activity would be common practice within an industry and/or region without the added incentive provided by the CFI (Woodhams et al. 2012).

Policy agendas that are aimed at promoting farm practice change for emissions reductions benefits without market support should consider the financial benefits of the practice change to the farmer. The financial sustainability of any enterprise is dependent on being able to meet market needs in a cost effective way (O'Reilly et al. 2009). For Australian dryland farmers to remain sustainable they must continue to provide their products at a global market price in the face of increasing input costs such as fertiliser and oil. They have managed this in the past by driving down their cost of production through adoption of technology, increasing economies of scale and adopting new management practices that enable efficiency gains (Wylie 2008). CA farming systems have delivered increased productivity gains for those farmers that have adopted the new practices, but there is still a significant potential to increase the uptake of emerging practices (e.g. Precision Agriculture and Control Traffic Farming) that reduce energy demands (Blumenthal et al. 2008; Butler 2008; Edwards et al. 2012). The adoption of these new CA practices would not only benefit farmers, but also reduce energy input costs per tonne of grain, which could also reduce Australia's net emissions on a production basis.

Policy makers tasked with the role of mitigating the impact of climate change on food security, need credible options that allows agriculture to continue operating and minimise its impact on the environment. This means that policy makers need to set justifiable priorities, and to achieve this it needs effective policy decision support tools. This thesis analyses the policy options for farming practices in the Australian dryland sector. Balancing all the competing needs requires a detailed understanding of the emerging practices, their greenhouse gas implications and how the industry is likely to respond.

Despite the difficulties in monitoring GHG emissions from agriculture, Australia should not ignore such a significant emitting sector. It should consider what options are readily available to deal with the issue. The introduction of a Carbon Farming Initiative (CFI) and the current policy green paper by the government is an indication of political intention in this area (DCCEE 2012; Australian Government 2013b). Is CA farming practices such as reducing tillage one of the possible solutions as indicated by the Garnaut review in its 2008 report? If so, what do we need to know to put it into practice within a reasonable time frame?

1.4 Summary of thesis rationale

Cropping agriculture in Australia is a major ongoing emitter and the history of agriculture has been responsible for a shift in carbon from the soil to the atmosphere by clearing land for cultivation and the mineralisation of soil organic carbon. There is a view amongst some scientists that cropping agriculture could restore atmospheric carbon back to the soil by increasing soil organic carbon. They do not however offer an economic cost for doing this. As a biological system, cropping is dependent on a variable agro-ecological and social context. Therefore the amount of GHG emissions produced is not readily measurable on a day to day basis without expensive instruments. In most cases there are no previous baselines of carbon stocks available by farms in Australia. Furthermore, carbon and nitrogen are cyclical in a cropping system and they are in fact inter-dependent, since plants need nitrogen to produce and maintain carbon biomass. It has also been shown that reducing tillage reduces mineralisation and therefore it is postulated that this leads to increasing soil organic carbon. As outlined in a draft paper being considered for journal submission in section 4.7.1 (A study of developing carbon offset projects using conservation tillage on grain farms in northern Australia**),** there is some evidence of a correlation between no-till systems and soil organic carbon. It has also been reported that this correlation does not work as consistently in arid zone cropping systems like Australia (Murphy et al. 2013). Stubble or crop residue retention helps increase soil organic carbon but the process is incremental and slow, therefore the amount of measurable carbon units is low and going to take decades to be relevant to the point of being an effective tradeable unit (Chan 2008). Soil carbon in dryland systems, plagued by droughts (which is likely to increase as a result of climate change) is vulnerable to being lost once again through mineralisation. Those industries purchasing credits in an emissions trading scheme want some guarantee that the units are real for the long term. It would seem reasonable that they would also want access to the most economical unit they can possibly have to minimise their business cost. Cropping agriculture also creates N_2O emissions and CO_2 emissions, principally from inefficiencies in fertiliser application and fuel consumption. Transaction costs in the aggregation of units and verification process of the sequestration or emissions reductions unit is an uncertain cost.

The aim of this thesis is to evaluate to evaluate current climate change policy in Australian agriculture and what type of policy consideration will more effectively engage grain farmers in reducing on-farm GHG emissions. This involves examining how emissions and offset units can be derived from grain production and what are the drivers that create on-farm change towards CA practices which have demonstrated mitigation and adaptation potential to climate change. The thesis also considers the policy options that support the drivers of change and the adoption of CA practices to support better climate change mitigation and adaptation.

1.5 Research problem and Research question

The introduction of recent legislation (*Carbon Credit (Carbon Farming Initiative) Bill 2011*) would indicate that the Australian Government is expecting that agriculture will be part of a broader carbon economy as a source of emissions reductions carbon credits. A carbon credit is defined as sequestering or avoiding the equivalent to one tCO_2e. Under the current policy, a unit can only be derived and allocated based on a scientifically approved methodology that makes a clear nexus between the farm practice and the carbon credit unit. As of April 2016, there are no carbon offset methodologies under the Australian CFI for dryland cropping-based farming practices.

1.5.1 Overall Research Problem

The Research Problem of this thesis is; **'how can the potential climate change mitigation and the adaptation benefits of Conservation Agriculture be most effectively integrated into dryland grain farming enterprises in Australia?'**

If the aim of current climate change agricultural policy is to reduce emissions by having farmers change their farming practices, we need to consider what are the practices that policy would seek to change. Current funded research by the Australian Government under the 'Filling the Research Gap' program aims to examine the underlying scientific evidence on emissions that would support practice change. Such programs are looking at areas such as quantifying N_2O emissions from fertiliser application. As the evidence linking practice change and emissions becomes more apparent than a more extensive enquiry into the adoption of farming practices and their role in climate change mitigation should be considered. As indicated by Pannell & Vanclay (2011), facilitating change by land managers requires an understanding of the complex social, psychological and economic dynamics that affect their decisions. This broader approach of inquiry to direct policy implementation is also supported by Horan & Shortle (2001) reviewing environmental instruments for agricultural pollution control (Horan and Shortle 2001).

Knowing that a practice is effective in reducing GHG does not necessarily mean that that practice will be a feasible carbon offsetting activity. An understanding of the drivers for adoption of that practice is also required. Therefore the research problem goes beyond having the scientific knowledge that a particular farming practice will reduce emissions, to how we can create climate and land policies that will drive that change within the time frame that the IPCC has indicated is required to avoid dangerous climate change.

1.5.2 Research Questions

The Research Questions of the thesis are outlined in Table 2.

Table 2 Research questions and explanatory notes

Research Question	Explanatory Notes
1. What is the current role of Conservation Agriculture in grain farming enterprises in Australia?	I begin by looking at the current status quo in terms of what forms of Conservation Agriculture is being practiced by farmers in the dryland grain cropping industry in Australia. Australia is one the more unique OECD countries in the southern hemisphere in that it has a highly industrialised level of agriculture operating in an extensive relatively hot and arid zone climate.
2. How does Conservation Agriculture influence greenhouse gas emissions from grain farming enterprises in Australia?	I review the main variables that account for the farms' greenhouse gas emissions. They include such things as fuel and fertiliser, and can be considered as a stock of inputs into the system. The farm processes the input stocks to produce grain commodities but also emit greenhouse gas emissions as part of that process. CA practices were based on the foundation of improving soil organic carbon and improving the efficiency of finite input resources such as oil, fertilisers, water and chemicals. The use of the above input resources into crop production also represents an emissions factor. Improvements in production efficiencies in turn results in a reduction in emissions per tonne of grain

	produced. Increasing soil organic carbon, if it can be stabilised over the long term results in the movement of carbon from the atmospheric pool as greenhouse gases to the pedosphere.
3. What factors influence adoption of Conservation Agricultural practices in Australian grain production?	If there is to be a difference in emissions consequences from changing one farming practice for another, than it is relevant to consider the drivers for adopting change, and ask whether these changes are sustainable over the long term. We need to understand the relative strength of the drivers and the factors that might lead to change from a policy perspective. To address this question, I interviewed industry experts and farmers to get a deeper understanding of what has motivated them to make past changes to CA.
4. What climate policies are likely to increase adoption of CA in Australia?	Emissions reductions practices not directly contributing to productivity benefits are unlikely to be taken up by farmers without some form of imposed financial penalty or incentive (Addiscott 2004; Hamilton et al. 2008; Lal et al. 2009). The use of markets as a means of driving practice change is well established (Uri 2006) but requires detailed knowledge of the practice to determine units of trade. To answer this question, I evaluate what constitutes an acceptable carbon offset unit and interview industry practitioners to develop an understanding of their perspective. I also critically analyse current government policy and consider if there are alternatives policy options to improving emissions reductions.

1.6 Thesis structure

This thesis is presented in eight chapters:

Chapter 1 reviews the literature and provides an introduction to the rationale for the research on the role of CA in climate change in terms of emissions reductions, sequestration and its adaptation capacity under climate change. The chapter outlines the research problem and states the questions that would contribute to a better understanding of the issues and the likely solution to the problem.

Chapter 2 provides an understanding of the role of CA in Australia from the literature and is presented as a book chapter published in a book entitled *Conservation Agriculture: Global Prospects and Challenges* by CABI International in partnership with the International Crops Research Institute for the Semi-Arid Tropics. The book was published on 13th December, 2013 (Rochecouste and Crabtree 2014).

Australia, as a leader in industrial agriculture, needs to also consider the impact it has on the agriculture of developing countries. This is considered within chapter two in a paper format published in the *Annals of Tropical Research*, vol. 33, no. 1, p. 85-100, in 2011 titled *Opportunities to produce carbon offsets using conservation farming practices in developing countries*.(Rochecouste and Dargusch 2011)

Chapter 3 summarises the thesis methodology, including the systems-based and mixed-methods approach to data collection and analysis.

Chapter 4 addresses Research Question 2 and reviews the emissions and sequestration factors associated with CA from the literature. It considers the opportunities for practice adoption that reduces agriculture's national emissions or sequestration of carbon. It includes a section on tillage practice change in a paper format as the predominant practice change to have occurred in the last 40 years in Australia, currently under review in the journal *Land Use Policy*.

Chapter 5 reviews the underpinning knowledge to address Research Question 3 by exploring adoption theory in agriculture so as to understand the drivers that influence changes in farm practices. I also analyse the 'systems' context of the dryland sector in terms of factors that influence farmers' behaviour.

Chapter 6 directly addresses the question as to what factors influence adoption of CA practices in Australian grain production by collecting direct industry. The chapter is presented as a paper that has been published in the journal *Agricultural Systems 2015 vol. 135, pages 20-30*.

Chapter 7 addresses Research Question 4 and looks at the opportunities for producing market offsets in dryland cropping in Australia. This is presented in a paper format as a policy discussion from the available evidence. The paper has been submitted to the journal *Carbon Management* and is currently under review.

Chapter 8 finishes with a concluding summary and the significance of this study in policy terms. The chapter outlines the limitations and future research questions that need to be addressed.

1.7 Definitions

Some of the practices terminology used by industry need to be outlined to be sure that we are referring to the same terms, because their impacts on GHG emissions will vary.

Conservation Tillage (CT): Conservation tillage was defined in 1984 by the U.S. Soil Conservation Service (currently the USDA Natural Resources Conservation Service) as “any tillage system that maintains at least 30% of the soil surface covered by residue after planting primarily where the objective is to reduce water erosion”. Conservation tillage has thus been described as a “collective umbrella term” that denotes practices that have a conservation goal of some nature (Reicosky 2002).

Minimum-Till (MT): The term “minimum tillage” has been adopted as a subcategory of CT (Reicosky 2002). It refers to systems that reduce tillage passes and thereby conserve fuel for a given crop by at least 40 percent relative to what was conventionally done in the year 2000.

No-Till (NT) or Direct Seeding: In no-tillage or direct seeding systems, the soil is left undisturbed from harvest to planting except perhaps for injection of fertilizers. Soil disturbance occurs only at planting by coulters or seed disk openers on seeders or drills. Weed control is generally accomplished with herbicides. “Direct seeding” is a synonym for the term “no-tillage” which is commonly used in small grain production systems.

Zero Till: The term refers to the use of a slightly offset disc opener for planting; it creates minimal soil disturbance in the range of 10-12% depending on the angle of the offset. It can operate at higher speeds and has less drag (less energy demand) but is more difficult to set up and operate. It is only operated at planting.

Conventional (Traditional) Tillage (CT): Traditional, or conventional, tillage refers to the sequence of operations most commonly or historically used in a given field to prepare a seedbed and produce a given crop (ASAE 2005) . Conventional tillage involves full soil disturbance, although it varies widely among regions, has been defined as incorporating most crop residue and leaving less than 15 percent of the surface covered by residue after planting. Today it is most commonly used in irrigated broad acre crops such as cotton, soybean and maize where the soil is worked into a seedbed condition ready for planting.

Conservation Agriculture (CA): Conservation Agriculture is a concept for resource-saving agricultural crop production that aims to achieve acceptable profits and sustained production levels while concurrently conserving the environment. It is fully outlined in Chapter 2.

Stubble retention: Involves the retention of the crop residues after the grain is harvested. It includes the chaff (the collected plant head material after grain removal) and stems. Stubble can be cut high and left standing (minimising chaff) or cut low with the chaff chopped and spread across the back of the header.

Control Traffic Farming (CTF): Refers to the operation of farm machinery along dedicated traffic lanes across the paddock to avoid soil compaction from wheel tracks. Farming operations such as planting, spraying weeds and harvesting all follow the set tracks with the assistance of global navigation satellite signals. The aim is to reduce damaging soil compaction that limit root growth to an absolute minimum (Tullberg 2008).

Cover cropping: A crop grown solely to protect the soil in between the main cropping season. There is no harvest and it may be ploughed in as a green manure crop (Dabney et al. 2001; Roldán et al. 2003; Bodner et al. 2010).

Recycled organics: Refers to animal manure fresh or composted from the intensive animal industry. It may also refer to processed municipal waste (Gibson et al. 2002).

Greenhouse Gas (GHG) Emissions: In this context refers to Scope 1 on-farm emissions of greenhouse gases such as Nitrous Oxide, Methane and Carbon Dioxide. This is generally referred to as units of grams of Carbon Dioxide equivalent (CO_2e). Scope 2 (electricity) and scope 3 inputs are not included in this policy analysis.

2.0 CONSERVATION AGRICULTURE IN AUSTRALIA AND INTERNATIONALLY

The following chapter is presented in two parts. The first part as a publication titled, 'Conservation Agriculture in Australia', in *Conservation Agriculture: Global Prospects and Challenges:* International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Publisher CAB International, London. Publication date was 13th December 2013. It was co-written with a farmer from Western Australia Mr Bill Crabtree and had some general inputs from researchers and other No-till farming organisations around Australia. It is published in Jat, R.A., Sahrawat, K.L. & Kassam, A.H. (eds), 2014, *Conservation Agriculture: Global Prospects and Challenges.* International Crops Research Institute for the Semi-Arid Tropics and Food and Agriculture Organization, Publisher CAB International, UK as chapter 5 under Rochecouste, J.-F.G. and Crabtree, B. *'Conservation Agriculture in Australia*', on page 108.

The second part is a published paper on the potential for the production of carbon offsets using CA within an international context. It was published as Rochecouste, J. and Dargusch, P. 2011, ‘Opportunities to produce carbon offsets using conservation farming practices in developing countries’, *Annals of Tropical Research*, vol. 33, no. 1, p. 85-101. It is attached as Appendix A

2.1 Conservation Agriculture in Australian Dryland Cropping

The chapter in Jat, R.A., Sahrawat, K.L. & Kassam, A.H. (eds), 2014, *Conservation Agriculture: Global Prospects and Challenges.* International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) and Food & Agriculture Organization (FAO), Publisher CAB International, UK is inserted below:

Notes

The following two publications are the manuscript as sent to the publisher. The tables and figures are not listed as part of the thesis but follow the numbering pattern of the text in the publication. The figures have a border to distinguish them from figures in the main thesis. The bibliography has been removed and incorporated into the thesis bibliography. There may be slight differences in presentation format from this thesis based on publication editorial policy.

Conservation Agriculture in Australian dry-land cropping

By Jean-Francois Rochecouste[9] and Bill Crabtree[10]

Abstract

Australia has seen a rapid adoption rate in no-till practices from about 1997 to the present day, primarily led by the state of Western Australia as a result of its demonstrated financial benefits in retaining soil moisture under dry conditions. The main changes in tillage practices involved the adoption of narrow knife point tines and disc seeders to minimise soil disturbance. Other conservation agricultural practices such as stubble retention, crop rotation and controlled traffic farming have followed suit to various degrees. Current trends involve an increasing use of global positioning technology combined with remote (satellite) and proximal (tractor) sensors to more efficiently deliver resources such as fertiliser and chemicals. Precision agriculture technology is also being used to reposition the planting row to the inter-row between the standing stubble; thereby reducing energy demands on machinery and protecting the emerging seedlings. Herbicide resistance, primarily to glyphosate, is becoming an increasing problem with previous overuse as a stand-alone application instead of in mixed herbicide combinations. A number of practice changes to restore soil organic matter including cover cropping and using recycled organics from the livestock industry are also being applied where conditions are favourable. Conservation agriculture is recognised as contributing to the long term sustainability of the cropping sector through supported extension projects by the Australian Government under the Care For Our Country program. The concept of a payment to farmers as land managers for maintaining the natural systems on farmland to supply ecosystem services to the general community is being researched by the Alliance of no-till farmers as a future policy option. The Australian Carbon Farming Initiative (CFI) was legislated in 2011, designed to reduce land sector emissions and provide a source of carbon credit to high emissions industries; the potential fit for conservation agriculture into this program is being researched but has not yet developed adequate methodologies.

Key words:

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no-till, reduced tillage, controlled traffic farming, crop rotation, stubble retention, precision agriculture, inter-row seeding, herbicide resistance, recycled organics, ecosystem services.

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Introduction

The Australian grains industry generates approximately 45 megatonnes (Mt) of grain annually, depending on seasonal conditions. They do this within a 200mm to 800mm annual rainfall zone that extends from central Queensland to Western Australia (WA). Most of this production occurs on light, low-fertility soils with limited water-holding capacity and an annual rainfall of less than 450 mm. Grain production is directly reliant on rainfall and there is a strong correlation between yield and available soil moisture in the northern Australian states, and in-crop rainfall in the southern states.

The incentive for a change in farming practices in Australia was created through three significant consequences of the traditional tillage farming system; erosion, the loss of soil moisture and delayed time of sowing. The most visible consequence of full-cut tillage was erosion from both water and wind depending on local climate patterns. In the northern cropping zones of Australia, high-intensity summer storms prior to summer cropping resulted in severe loss of topsoil and the associated loss of organic matter in the A horizon. In the southern and western cropping regions where lighter soils predominate, pre-frontal late autumn dust storms were similarly removing topsoils with severe impacts on soil fertility. The consequence of these seasonal weather events was not immediately felt by most pioneer farmers as the negative impact on yield was a gradual process. The exception was circumstances in the sandier regions where crops were killed by sand-blasting in high winds. However, the economic and emotional impact of declining yields from land degradation was a strong incentive for change. Less visible, but more evident to farmers on a seasonal basis was the loss of soil moisture from cultivation and the resulting lack of planting opportunities in the dry years.

Following visits to the United States and the United Kingdom, Australian soil conservation researchers and innovative farmers in the mid-1970s began experimenting with reduced tillage in all states. They were primarily interested in managing soil erosion from high-intensity rainfall events on hill slopes in Queensland, and managing severe wind erosion in South Australia (SA), WA and Victoria. By the late 70s, the herbicide companies Monsanto and Imperial Chemical Industries had established a number of demonstration trials where herbicide was substituted for tillage, and crop residue was maintained as a form of soil cover to better manage the off-site impact of erosion. The early results demonstrated both a significant reduction in erosion and a significant boost in available soil moisture.

From the early 1980s, leading farmers across Australia began experimenting with reducing the number of tillage operations to two, than to zero cultivation prior to sowing. Later farm trials showed increased planting opportunities over time and returned significant financial benefit relative to traditional multiple cultivation systems. Despite the obvious financial benefits (Table 1); uptake of such a new farming system by farmers at the time was relatively slow. It required a significant paradigm shift in the attitudes of farmers and support for change was limited by a range of factors. Foremost was the required change in seeding machinery and the lack of commercially available equipment. Weed control was also an issue, because without maintenance tillage in the fallow, cost-effective herbicides and sprayers were needed.

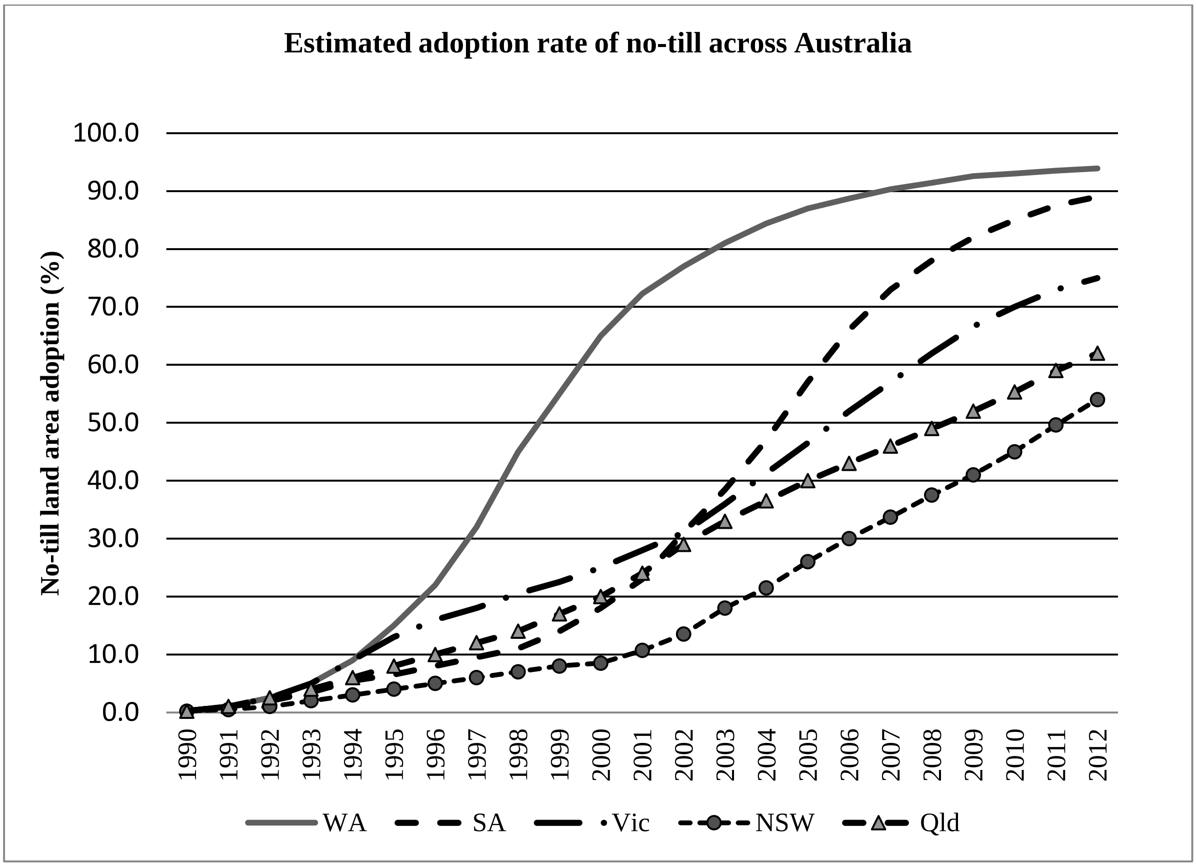
'Table 1 Wheat yields (tonnes/hectare) comparing farming practices over four years at two locations in Queensland. Relative cost benefit to growers based on current grain market price (Wylie and Moll 1998).

Compared practice	Biloela 1989–92	Goondiwindi 1989–92
Conventional cultivation	2.5	1.6
Stubble mulch	3.1	1.8
Reduced tillage	3.3	2.0
Zero-till	3.4	2.2
Relative income differences in moving from *conventional* to *zero-till* in today's dollar value ($212/t*) for a 500 ha per year crop	$95,400	$63,600

*Price based on multi-grade APW1 at Goondiwindi on the 28 May 2012, sourced from Graincorp (www.graincorp.com.au/pricing)

Reduced tillage

In the early stages of reduced tillage adoption, no-till equipment was not commercially available and many farmers were already locked into conventional planters/seeders designed for a pre-seeding finely worked seedbed rather than one that would need to develop its own seedbed. The process of adoption took many years, led most often by farmers in the more marginal areas who had the most to gain from retaining soil moisture and timeliness of sowing. Adoption was faster in the dryer western part of Australia, and is ongoing in eastern Australia where some farmers are still experimenting with reducing the number of tillage operations. Locally made commercial products are now supporting more rapid adoption. The cost of the herbicide glyphosate also became more competitive and over a span of 40 years reduced tillage has become the standard practice (Figure 1).



'Figure 1The adoption of reduced tillage farming practices in area terms by Australian states, updated to 2012 from (Crabtree 2010)

Definitions of tillage

The definitions of tillage practices have been variously described over time and it is likely that farmers' interpretations have also varied over time. This has implications for survey questions that compare today's practices with those of the past. Australian Conservation Agriculture (CA) farmer groups use the terminology below for common practices:

- conventional (or multiple) tillage –two or more tillages before seeding
- reduced tillage – one pass of full-soil disturbance prior to seeding
- direct drilling – one pass seeding with a full-cut or greater than 20% topsoil disturbance

- no-tillage – knifepoint or disc seeding with 5–20% topsoil disturbance
- zero-tillage – disc seeding without soil throw, but note that some discs do throw soil(Crabtree 2010).

The term ‘conventional’ is becoming misleading as it now represents a minority practice in most cropping regions. The current trend has been for farmers to continue to reduce soil disturbance. Adoption of disc seeders has been more common in areas where livestock has been removed from the farming system and where diverse crop rotations are economically feasible. There are some regions where disc Z*ero-till* has been popular and is close to 100% adoption (Crabtree 2010). The dominant reduced tillage system in Australia now is *No-tillage* and seeding with narrow (20-40 mm- knife points (see figure 2) on 25–35cm row spacing, along with press wheels (see figure 3). *No-tillage* seeding using knife points following surface applied pre-emergent herbicides has sufficient soil throw to cover the inter-row area and allows for safe and effective weed control. This does not work as efficiently with disc zero-till.

‘Figure 2 Narrow knife point with seed slot at rear (photo courtesy of Neville Gould from Conservation Agriculture and No-till Farmers Association, Wellington NSW)

‘Figure 3 Press wheel located behind knife point (photo courtesy of Neville Gould from Conservation Agriculture and No-till Farmers Association, Wellington NSW)

Retained stubble

Australia has seen an increasing trend to stubble retention, which represents a change in practice. In the past, one purpose of ploughing was to incorporate the plant residue left after harvest, allowing it to be broken down by soil microorganisms and facilitating the next planting (Thomas et al. 2007c). This involved a considerable amount of energy and often required several machinery passes to break up the plant material and mix it with the soil (Quick et al. 1984). In the more arid regions of Australia which experience dry conditions for a large part of the year, there was generally insufficient topsoil moisture to allow the breakdown process to occur to an acceptable level for planting without mechanical intervention (Roper 1985). Planting problems were more pronounced following years when high yields created biomass levels greater than four tonnes of dry matter per hectare (Ashworth et al. 2010). In the past, farmers responded to these high levels by grazing the stubble, baling it as feed or burning it with the aim of removing much of the crop residue prior to cultivation (Anderson 2009). Although grazing and burning is still an option, many Australian farmers and agronomists see the value of leaving the stubble in place to protect the soil from high-intensity rainfall and erosion by water and wind (Silburn et al. 2007). This benefit could be extended post-sowing but this required seeding equipment capable of operating successfully in these conditions, without the tines serving as a rake (Butler 2008;

Ashworth et al. 2010). A range of approaches were used in adapting seeding machinery for this purpose, including many combinations of:

- Cutting crops 15–20 cm high, using harvesters with residue choppers/spreaders.
- Increasing row spacing (often to 30 cm or more)
- Using coulter cutting blades ahead of the seeding times to cut through residue
- Deflecting residue ahead of each tine to be inter-row space
- Distributing seeding tines between 3-5 machine bars, to increase the gap between adjacent tines on the same bar.

Despite the issues of seeding through crop residue, farmers and natural resource officers all considered the benefits exceeded the costs in effort and expense. Today more than 30 commercial machinery suppliers offer a large range of seeding machines and seeding machine adaptations. This includes a variety of seed-trench firming "press wheels", which can have a major positive impact on crop emergence under marginal moisture conditions. Overload release ("stump jump") systems are universal in some areas, and individual row depth control ("parallelogram mounts") mechanisms are increasingly common.

To further reduce soil disturbance, farmers have moved to disc seeding equipment, usually with individual row depth control and varying fertiliser placement systems. Some of these units are extremely heavy and capable of cutting through substantial volumes of dry residue. Most have some problems of pushing residue into the seed trench in soft moist conditions, when soil adhesion can also be a problem. An increasing number of farmers are addressing the issue of seeding through heavy residue by "inter-row seeding" using high-precision guidance to place seed in a precise relationship to the standing stubble rows of the previous crop. Disc seeders disturb less soil, and hence encourage less weed-seed germination, but they are not as good as knife openers in producing even soil throw to incorporating pre-sowing residual herbicides. Consequently, where disc seeders are common, farmers are relying more on diversity in crop rotation as a weed management tool.

Some of the more important benefits of stubble retention in Australia’s dry climate and poor soils include a reduction in surface sealing and herbicide movement into the seed furrow resulting from raindrop impact, together with improved infiltration, and reduced soil erosion. Crop residue can also impair weed growth, return nutrients to the soil and provide some protection for emerging seedlings (Roper 1985; Jacobson et al. 1992; Unger 1994; Malinda 1995; Lal 2008; Anderson 2009).

Stubble is also a source of organic material contributing to the nutrient cycling performed by soil microorganisms and increases soil organic carbon. Wheat stubble consists of approximately 40% carbon, 0.58% nitrogen, 0.05% phosphorus, 1.42% potash and 0.19% sulphur and the degradation of crop residues releases about 55–70% of the carbon to the atmosphere as CO_2(Schomberg et al. 1994; Tan 2009). Microbial biomass takes up 5–15% of the carbon and the remaining 15–40% is partially stabilised in soil as new humus (Jenkinson 1971).

'Table 2 The advantages of crop stubble retention in Australian agricultural systems (Scott et al. 2010)

Benefit	**Description**
Water erosion control	Reduced erosion by protecting the soil surface from the impact of raindrops during high-intensity storms predominantly in the north.
Wind erosion control	Reduced loss of soil from the winds that cause dust storms, as wind speed is significantly decreased at the soil surface. Standing wheat stubble with rows across the wind direction reported the most effective to reduce wind erosion.
Slows evaporation of soil moisture at the surface	Speed of loss proportional to volume of stubble. Standing stubble more effective in resisting evaporation from wind.
Increases soil moisture storage	In the higher rainfall areas, stubble cover increases net soil moisture by reducing the amount of surface run-off. In the southern lower rainfall areas stubble cover reduces evaporation to retain soil moisture.
Nutrient conservation	Nutrient component of the stubble is returned to the system but with some immobilisation during decomposition.
Soil organic carbon (SOC) accumulation	May increase net SOC to a higher equilibrium or reduce the ongoing decline of SOC depending on other farming practices.

Increased micro-fauna	Populations of several species of earthworms have increased with stubble retention when combined with reduced tillage.

The level of carbon returned to the soil is variable depending on the stubble type, soil characteristics, environmental conditions and management practices (Chan et al. 2003; Wang and Dalal 2006; Robertson and Thorburn 2007; Liu et al. 2009; Luo et al. 2010). The 2010 Australian grain crop left a potential 56.5 Mt of residue after harvest prior to burning, grazing, or slow breakdown when retained for surface protection. This equates to 22.6 Mt of carbon, so changes in farm practices that involve residue retention became a bipartisan component of Australian government policy. This is currently expressed as part of the Commonwealth "Caring for Our Country" initiative to support projects that help farmers maintain ground cover. However, in farm management terms retaining stubble can create a number of logistical and production problems that need to be considered in any policy development (Unger 1994; Scott et al. 2010).

'Table 3The disadvantages of crop stubble retention in Australian agricultural systems (Scott et al. 2010)

Disadvantages	**Description**
Interference with seeding operation	Retained stubble can be a problem for machine operation at seeding causing blockages between the tines or poor establishment by interfering with seed placement.
Slow decomposition	In dry areas decomposition is slow and can interfere with future crop operations.
Disease carryover	Can be serious under the right conditions for disease development.
Pest carryover and habitat	Stubble can provide shelter that supports an increase in pest populations; more notably snails.
Weed adaptation	Some weeds have adapted to high stubble loads and the stubble can interfere with foliar application of herbicides.

The 2010–11 seasons were La Niña years and the fourth wettest on record for the eastern states, following similar La Niña events in 1973–74, 1955–56 and 1949–50. Wet seasons create excess stubble that becomes difficult to manage and also increases the occurrence of pest and disease carryover. This is exemplified by yield impacts from such diseases as yellow leaf spot (*Pyrenophora tritici-repentis*) and crown rot (*Fusarium pseudograminearum*) on wheat, and can be a significant incentive for stubble removal. If problems become excessive, residue disturbance or even burning becomes a management option.

In 2007–08, an Australian Bureau of Statistics survey indicated that only 43% of crop farmers (all sectors) left their stubble intact, although it should be recognised that the percentage of farmers is not the same as the percentage of production. Another 33% tilled crop residues and 34% baled or grazed the stubble with some overlapping practices (Pink 2009). Other surveys suggest the area of stubble burnt is about 20% of the cereal area (Llewellyn et al. 2009), but burning is less common in states such as WA and Queensland (Pink 2009), except in continuous wheat areas where weed resistance is becoming a problem.

Overall, the ongoing benefits of stubble retention to stored moisture and improved soil health has seen a majority of farmers make the choice to retain crop residues after harvest, and manage the associated disadvantages as best they can. Retained residues is more acceptable than burning in terms of soil carbon impact, but the proportion of the remaining residue that degrades into the more stable humus fraction of soil carbon is both small and uncertain. This uncertainty creates a problem when we consider measuring the carbon balance of cropping soils for sequestration under the climate change policy being developed.

Controlled traffic farming

The impact of soil compaction by heavy farm machinery has become more apparent as larger tractors are used to operate more land per unit time (Chamen et al. 1992; Chamen et al. 2003; Batey 2009). The effect of tractor wheels on soil compaction has resulted in crop production issues stemming from a disruption of structure (Hamza and Anderson 2005; Kirchhof and Daniels 2009), although not all soils are equally affected. The consequence has been reduced microbial activity, reduced water infiltration and poor root growth leading to yield limitations (Jones et al. 2003; Tullberg et al. 2007; Ahmad et al. 2009a; McKenzie et al. 2009; Botta et al. 2010). Controlled traffic farming (CTF) restricts the wheels of all heavy field traffic to permanent traffic lanes to prevent damage to the whole paddock area from conventional "random" operation.

The compacted permanent traffic lanes are laid out and managed for efficient traction, traffic and drainage, allowing the intervening crop beds to remain soft and in better condition for crop production. Because the harvester is the most difficult machine, controlled traffic operation has usually been achieved by modifying tractors to the harvester track width, using a harvester and seeder of the same width, and a sprayer which is a multiple of this width. This can provide machinery footprints in the range 12 – 16% of paddock area. This practice was taken up initially by farmers on heavier soil types, providing evidence of soil structural improvements, increased yields (Li et al. 2007), and substantial reductions in fuel use. Farmers also report that hard permanent traffic lanes allow a wider window of operation for machinery as they don’t have to wait as long for soft soils to dry out. Although farmers were initially concerned about the cost of machinery modification and tractor warranties, there has been an increasing adoption of control traffic farming (CTF) across the Australian cropping zone.

Use of compacted permanent traffic lanes resulted in greater energy efficiency than operating randomly on softer soils. The difference recorded by Tullberg (2007) showed a 39% reduction in energy requirement from employing CTF. Gas exchange between soft soils and compacted soils are still under investigation, but preliminary results (Tullberg , J. pers. comm.) show substantial reductions in nitrous oxide emissions from controlled traffic cropping beds. Emerging problems of CTF include the difficulty of controlling weeds in wheel tracks, and deep rutting of traffic lanes by continuous wheel passes in clay soils.

Despite the yield benefits of using CTF systems, the major barrier seems to be a false perception that machinery conversion is very expensive. Some current estimates of CTF in Australian agriculture indicate the number of farmers using some form of CTF at 15,320; which is about 21.9% of all crop farmers (ABS[11]).   Given the overall energy savings, yield benefits and improved soil condition across most soil types, there is an argument for CTF to be considered an important practice in conservation agriculture (Yule and Chapman 2011).

Crop rotations

Rotating crops by growing different types of plants sequentially in the same paddock has been a long-term practice of agriculture to reduce build-up of pathogens and manage the

[11]Australian Bureau of Statistics ARMS Survey: Broadacre crop farmers include those who planted cereals, canola, lupins, sugarcane and cotton (excludes fruit and vegetables).

nutrient demand of different crops (Bailey 1996; Feller et al. 2003; Korstanje and Cuenya 2010). Legume production crops are also highly valued in rotations as a means of increasing nitrogen inputs or minimising commercial demands for the next crop (Angus 2001; Lindemann and Glover 2003), but cereal crops are more profitable in the drier cropping regions. It can be financially difficult for farmers to rotate into alternative crops with poorer cash returns, despite the risk of plant disease carryover or increased weed burdens from not doing so(Godsey et al. 2007; Thomas et al. 2011).

Farmers will also move from one crop to another depending on market price; they will seek more profitable crop options if they are confident that they know how to grow the crop. Risk is another factor affecting the choice of crops. High input crops that are complex to grow often require a bigger outlay for greater returns, but there is also more to lose if conditions become unfavourable.

The value of legumes in supplying soil nitrogen for following crops is well-known to Australian farmers, but the economics of introducing a legume crop is not always acceptable when cereal grain prices are high but pulse crop prices low (Malcolm et al. 2009). Grain seasonal prices have varied as much as 200% since 2004–05, with some legumes having similar variations though not necessarily in tandem. This has resulted in variable production volumes and a gradual decrease in the area planted to pulses over the last decade (O'Connell 2010). Some of the more effective legume crops for fixing nitrogen are not always the most economical from a production perspective (Lindemann and Glover 2003; Thomas et al. 2011).

In a recent report, the Grains Research Development Corporation evaluated the benefit of break crops from a series of long-term trials in WA (GRDC 2011b). It indicated that the yield benefits of legume break crops were highly variable, often riskier and less profitable than cereals. The average yield benefit from the inclusion of lupin or field pea in the rotation compared to ‘wheat following wheat’ was in the range 0.3–0.6 tonnes/hectare in favour of a legume break crop.

These yield benefits were more evident in the higher rainfall areas, with improved water use efficiency over time attributed in part to no-till practices. Following the break crop, the following cereals still responded to nitrogen application; however the rate of response was relatively low and more often dominated by non-nitrogen related benefits (diseases and weed control). The break crop benefit was also reported to last up to a third wheat crop (Seymour et al. 2012). Despite the perceived value of crop rotations, especially legumes, the choice of cereals is predominantly driven by economics in many marginal areas.

Current trends in Australian conservation agriculture practices

Conservation agriculture (CA) is said to offer a new paradigm that offers greater productivity from the same area of land using fewer resources and reducing negative impacts of agriculture on the environment (Collette et al. 2011). Innovative farmers in Australia have moved beyond reducing tillage, maintaining ground cover and including crop rotations. They have sought further efficiencies in the use of resources from CTF and the application of precision agriculture. Precision agriculture is defined as farming using computers and information technology; it combines various sensors on farm with global positioning systems to match farming practices more closely with crop needs(Bloomer and Powrie 2011).

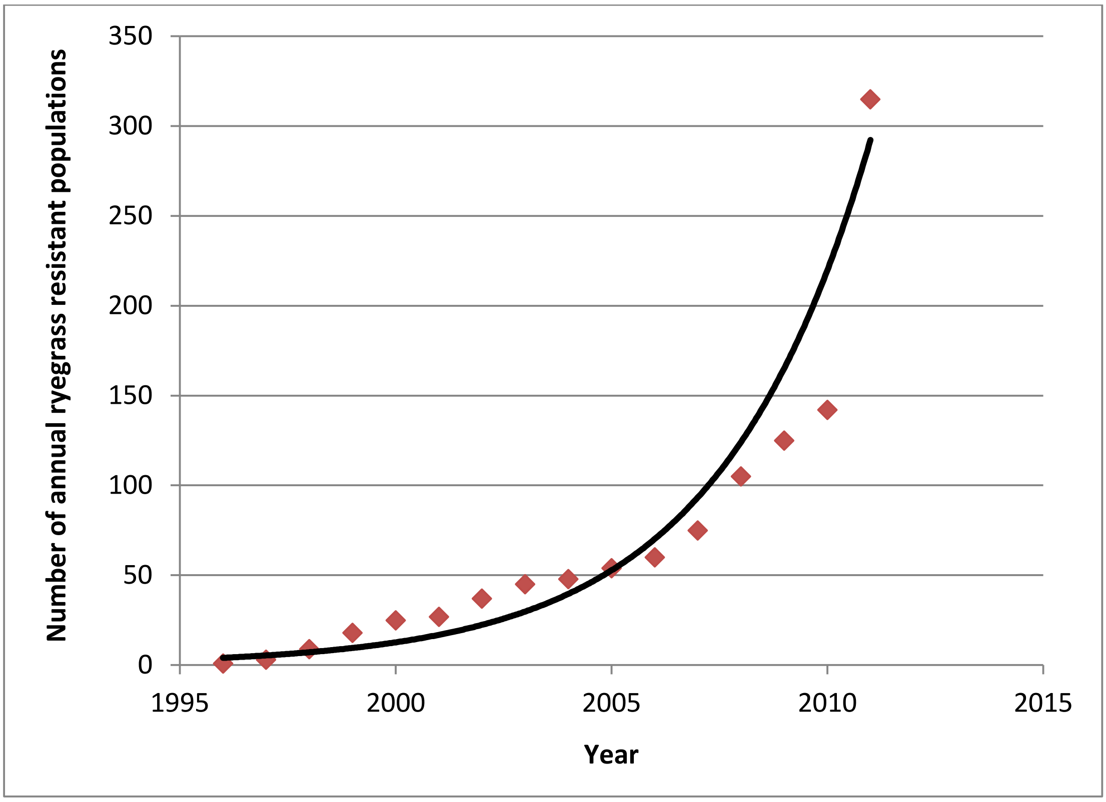
These innovations have not been without their challenges in the management of weeds, pest and diseases. Australia has benefited greatly from engineering innovations, research in weed control, digital sensors and satellite technology. General acceptance of the benefits of CA by farmers has encouraged industry suppliers to provide products that further support CA practices.

Machinery advances

Many modern no-till seeders can achieve precision seed placement in changing soil types (wet and dry); they can place the seed and fertiliser separately, ensure the crop seed is safely separated from herbicides, are capable of seeding through thick crop residues, and can ride over obstacles efficiently with less machinery damage. No-till seeders for instance, are increasingly using hydraulic systems to provide adjustable down-force control for openers and press-wheels, together with overload protection.

Herbicide resistance

Research into weed control has been critical to the development of CA. Fallow weed control usually depends on glyphosate and some populations of annual ryegrass (*Lolium rigidum*) have become glyphosate resistant, an issue which first emerged in 1996 in Victoria. Later, glyphosate resistance also occurred in awnless barnyard grass (*Echinochloa colona*), liverseed grass (*Urochloa panicoides*) and windmill grass (*Chloris truncata*) in New South Wales (NSW). The first recording of broadleaf resistance was in fleabane (*Conyza bonariensis*) in Queensland. The most recent occurrence of resistance was in great brome (*Bromus diandrus*) in 2011 in SA. Resistance problems have not been limited to broadacre cropping but are also evident in horticulture, industrial weed control areas, railway lines and roadsides.



'Figure 4 The cumulative increase in the number of ryegrass resistant populations over time (source: courtesy of C. Preston, University of Adelaide)

To counter the increasing threat of resistant weeds, research has focussed on rotating herbicides from different chemical groups, managing the post-harvest weed seedbank with windrow burning where the harvested chaff is stacked in rows and burnt.

Reducing tillage limits moisture loss from evaporation but not from weeds, so when cultivation is not an option, weed control relies heavily on herbicides. The use of Glyphosate has been an inexpensive and effective broad-spectrum knockdown herbicide, but its continuous use for fallow weed control has created an increasing problem of herbicide resistance (Code and Donaldson 1996; Peltzer et al. 2009; VanGessel et al. 2009). An integrated weed management strategy to slow the development of resistance requires the addition of other herbicides and a range of agronomic strategies, such as rotation and harvest adaptations to reduce the weed seed bank. These all threaten to increase the cost of weed control (Beckie 2011).

Technology that uses optical sensors to detect weeds , along with on-off solenoids on the spray line would limit herbicide delivery to weed infestation areas instead of spraying the whole paddock (Hilton 2000). The increasing use of this 'weed-seeker’ technology is aimed at reducing the volume of herbicides, thus allowing a broader range of herbicides at reduced cost. The difference in application may not be obvious when wet years produce high weed populations, but becomes more significant in drier years with non-uniform establishment. Although expensive, this technology can provide substantial resource savings in the fallow weed control required to reduce soil moisture loss (Figure 5).

Area to be sprayed	264 hectares
Water rate	80 litres/hectare
Actual usage	4.5% of volume
Actual area sprayed	11.88 hectares
Actual cost of chemical	$583.30
Chemical cost normal spray	$12,962.40
Actual cost saving	**$12,379.10**

‘Figure 5 Demonstration by Crop Optic Australia at a farmer field day on how the optic sensor identifies a weed and activates the spray solenoid over that area (picture on left). The data is based on a case example supplied by grain and cotton farmer J. Grant on the Darling Downs (Queensland).

Precision agriculture

The label precision agriculture was first applied when the combination of harvester yield monitoring and satellite-based global positioning systems(GPS) allowed the economic production of paddock yield maps, but 'PA' is now a generic term covering a wide range of satellite and sensor-based technologies. The most widely adopted of these is 'GPS Autosteer’(self-steering) for farm equipment.

The world's first commercial satellite-based auto-steer using Real Time Kinematic (RTK) GPS correction for precise tractor steering, the 'Beeline Navigator', was developed by an

Australian in the early 1990s. Guidance equipment of this type is now manufactured by several international organisations, and is a built-in option or standard unit in many tractors and harvesters. Inexpensive units claim pass-to-pass (repeatable only in the short term, not year-to-year) accuracies of ± 10 to 30cm, but more sophisticated units provide "2cm" precision (± 2cm 67%; ± 4cm 95% of time). This development was originally driven by early controlled traffic adopters, but benefits – such as increased productivity with the elimination of overlap, and reductions in operator fatigue are large, often quantifiable, and easily justified by farmers managing increasingly large areas.

Accurate digital GPS position monitoring and recording now provides a platform for a large number of precision agriculture applications where data from various proximal sensors (Table 4, below) and other spatial information (e.g. satellite images) can be combined to provide resource efficiencies of the key farm inputs: labour, fuel, fertiliser and chemicals. The input cost benefits are balanced by the cost of establishing a digital network system on farm and the human factor of having to learn how to use the system efficiently.

'Site-specific management' – the matching of seed, fertiliser and crop chemical inputs to crop requirements or soil characteristics of each paddock zone – became possible with the development of GPS-based harvest yield monitors and variable rate applicators. It has also become cheaper as more monitoring capability is standard equipment built into harvesters and applicators. Many Australian grain growers have now used yield mapping to provide useful management information, but the next step – 'zone management' using variable rate technology– requires complex assessment of soil/crop response characteristics and their interaction with climate probabilities. Scientific enthusiasm and investment in this technology has not been matched by practical adoption, which has been slow.

‘Table 4 Illustrates some example of sensors and related information for farmers

Farm asset	Sensor	Data	Information
Soil texture	Electromagnetic induction	This is a non-contact method of measuring electrical conductivity involving inducing a magnetic field into the soil	Structure and depth of topsoil

		and measuring the electrical current response field.	
Soil moisture	Various: Reflectometry, microwave or radio frequency via probe	Moisture curves	Current soil moisture trend
Soil pH & nutrient	Electrochemical sensors	various	Field pH and nutrient status
Crop vigour /weed presence	Optical and radiometric	Crop vigour (relative)	Areas of poor growth, nutrient, disease, insect damage or presence of weeds
Yield monitors	Flow meters	Grain yield (relative)	Harvestable yield based on management
Variable seeding	Ground speed sensor	Seed volume	Plant population
Variable rate fertilising	Flow meters/ Chlorophyll sensors	Fertiliser output	Fertiliser volume

More recent development of crop condition sensing equipment shows greater promise of rapid application, particularly when early problem detection (e.g. nutrient deficiency) can enable timely and effective management response (e.g. foliar nutrient application). Development of systems to integrate proximal and remote sensor outputs to deploy farm operation more accurately has also interested farmers managing increasingly expensive and limited resources (Rochecouste 2009). The aim is to optimise economic performance and avoid wasteful uniform applications by limiting inputs (e.g. fertilisers and chemicals) to "what is needed, where it is needed" (Whitlock 2006; Butler 2008). This use of precision agriculture continues the trend towards increasing efficiency in the use of limited resources (Cook and Bramley 2000; Shoup et al. 2004).

Most farmers and agronomists have taken up some aspect of digital technology as part of their management, and the trend is increasing. Continuously Operating Reference Stations (CORS) are being built and gradually covering much of rural Australia. CORS is a network of permanent Global Navigation Satellite System (GNSS) tracking stations which provide the RTK correction signals necessary for precise satellite positioning for industry and agriculture (Janssen et al. 2011). CORS installation in Victoria is complete with 100% coverage. New South Wales is more than 50% complete, Queensland has coverage but mostly in the south-east and Western Australia and South Australia have limited coverage. This technology will be an integral component of a more resource-efficient, productive and sustainable mechanised farming future.

Inter-row seeding

As the practice of retaining crop residues increased to protect soils, farmers noticed that crops sown between standing stubble rows performed better. Leaving the stubble standing after harvest reduces the problems of tine planter residue blockage and disc planters 'hairpinning' through failure to cutting through flat, wet stubble on soft soils. Precision autosteer made it possible to routinely place an alternate row between existing rows of standing stubble, perhaps after some increase in row spacing, and adjustment of sprayer nozzle positioning. Inter-row planting provides a more consistent soil cover and associated weed control benefits (Roberts and Leonard 2008), and is simply achieved by use of an offset hitch to displace the seeder frame relative to the previous year's planting . Yield improvement of legumes sown within cereal stubble has also been reported, attributed mainly to reduced lodging and improvements in harvest efficiency (Roberts 2008).

Cover cropping

Planting cover crops helps protect the soil from erosion. Cover crops add organic matter and immobilise soluble nutrients that would otherwise be lost down the soil profile. A cover crop is generally not grown primarily for harvest but returned to the soil as a green manure input. If the cover crop is a legume, there is an additional nitrogen input. The benefits are well recognised, but dry-land farmers are concerned that cover crop moisture requirements will compromise moisture availability for the following economic crop. Cropping windows on the lighter soils in the south and west are also short. Positive evidence about the impact of cover crops continues to accumulate, but it is still not common, except in those areas with reliable rainfall in the off-season.

Recycled organics

The nutrient value of animal industry waste as an alternative fertiliser and means of improving long-term soil structure has been a point of discussion among farmers. This applies particularly to those cropping zones with a number of intensive livestock enterprises producing animal waste is conveniently located. Farmers have started purchasing and applying this waste, and in most cases seen a yield increase, primarily due to the nutrient content, released over several years. The cost of manure is comparable to traditional inorganic fertilisers, but manures are generally less predictable in its NPK nutrient value, and transport/application costs are significant. Uncomposted product has high water content, and raw manure can also tie up nitrogen for some period of time. Despite these issues a significant increase in its use occurred in 2008–09 when global fertiliser prices rose sharply.

In addition to the nutrient benefit, some farmers have also reported better long-term water-use efficiency from increased organic matter. This could be attributable to improved water-holding capacity (WHC) where agriculture is dominated by sandy soils, as outlined by the Waste Authority Western Australian (WAWA 2010). Other benefits attributed to recycled organic amendments include increased water infiltration and improved soil structure. Although the linkage between water-use efficiency and WHC is well researched; it is unclear if adding a range of unspecified animal manure to fine-textured, low-fertility soils in an arid climate will lead to long-term improvement in WHC.

Use of urban sewerage is being trialled in some areas but there is concern about the likely build-up of heavy metal contaminants. Grain farms are also generally distant from major urban areas, making transportation costs prohibitive, so while the practice is favoured by many farmers, logistics limits its use to certain areas within easy transport reach of waste outlets.

Ecosystem services

Ecosystem services are defined as the public benefit of maintaining land in good condition, and payment for ecosystem services has often been advocated. Public benefit could include changes in land characteristics that improve soil and water quality, increases biodiversity or sequesters carbon. As a compensation for adopting land practices that reduce externalities, the proposal is that farmers be paid by governments on behalf of taxpayers or by private organisations looking to demonstrate their corporate social responsibility. This is still being explored in Australian policy terms.

Some environmental services are already being delivered by conservation farmers in the form of reduced erosion and improved soil biodiversity from retained stubble leading to improved water quality. Extending this scheme could include an annual performance-based cash flow to farmers to support revegetation on non-cropping marginal land (biodiversity refuges, carbon sequestration), maintaining or establishing natural vegetation along riparian areas (hydrological services), protecting established natural habitats (biodiversity), and the use of cover cropping in the rotation when economic crops are not available (soil carbon sequestration, soil biodiversity).

Policy impacts on conservation agriculture in Australia

The Australian Government has three rural policy programs directed at farmers that are likely to impact on conservation farmers.

1. "Care for Our Country" is a two-billion dollar spending initiative to improve Australia's environmental assets which includes a multi-year budget of 15 million dollars for sustainable farm practices. The target involves improving land management practices of 42,000 farmers across 70 million hectares, and includes initiatives to reduce tillage, maintain ground cover and build-up soil organic matter.
2. The Carbon Farming Initiative (CFI) was announced by the government in August 2010 with the aim of giving farmers, forest growers and land-holders access to domestic voluntary and international carbon markets by providing a framework to remove carbon dioxide from the atmosphere and to avoid the emissions of greenhouse gases (GHG). The CFI is supported legislatively by the *Carbon Credit (Carbon Farming Initiative) Act 2011*, and is a market-based instrument to encourage farmers to become a net sink of carbon.

3. As part of the Clean Energy Future plan, the government included within the *Tax Act* a provision entitled The Conservation Tillage Refundable Tax Offset. 3.1 Schedule 2 to the Clean Energy (Consequential Amendments) Bill 2011. This amends the *Income Tax Assessment Act 1997* (ITAA 1997) to provide a Refundable Tax Offset (RTO) for certain new depreciating assets used in conservation tillage farming practices. The new law entitles the taxpayer to an RTO of 15% of the cost of an eligible asset. This would include tine machines fitted with minimum tillage points to achieve minimum soil disturbance, disk openers and suitable hybrid machines.

These rural policy programs offer some form of incentive to reduce tillage, retain on-farm biomass, increase soil organic carbon, or to support new methodologies to reduce on-farm greenhouse gas emissions. Farmers applying CA practices have some opportunities to benefit from these policies.

Carbon sequestration using no-till in an Australian context

The concept that no-till practices will lead to significant carbon sequestration does not seem very likely in Australian dry-land farming, where low rainfall limits biomass production, and high temperatures accelerate the loss of soil organic matter. Soil carbon sequestration faces the same 'additionality' and 'permanence' tests as other sequestration mechanisms participating in carbon offset trading. The potential role of increasing Soil Organic Carbon (SOC) in Australia has been reviewed by Sanderman et al. (2010). Grain cropping covers approximately 23 million hectares of production (GRDC 2012) dominated by light-textured soils. Cultivated soils lose organic carbon at variable rates depending on the clay content and annual rainfall (Swift 2001). In a range of clay soils, losses of organic carbon averaged 0.6% per year (Dalal and Chan 2001). The limited rainfall and high summer temperatures of the cropping region limits the opportunity to significantly increase the organic carbon content of these soils (Chan et al. 2008; Baldock et al. 2009).

Under these conditions, reduced tillage practices have limited capacity to increase soil organic content, and in most situations they can only mitigate the ongoing loss (Wang et al. 2010). This would mean that many of the cropping soils would show only marginal increases in SOC over time (Luo et al. 2010; Chan et al. 2011). Such small changes are unlikely to find sufficient offset units across the average grain farm to interest traders and would require some form of pooling to create the necessary economies of scale (Renwick et al. 2003).

This is further complicated by the error margins associated with measuring SOC that emanate from variations in bulk density (Throop et al. 2012) when sampling occurs to fixed depth, rather than equivalent mass across heterogeneous soil types (Sanderman et al. 2010). Sanderman and Baldock (2010) also argue that predicted stock change data from agricultural trials may not truly reflect sequestration when the state of the soil carbon at the beginning of the trial is unknown; that is, when there is no comparable baseline at the start of the field trials. Thus current International Panel for Climate Change (IPCC) accounting methodologies developed from trial results may not show the true value of the carbon storage based on the management activities (Sanderman and Baldock 2010).

This uncertainty is likely to affect confidence in the market allocation of carbon credit units for offsetting a unit of emissions using soil carbon sequestration. Nevertheless, CA significantly reduces the loss of SOC to the atmosphere, and in certain seasons does create a carbon sink. Although it may not fit the mainstream carbon market, this should perhaps still be considered as a market-based instrument to encourage the benefits attributable to CA through reduced emissions and positive effects on the soil carbon balance.

Carbon market options

The role of agriculture in carbon trading has been reviewed in Australia by the CSIRO (Walcott et al. 2009). Current carbon markets in Australia are mostly voluntary and involve predominantly offsets derived from designated carbon sinks – usually forest plantations– with variable project methodologies (Ribon and Scott 2007; Hassall 2010). The operation of these markets using offset units from agricultural practices is still evolving. This is in part due to the uncertainties perceived by farmers that relate to contract terms in the offset market; that is, what sort of monitoring is involved and how long would the payment last? (Sanderman et al. 2010).

The extent of reductions and the means of measuring emissions performance from a farm practice in Australia are still unclear (Sanderman et al. 2010). The determination of an accepted methodology for international markets is currently determined by agreements within the United Nations Framework Convention on Climate Change (Hodgkinson and Garner 2008). In Australia, research is underway into methodologies that can produce an Australian Carbon Credit Unit. The Domestic Offsets Integrity Committee has endorsed four land-based methodologies (capture and combustion of landfill gas, destruction of methane generated from manure in piggeries, environmental plantings and savannah burning) and these have been approved by the Parliamentary Secretary for Climate Change and Energy Efficiency. As farming provides a critical service in terms of food production, it is important that emissions reductions should not be at the cost of our food production. This would be likely to shift unintended consequences of food shortages to other nations to meet local national emissions reductions targets.

At present, market options for a carbon credit unit based on CA practices are limited by not having a methodology, due in part to the complex biophysical processes of both the carbon and nitrogen cycles in seasonal agricultural practices.

Climate change consideration on future productions

Following the IPCC Fourth Assessment Report: Climate Change 2007, the IPCC Working Group I noted in its executive summary that a 0.6^{o}C increase was observed across the Australian continent. They also noted that southern Australia, which holds a significant portion of the cropping belt, is becoming drier. In 2010, the Australian Parliament's House of Representatives Standing Committee on Primary Industries and Resources held an inquiry into the role of government in assisting Australian farmers adapt to the impacts of climate change. The Conservation Agriculture Alliance of Australia and New Zealand (CAAANZ) made a submission on behalf of its members. A farmer representative informed the committee that conservation farmers had already been adapting to climate changes by deploying technology such as zero-till, CTF and retaining crop residues to conserve moisture. The committee was further advised that although gradual changes can be managed with adaptation strategies, of more concern to farmers is an increase in the timing of temperature extremes, and in the pattern as well as the level of precipitation. CAAANZ alliance members sought support not only in research for adaptive strategies but also requested that it be coupled with suitable extension programs.

The average rainfall in the grain production areas lies between 200 and 800mm per year, but this can fluctuate with drought and flood years depending on the various climatic patterns of the Indian and Pacific oceans. While the production areas are familiar with drought and flood years, they are nevertheless economically vulnerable to future climate change impacts on rainfall, evaporation and temperature (Crimp et al. 2008; Howden et al. 2010). Of particular concern to crop yield in the short-term outlook are reductions in net rainfall and the timing of that rainfall, with the possibility of a trend to increases in rainfall intensity going to run-off and limiting infiltration (Stephens and Lyons 1998; van Herwaarden et al. 1998; Hope and Ganter 2009).

Potential changes in rainfall will vary across regions but overall the trend is towards reduced rainfall across the cereal belt (–30% to +20%). Increasing temperatures in the range 0 to 4°C will also impact on evaporation. Cropping as a farming enterprise generally yields better profit than livestock production, but it is also more economically vulnerable to climate risk in dry years due to grain yield sensitivity to moisture loss (van Herwaarden et al. 1998; Day et al. 2010). Predicted meteorological changes increase the risk conditions of reduced rainfall and reduced crop production which is likely to have a significant impact on the future of farm profit if those risks are realised (Stephens and Lyons 1998). Research may provide future solutions but that is purely speculative at this point. Successful adaptation therefore relies on the capacity of farmers to manage their production vulnerability through better farm management.

CA has played a key role in the marginal grain production areas to manage the risk of drought over the last 30 years (Armstrong et al. 2003; Turner and Asseng 2005; Thomas et al. 2007c; Thomas et al. 2011). The compelling benefits of CA in increasing crop yield by managing soil moisture and fertility have allowed farmers to meet the economic realities of increases in production costs and a reduction in the relative price of grains (Turner 2004; Mullen 2007). These gains are being further challenged by the risks associated with climate change (Howden et al. 2010). Available soil moisture will be a key driving factor for farmers in managing future risk in Australia (Acuna and Wade 2005; Branson 2011).

2.2 Production of Carbon Offsets using Conservation Agriculture practices

This section is presented as a paper and is published as Rochecouste, J. and Dargusch, P. 2011, 'Opportunities to produce carbon offsets using conservation farming practices in developing countries', *Annals of Tropical Research*, vol. 33, no. 1, p. 85-101.

Notes

This paper was published very early in the preparation of this research as part of an invited review into the potential for carbon offsets using conservation agriculture in developing countries. It does not directly deal with the main topic of the role of conservation agriculture on Australian dryland farming systems. It does however support the early literature review of the linkages between carbon offset and conservation agriculture. The paper has not been included to avoid confusion over the main topic of the thesis that deals with the Australian context.

3.0 RESEARCH METHODOLOGY

This Chapter outlines the Methodology and methods applied in the thesis, including data collection and analysis. Given the complexity of socioeconomic, ecological and policy factors influencing the Research Problem, I believe that a mix-method approach was required (Creswell 2003). Some of the data to be analysed for research question 1 and 2 for example (The role of CA in Australian grain farming practices & its influence on greenhouse gas emissions) was going to require the collection of empirical data to outline the baseline for existing practice. Research question 3 (what factors influence adoption of CA) was going to require an interpretive analysis of what motivates farmers to change CA practices and there was a need to deal with classifying what were the CA practices that were being adopted to begin with. Finally both sets of data needed to be interpreted when considering the policy framework that looks at supporting farmers making a change in farm practices. This involved integrating quantitative and qualitative approaches concurrently so as to generate new knowledge by interpreting both sets of data format.

A variety of data collection and analysis methods were used including discourse and document analysis, semi-structured interviews and case studies to generate the data. It was important to understand what drives farmers to adopt CA practices in-situ. A systems-thinking approach was applied as a tool to analyse the nature of the data collected and the extent of the relationships between factors influencing what drives CA adoption. I believe that practice change and the policy framework that would support the means for farmers to change land practices needs to consider the various economic and social drivers as a system. This approach is integrated as a socio-economic analysis and presented as a paper in chapter 6.

3.1. Introduction

In this chapter I present the methodology as a ‘Mixed-Method’ analysis which is used to address the Research Questions outlined in section 1.5.2 of the Introduction. In considering the evidence that would answer the questions about the ‘current role of CA in the Australian grains industry’, ‘the impact of these practices on emissions’, ‘how do we get adoption’ and ‘what policies support these farm changes’, I collate a range of data, both ‘quantitative’ and ‘qualitative’ from different sources into an integrative unit for interpretation. A study of how particular climate change policy might promote sustainable agriculture within an industry requires consideration from multiple disciplines; agricultural science, economics, financial management, sociology, politics, sustainability science and environmental management. I used a Mixed-method approach to collate a range of data from various sources such as farmers, advisers, suppliers, researchers and government literature in considering the evidence they represent when deriving the policy recommendations. It was particularly important to understand the drivers in 'changing practices towards CA', so farmer interviews were targeted towards what motivated them to make past changes and consideration for future changes.

The conceptual framing underpinning my methodology is that of a human activity systems. In terms of a method of analysis for the data it was proposed by Checkland (1999) that human activity systems are unlike natural systems and are not testable in the same fashion, but are perceived by the likely behaviour of its constituents. Farmers differ in their approach to the way they operate their farm, there can be many balancing factors that individual farmers consider in choosing between a range of practice options (Vanclay 2004). These apparently small details (e.g. cultivation tools) will impact the emissions profile of a farm in different ways. The Research Problem of this thesis involves the study of both the social and economic drivers that cause changes in farmer behaviour, and is better considered a 'Human Activity System' given the lack of predictability of future behaviour and therefore the lack of suitability of a reductionist approach (Creswell 2003).

'Human Activity Systems' requires a more inductive and exploratory approach to research (O'Leary 2004). I recognise that the use of climate policy to attempt to change a farmer's practices to achieve changes in externalities created by the farm can have uncertain outcomes due to the inherent complexity of agricultural practices. Given the traditionally slow progress of agricultural social change and the urgency of climate change there is a risk that poorly conceived policy would simply result in inaction in farm practice change, hence the need on research on farm practice change relating to climate policy (Feder and Umali 1993; De Souza Filho et al. 1999; Vanclay 2004; Vignola et al. 2010). In this thesis I have accepted that the approach should consider a wider range of views than either a 'quantitative' or 'qualitative' approach in order to derive effective policy. I proposed that if the aim of current climate change policy was to reduce emissions by having farmers change their farming practices, than making a change requires an investment by the farmer in either time or money. Framing a policy to encourage this investment needs an understanding of the activity system of the farmers involved. We need to consider what are the practices that policy would seek to change and what would motivate farmers to make an investment to change. As outlined by Vanclay (2004) the motivation for change in agriculture is not just a rational economic decision, it is also significantly influenced by family and other social considerations.

Using a Mixed-method analysis to understand a farmer's motivation involves a review of both the empirical data available to the farmer in terms of such things as the cost to change and resulting production outcome; but also the social consideration such as the ability to take on digital technology or their risk appetite for introducing new methods. Weighing the influential value of these various data sources is part of interpreting a human activity (agricultural) system.

In the following sections of this thesis I will outline the data sources, the method of analysis, how the data is structure for analysis and finally the boundaries of the study.

3.2. Data Sources

CA is an accepted term to describe the phenomena of changing farm practices in a way that reduces demand for finite resources such as fossil fuel and encourages soil organic matter recycling (Friedrich and Kienzle 2007). There are however no set definition of CA and different jurisdiction use the term loosely referring to a range of farm practices. In the context of this thesis it will refer to its application in the Australian grains industry.

Data was collected from document analysis and through the discourse of farmers and industry practitioners. Data came from various sources, including farmer magazines, conferences, industry and government reports as well as the academic literature. The data is organised into themes by individual CA practices and analysed for its impact on emissions and how it can be influenced by policy. This thematic approach to analysis is outlined by Lapadat (2010). According to Lapadat it is widely used by qualitative researchers for its insightful interpretations of large mixed sources of data despite criticism from positivist researchers as having an ambiguous approach that is not easily replicable (Lapadat 2010). However policy is more about trying to understand factors that influence a change of behaviour. It seems logical that policy initiatives need to consider the likelihood and extent of what will drive policy adoption. There is therefore value in understanding the current practices within the various agro-ecological zones and the drivers that created them; as well as having a critical understanding of policy impacts and the options available. Such a study of factors affecting policy options is generally limited by having insufficient quantitative data, particularly in the early stage of any policy deployment.

The basis for this mixed approach to the collation of data is discussed by Rapley (2007) who suggests that industry literature supplies a rich source of data for academic research and that there is much to be learnt about the direction and trajectory of culture and institutional practice by engaging in such documented material and that literature such as industry magazines, books and digital media provides a strong sense of context to industry thinking, more so than simply relying on interviews (Rapley 2007). This thesis presents a range of data and analysis methods including *document analysis* (published and unpublished data from industry & government departments), *discourse analysis* (what the industry communicates to its farmer constituents via farmer magazine and websites) and *semi-structured interviews of farmers and industry experts*. Document and discourse analysis refers to dialogue, written texts and mixed digital media engaged in by the industry around farm practices (Titscher et al. 2000). The interviews are intended to elicit a deeper understanding of farmer's motivational factors that drive or constrain CA practice change in the current circumstances and use an "Interview Guide" approach as per Patton (2002). Where possible the validity of these methods is supported by triangulation with on-ground observations, interviews and the scientific literature.

The data collection and analysis methods used are summarised in Table 3. I list the source of the data, highlighting some examples and the areas of the thesis that it relates to.

Table 3 Data Type and form used in document analysis

Data type	Example	Chapter reference
Government Publications	Government reports and fact sheets in relation to agricultural emissions and farm practices	Chapter 4, 6 & 7 Research Question 2
Statistical data from Australian Bureau of Agriculture Resource	Data reports of agricultural statistics on energy and farm inputs such as fertiliser	Chapter 4 & 6 Research Question 2 & 3

Economics and Science (ABARES)		
Government Development Corporations	Data on farmer practices and industry figures and changes over time	Chapter 2 & 5 Research Question 1& 3
Industry peer reviewed literature	Includes publications such as Agriculture, Ecosystems & Environment or Climate Policy	All sections
Industry literature	Data collected by farming organisations such Grain Council of Australia or the Grain Producers Association in regards to fuel use by farmers over time	Chapter 2, 4 & 5 Research Question 1
Industry unpublished data	Data collected by farmer organisations as part of extension and research projects and may include such things as machinery use and type. A lot of industry material as part of research projects is unpublished and stored on-site. Companies may also hold farm data sets in regards to such things as soil analysis by region.	Chapter 2 & 4 Research Question 1, 2 & 3
Corporate industry literature	Documents related to government commissioned projects by legal firms on such topics as legal evaluation of carbon farming	Chapter 7 Research Question 2 & 3

Industry technical magazine	A number of farm organisations and natural resource management group produce technical documents often supported by government scientists.	Chapters 2, 5, 6 & 7

Note that wherever possible the data was cross referenced across a range of sources. Where that was not possible, some cautionary notes are included.

3.3 Methodology of analysis

In Section 3.2 I considered the nature of the data being collected from mixed sources. I grouped the data into themes based on CA practices and I considered what the data was telling us in regards to the Research Questions. In this section I outline the method of analysis applied in this thesis.

To begin, I restate that the aim of this thesis is to evaluate to evaluate current climate change policy in Australian agriculture and what type of policy consideration will more effectively engage grain farmers in reducing on-farm GHG emissions. It considers the inputs into the farming system and how the policy-management complex of those inputs affects the greenhouse gas outcomes and farm profitability. The farm inputs produce varying degrees of output which are in turn influenced by the various types of farming practices (e.g. no-till), social conditions (e.g. education) and macro-economic factors (e.g. cost of finance). In order to determine policy investment options to reduce greenhouse gas emissions, it is important to consider how a policy initiative (e.g. carbon tax) will impact on the influencing factors (e.g. price of fertiliser) to produce a different output (e.g. grain profit and reduced GHG). To estimate the degree of emissions reductions that can be gained from introducing new practices we need to include data from many parts of the process. This tells us that farm practices across the Australian grains industry is a highly complex system. The ‘systems’ paradigm referred to by Weinberg (1975) and Sherwood (2002) is concerned with wholes and their properties and every system has a purpose. The dryland farming system operates to produce food grain for export and is a source of input into livestock production or local food manufacturing. The farmers operating the system are motivated by a ‘reasonable’ level of profit that allows them to keep farming (Vanclay 2004). In the process of doing this they create a vital community resource, food; but they also create externalities over an area of some 23 million hectares. This outlined in detail in section 5.2.

The development of policy to create changes in practices to manage externalities would need to consider the complex set of drivers that creates farm practice change. It should be noted that historically practice change is more usually targeted at short term production benefit as opposed to long term risk associated with externalities (Feder and Umali 1993). A ‘system’ also consists of a number of interacting parts that influence the internal processes; in such agricultural systems there are inputs from suppliers, agronomic advisors, researchers, peer facilitators (grower groups), rural communities, grain buyers, government services and policy makers. A farming system is further affected by commodity markets, the weather and soil conditions.

In analysing such a complex system the research began by reviewing the literature on what is the current role of CA in Australian grain production. The literature is used to validate the personal observations of this author from direct involvement in a range of industry events. It was evident from the literature that CA in Australia had unique issues given its heavy reliance on technology and its geographical context of large scale production in an arid zone environment. It was also evident that gaps were present when emerging research on emissions indicated that Australian conditions could not rely entirely on research outcomes from other jurisdiction and Australian policy would need to take this into consideration (Dalal and Chan 2001; Schwenke 2005; Walcott et al. 2009; Chan et al. 2011; Maraseni and Cockfield 2011).

A systems-thinking approach was adopted to deal with the complex nature of the grain production system as it applies to an Australian context and the drivers that influence it (see Figure 24). This is intended to support the research question 3 looking into the factors that influence the adoption of CA. Managing complex world problems using systems-thinking has been outlined by a number of authors mostly in the business field as a means of testing solutions to complex business problems (Sterman 2000; Sherwood 2002; Maani and Maharaj 2004; Richmond 2004; Nguyen et al. 2011). It recognises the principle that a problem may be better understood and managed by examining the various interacting drivers of the system, rather than concentrating on an isolated part of the system. In this thesis a systems thinking model is used to analyse the factors that supports the adoption of various farm practices.

Understanding those drivers can assist us in the framing of agricultural policy that might create changes in practices. Agricultural policy decision to support emission reductions from farms also requires an understanding of the farm practices by industry sectors, what drives it and what impact it will have on emissions. The policy factors that drive the grains industry are not the same as the cattle, sugar or horticultural industry; hence the need for considering sectoral analysis such as limiting it to the grains industry.

I developed a systems model as per Sherwood (2002) to discuss and better understand the factors that influence changes in farm practice behaviour. I recognise that the development of policy requires policy makers to consider the history of events and the belief, values and assumptions of individuals and organisations that are likely to affect policy (Maani and Maharaj 2004; Nguyen et al. 2011). In this analysis the systems model will consider both the economic and social drivers that creates a change of behaviour towards practices that reduce net farm emissions.

3.4 Data collation and methods applied

The following section describes the data collation and methods by Research Questions. I accept that the information associated with GHG emissions by farmers' practices in some sectors is limited and would seem inadequate to support policy development in changing farming behaviour. In such circumstances the available data is still presented but a systems analysis is not conducted. In Chapter 6, systems models are presented on reducing tillage, stubble retention, control traffic farming and legume rotations, but not precision agriculture, recycling organics or cover cropping. The reason being there is insufficient reliable data to derive the model on the latter 3 practices at this time.

Further details of the methodology applied to derive the analysis are referred to in the corresponding chapters 2, 6 and 7 that are published as papers.

3.4.1 Research Question 1 - What is the current role of Conservation Agriculture in grain farming enterprises in Australia?

Participant observation and literature review was used to collect data to address Research Question 1 of this thesis. The literature (including general, industry, Government reports and policies, text books and peer reviewed journals) provide useful information in terms of current issues in CA. I also decided to engage with the dryland farming sector more fully by attending industry conferences and workshops, visiting farms directly to gain in-depth details and talk to industry researchers, industry practitioners, CA farming executives and farmers to gain a clearer picture of what is happening on the ground. Quantitative industry datasets (e.g. Grains Research Development Corporation and ABARES surveys) were also used, in combination with participatory observation.

The specific activities I undertook as part of this participatory observation method included;

- Attended an Australian Control Traffic Farming Meeting on 23 March 2010.
- Visited a farm in WA and talked with owners, manager and consulting staff in detail over a 2 day period. 19-20th October 2010
- Being on the organising committee for the 5th World Congress of Conservation Agriculture held in Brisbane on the 26-29 September in 2011. This provided wide access to CA industry participants and researchers from 2010 to 2011.
- Attended Manure recycling and spreading farmer field day Darling Downs on 21st October 2011
- Attended a Precision Agriculture Conference at the Twin Waters Qld on 16-18 February 2012
- Met with Umbers Rural (Farmer & Agricultural Consultant Grenfell NSW) in Canberra on 21st November 2012 to discuss GRDC practices survey an industry views in regards to emissions reductions
- Attended South Australian No-Till farmers Conference in Tanunda South Australia on 22 February 2013 to talk to farmers and industry
- Attended meetings with Victorian No-Till Farmers Association on three occasions in Horsham 11-13 October 2012, Melbourne 25th March 2013 and Birchip on 25-26 August 2013 speaking to farmers.
- Attended meetings with Conservation Agriculture and No-Till Farmers Association in Wellington NSW on 7 February 2013
- Attended the 1st International Control Traffic Farming Conference held in Toowoomba Queensland on 25-27 February 2013
- Attended a strategic Tillage farmer field day on 25th June 2013
- Visited farmers locally, August 2012, December 2012, 23 June 2013, July 2013

The validity of this document and discourse analysis was checked by triangulating the data collated with data collected through semi-structured interviews with 31 farmers and six industry experts, and a review of current government publications, reported surveys and peer reviewed literature in this area. The practices being observed as part of the grains industry were tillage practices, stubble management, control traffic farming, legume crop rotations, cover cropping, precision agriculture and the use of recycled organics.

The response to Research Question 1 'what is the current role of Conservation Agriculture in grain farming enterprises in Australia?' is reported as part of a book chapter entitled 'Conservation Agriculture in Australian Dryland[12] Cropping' and can be found in *Conservation Agriculture: Global Prospects and Challenge*, for the International Crops Research Institute for the Semi-Arid Tropics and Food and Agriculture Organization, Published by CAB International, UK.

Research Question 1 is also partly discussed in a paper I co-authored on the role of Australian Conservation Agriculture practices for the Organisation for Economic Co-operation and Development (OECD) for the 35th session of the Joint Working Party on Agriculture and the Environment in April 2013. The report is entitled 'An Analysis of the Impacts of Conservation Agriculture Practices on Resource Productivity and Efficiency in Australian Cropping'. The report is not included as part of this thesis, and is yet to be released.

3.4.2 Research Question 2 - How does Conservation Agriculture influence greenhouse gas emissions from dryland farming enterprises in Australia?

The method of analysis used to answer Research Question 2 relied on document analysis of literature from industry and Government publications and technical reports from research institutions and journal articles. Data on emissions were sourced principally from government publications dealing with a broad range of farm practices not always related to CA. The various reports are collated to cover greenhouse gas emissions from those specific CA practices such as tillage or stubble management outlined previously in Research Question 1. Where available, industry data on farm practices survey such as fuel consumption, chemical and fertiliser use is also collated to support details of practices in the current Australian context. The emissions characteristic of a practice on grain farms is reviewed in the

[12] Note: The vast majority of Australian grain production is dryland, hence representative of grain farming enterprises.

international academic literature for validation. There are a number of direct links reported in the international literature including reports from the UNFCC on farm practices and production inputs in relation to levels of emissions. The Australian context derived from the previous research question is examined in terms of the emissions characteristics for CA and non-CA farm practices. The data is collated to form a picture of the current understanding of the emissions profiles of various CA farming practices to allow us to compare the value of changes in practices.

The data collection and analysis methods used to answer Research Question 2, 'how does CA influences greenhouse gas emissions from dryland farming enterprises in Australia?' are outlined in detail within Chapter Four of this thesis and notably in the paper titled 'A study of developing carbon offset projects using conservation tillage on grain farms in northern Australia', which is currently under review in the journal *Agroecology and Sustainable Food Systems*. An examination of the international literature in regards to CA and emissions characteristics is also reported within another paper entitled 'Opportunities to produce carbon offsets using conservation farming practices in developing countries', published in the *Annals of Tropical Research*, vol. 33, no. 1, p. 85-101 in 2011. Chapter Four of this thesis also reviews the literature to consider emission reporting issues in dealing with the variables that impact on greenhouse gas emissions from farming practices.

3.4.3 Research Question 3 - What factors influence adoption of Conservation Agricultural practices in Australian grain production?

Research Question 3 was addressed using two methods; first; data was collected from semi-structured interviews with farmers and industry advisors, and second, a review of the literature on adoption and the factors likely to act as drivers for change (e.g. social concern) or constraints (e.g. economics) was undertaken. The review provides the basis for the questions but also for reflecting on the responses. The factors are framed into a systems analysis using Causal Loop Diagrams (Weinberg 1975; Checkland 1999; Sherwood 2002; Maani and Maharaj 2004; Bosch et al. 2007).

The theory of technological and practice change adoption is well covered in the literature and I used this as a platform to examine the research question. I have examined farmer's behaviour and operational practices from direct observations on farm, supported by practices survey and industry publication. Research Question 3 is answered based on the scientific literature as a means of validating my observation and industry reports. Where there is uncertainty in interpretation this is explicitly stated in cautionary statements within the text. The main theory examined for practice change requirement correlated with rate of adoption is that of Rogers Diffusion of Innovation model (Rogers 2003). I also note that a number of technical adoption observations do not fit a typical sigmoid adoption curve evident from Rogers' theory but they also did not match some of the requirements for the model proposed by Rogers. The reason as to why this may be the case is discussed in Chapter Five.

I have further included the concept of a systems model as a means of interpreting the various socio-economic drivers that influence the adoption of CA. Changes in a system such as agriculture interact in complex ways, so I developed a series of systems models to visually describe the main factors that drive the adoption of CA practices in Australia. Applying 'systems thinking' to an issue helps us understand the interactions that drive adoption in complex situations (Sterman 2000; Quan Van and Nam Cao 2013). I have summarised the variables from chapter 4 in a series of visual model to explain the interactive factors that support change of practices (Bosch et al. 2007; BeLue et al. 2012). Representative mental model are used in a range of disciplines to identify how a system operates and how they might interact, thereby provide a framework to manage change by understanding dynamic feedback (Sherwood 2002). To develop this framework I use Causal Loop Diagrams (CLDs) consisting of identified variables and arrows that represent causal relationships between variables as either (+) or (–) (Ventana-Systems 2013). This is described in a paper entitled 'An analysis of the socio-economic factors influencing the adoption of conservation agriculture as a climate change mitigation activity in Australian dryland grain production'; this paper has been accepted with revisions in the journal *Agricultural Systems*. This paper is included as Chapter Six of this thesis.

Note that although the literature provides an important framework for this analysis, not all of the factors for change are covered in the literature, nor are they contextualised to current Australian conditions. I therefore also used semi-structured interviews with CA farmers to determine what influenced their decisions for practice change. From across Australia's diverse farming regions, I interviewed 31 farmers who were willing to take part in an extended conversation as to what led them to adopt or not adopt each of the CA practices in their area. The research approach I applied is known as phenomenography with CA perceived as a phenomena (Marton 1981). The number of interviews was limited by cost and my ability to cover the large geographical spread of the Australian grain belt to talk with farmers face to face. The details of the interview formats are outlined in the methodology description presented in the paper in Chapter Six.

Further data was collected from case studies of specific farms. For example several days was spent at “Bungulla Farming” in WA where a detailed case study of the operations of the farm was conducted. The results of this case study were presented at the following conference:

Rochecouste, J., Jones, B. and Betti, J. 2011, 'Managing crop production uncertainties and climate variability through a map-based system – WA case study', presented to The Climate Change Research Strategy for Primary Industries (CCRSPI) Conference 2011, Melbourne, 14-17 February 2011.

The learnings from this case study was that the owners are aware of significant risk scenario presented by a changing climate and rising input costs of fuel and fertiliser. With limited investment resources it was necessary to clearly identify risk in terms of likelihood plus impact, and management options for investment. This presentation identifies critical points of production failure and demonstrate the use of a map based system using spatial data as a tool to collate and analyse production variables across 70 paddock zones. Each critical operation sought to have relevant spatial layers from remote and proximal sensors that allowed managers to analyse issues for discussion with advisors. The layers are used to implement prescriptive farming systems using variable rate controllers. Efficiency was based not only on demonstrated reduce inputs (e.g. fertiliser, chemicals) but speed of operation to allow for example an investment in fertiliser application on a predicted rain-front rather than a pre-set operation.

The scenario of changing climatic conditions (dry years) allows the farm manager to invest resources on better performing paddocks.

The interactive data layers included such things as:

- Soil type proximal EM38 (completed)
- Crop history & yield (historical available)
- Topography (completed)
- Vegetation (completed)

- Fertiliser variable inputs (available)
- Chemical variable inputs using Weedseeker (in progress)
- Soil moisture (in progress)
- Weed population (in progress)
- Disease population (in progress)
- Waterways & drainage (completed)
- Fuel use in map form (in progress)
- Financial return by paddock (in progress)

Some current problems include layers not being interactive on one system, nevertheless the investment in this process has demonstrated substantial savings in terms of fertiliser/fuel inputs but more significantly it has reduced the risk profile to manage inputs away from unreliable mid-term forecast. It allows operation to operate more effectively on more reliable short term forecast, as expensive inputs can be held back longer towards critical timing points.

In other conversations with farmers where they have supplied sensitive or personal information as part of the case studies presented in this thesis, the names of the farmers involved have been kept confidential. Other case studies where data was collated were from Rodney & Margaret Hamilton "Callitris" in Condamine 4416 Queensland and Peter and Nikki Thompson of "Echo Hills farming Co." in Wallumbilla Qld 4428.

3.3.4 Research Question 4 - What climate Change policies are likely to increase adoption of CA in Australia?

CA is a phenomenon that implies a particular constructed view of how agriculture should operate. The CA movement began by challenging traditional agricultural practices that were seen to be contributing to land degradation (Phillips and Young 1973) and became a movement for reform on farm management practices. It has distinct principles such as reducing tillage and retaining crop residues that is consequently reflected in reduced emissions profiles for agriculture. I am not primarily concerned with how the phenomenon evolved or its purpose, but how it impacts on GHG emissions and carbon sequestration into the future and what are the factors that might drive it in policy terms.

I have outlined a number of potential opportunities for CA in the preceding Sections 1.2.4 and 1.2.5, and further details are provided in Chapter 4 and Chapter 6. I am particularly interested in the response of farmers to the prospect of them changing their practices specifically for the purposes of capturing a carbon market opportunity. I have sought to answer this Research Question by engaging in direct dialogue with farmers and farming industry experts on how farmers respond to Market Based Instruments (MBI), which is the current policy model offered by the Australian Government.

The Australian Government's current Carbon Farming Initiative (CFI) is a recent and relatively complex piece of legislation and Australian farmers are still unfamiliar with MBIs in general as they are not widespread and still relatively new to land management (Whitten et al. 2004). To determine their response to an environmental service market, such as the CFI, I believe a qualitative approach is a useful means of analysing complex responses (Patton 2002; Maraseni and Dargusch 2008; Schirmer and Bull 2014). I looked at how farmers respond to an economic offer accepting that there is limited opportunity to cover the contract details, as there are limited emissions reduction methodologies presently in place for the Australian grains industry. I accept that farmers are unlikely to be aware of the details of the methodologies being developed (e.g. biochar), but there is some awareness of established methodologies (e.g. tree plantings) from the general media. I interviewed industry professionals who have a more detailed grasp of the CFI legislation and who work with farmers to add some insights from their on-ground experience with clients.

I applied a phenomenographic approach in interviewing 31 farmers and 6 industry professionals on the CFI opportunities and how such a policy is likely to be received (Marton 1981). This methodology has been used in the health sector to understand a patient's experience of various phenomena (Barnard et al. 1999). The value of qualitative research as part of this approach is that it allows broad views into intention to be assessed based on a 'phenomenon', in this research I am attempting to determine the constraints to 'participating in a carbon offset MBI' (Maraseni and Dargusch 2008). The interview structure is based on qualitative interviewing using an 'Interview Guide' approach as per Patton (2002). The interview questions are open-ended and based on a guided format to ensure the same basic lines of enquiry (themes) are pursued for each farmer. This provides some structural similarity but allows for individual perspectives and experiences to emerge. If farmers wanted to expand their views into a broader range of comments, they were encouraged to do so (Patton 2002). I did not believe it was necessary to explain all the details of the CFI market function to the farmers as I hope to capture the farming community's current interpretation of government policy. At present, the only carbon abatement methodology for dryland crop farmers involves environmental plantings on non-cropped land, which require farmers to hand over the rights of their non-cropped land to the project proponent under section 27 of the CFI Act 2011.

The data being collected for analysis uses second-order interpretation, that is, the meanings of the responses are grouped into summary responses for reporting on general trends (Tracy 2013). The discourses of the research are retained via transcribed recordings allowing the research to focus on people's understanding and interpretation of the carbon offset market and feelings towards these types of MBIs (Rapley 2007).

The interview process operated in different parts of the dryland cropping region: Western Australia (7), South Australia (11), Victoria (4), New South Wales (3) and Queensland (6). For the districts involved, the precipitation varied from 250 mm to 600 mm annual rainfall and the crops grown were wheat, oats, barley, sorghum, corn, mung beans, canola, faba beans, lentils, chickpeas and lupins. Some had mixed livestock enterprises, but none were exclusively livestock. Interviewees were asked about how they perceived the value of their non-cropped land, what role such land played as part of their enterprise, and whether they would be willing to be involved in a sponsorship agreement to provide vegetation services (tree planting) for financial benefit on their non-cropped land? The need for a legal covenant requirement of approximately 100 years was included in the explanation. They were further asked to elaborate on the reasons for either participating or not wanting to participate. The interview process did not elaborate on the soil carbon offset area as there is no detailed methodology that could be offered as part of the discussion and farmers did not seem to have an in-depth knowledge of how the CFI functions. The recorded interviews were typically 30 minutes and farmers were encouraged to expand their views based on the standard series of questions. The Australian Landcare vegetation program was used as a familiar concept of payment for environmental services, including the legal requirement for a covenant. The farmers were predominantly but not exclusively male, with a mix of ages though predominantly older. Specific age was not requested.

The industry professionals were from various agricultural industry positions and understood both the CFI and the farming constituency. They were asked to broadly explain how they perceived farmers would react to an offset scheme regarding tree planting, but also share their thoughts on their client's likely engagement to soil carbon projects. They were encouraged to elaborate why they believed their farmer clients would or would not participate in a CFI carbon offset scheme, based on their knowledge of the legislation and their close link with farmers.

The results of these interviews were incorporated in a paper as part of chapter 7.

3.4 The farm as a system boundary for emissions

In this thesis, I set a boundary around the emissions of farming practices to ensure the system I am examining are the farm variables that can be influenced by the farmer or farm manager. They involve factors that can influence the flow of GHG emissions or sequestration to the extent that farmers have the opportunity to change that flow by choosing a different product, introducing a new technology or adopting a change in practice. The choice for this boundary is that factors beyond the farmer's control have no effective role in farm targeted policy. Environmental policy targeted at farmers is intended to create changes in resource outcome, but it can only do so where a farmer's choice is applicable to that resource outcome. The focus of this study relates to the role of CA and is targeted to policies that influence a farmer's behaviour and agronomic practice choice. Policy in this area is complex and the outcomes uncertain due to various influential factors, including the economic output of farms, the varied forms of farming enterprises and the varied environmental landscape in which farms operate.

Boundaries also relates to the scopes of emissions. In order to avoid double accounting the Australian Department of Climate Change issues boundaries on scopes of emissions based on international standards. The emissions standards are as follows;

Scope 1 emissions[13]: The release of GHG into the atmosphere as a direct result of activities at a facility, which in this study is the farm business. This does not include external contractors whose operations are not under the control of the farm business.

[13] NGERS (Measurement) Technical Guidelines 2010 Page 22

Scope 2 emissions[14]: The release of GHG into the atmosphere as a result of electricity generation, heating, cooling or steam that is consumed by a facility. This relates to farm in relation to electricity use on farm for machinery maintenance, grain drying and pumps.

Scope 3 emissions: The release of GHG into the atmosphere that is generated in the wider economy as a consequence of a facility's activities but that are physically produced by another facility. These might include the manufacture of fertiliser, herbicides, seeds and machinery.

The farm boundary is related primarily to scope 1 emissions that relate to policy initiatives impacting on farm practices. Scope 2 emissions play a limited role in farm policy frameworks for dryland cropping unlike irrigators or horticultural producers, because they are not major users of electricity. Factors affecting electricity consumption will impact on all consumers and is covered by policy related to the stationery electricity generation industry. Some consideration is given to scope 3 emissions in our discussion as some policy options may include mandatory reporting of energy consumption in the manufacture of farm inputs. This may provide farmers with a choice of products that have a lower carbon footprint, although this option is not prevalent at this time.

The premise on which the boundaries are based is that policy initiatives directed at farmers can only really be concerned with factors that are within the scope of the farmers to change. The embedded energy in the production of machinery, fertilisers and chemicals are ultimately the responsibility of the manufacturers who should be required to pay emissions liabilities within their own jurisdiction. Such manufacturers may also have offset their energy liability within their product, but this may not be known unless they are required to report on it. A farmer using a brand of fertiliser or herbicide as a matter of necessity would not be aware if the imbedded energy in the product they have chosen has been offset by the manufacturer. This is an important distinction to consider; as an example, policy to reduce tillage inevitably leads to an increase in the use herbicides to control weeds. The imbedded energy of current herbicides may be known, but is not reported by the manufacturers. Manufacturers in a competitive environment are constantly adjusting formulation and processes, so energy data would need to be updated in line with those changes. Helsel (1992) reported on the energy requirement in the manufacture of a range of pesticides at the time which highlighted their

[14] NGERS (Measurement) Technical Guidelines 2010 Page 27

variation (Table 4) (Helsel 1992) and it is clear that their emissions impact is also dependent on the extent of their deployment. Current energy figures on the production of individual herbicides are not readily available from manufacturers.

Table 4 Embedded energy of some grain production herbicides calculated to emissions per hectare by Helsel (1992)

Herbicide	Energy inputs Gj/mt of a.i.	1L Diesel energy Mj	Diesel equivalent per kg of a.i.	Formulation	rate/ hectare	rate of a.i./ hectare	Diesel (L) equivalent per	Emissions Kg of CO2e/hectare
RoundUp	454	43.1	10.5	0.45	1.3	0.585	6.2	16.6
MCPA	130	43.1	3.0	0.5	0.5	0.25	0.8	2.0
2,4-D	85	43.1	2.0	0.5	0.7	0.35	0.7	1.9
Atrazine	190	43.1	4.4	0.9	3	2.7	11.9	32.1

NOTE: Gj = Gigajoules, a.i. = active ingredient, Mj = Megajoules,

Farmers are unlikely to be aware of the energy footprint of the herbicides they use, but they are clearly aware of its costs. The product life cycle system of analysis is an important consideration in terms of emissions across the supply chain to avoid policy distortions, but of equal importance is farmer behaviour. Agricultural policy targeted at the local level is generally more concerned with farmer behaviour than their international suppliers.

4.0 THE VARIABLES INFLUENCING GREENHOUSE GAS EMISSIONS ON DRYLAND GRAIN FARMS

In this Chapter I explore emissions from Australian grain farms as they relate to CA practices. I also consider if there are new environmental accounting systems that may influence agricultural policy impacting on the farm. I consider what the reason for intervention is, and if there is to be an intervention, what should the approach be and why such an approach is relevant. Given current established policies of a market-based instrument I consider what the reporting issues are for farmers participating. I also look at the sequestration factor as the other side of the ledger to emissions; especially given the government's interest in soil carbon as a role for agriculture.

Further, I look at current practices and examine the individual CA practices; namely reducing tillage, stubble retention, fertiliser management, reducing soil compaction by controlling farm machinery traffic, the inclusion of legumes in rotation or a green manure crops, emerging use of digital technology in the form of 'Precision Agriculture' and the use of recycled organics from waste streams. I explore policy considerations in relation to agricultural practices and the implication of data variability in reporting.

The final section of the chapter reviews the various practices in the farming system and the potential emissions and sequestration opportunities they represent.

4.1 Research approach

As this research is predominantly a policy analysis of the role of CA; the determination of what variables influence GHG emissions from the grains industry is based on a review of the technical literature specifically for CA practices. Some CA practices such as tillage reduction and stubble retention are well known and extensively discussed in the literature, other practices such as Control Traffic Farming, cover cropping are less well known and more limited in the available data. This chapter intends to collate the known facts in regards emissions and sequestration potentials from current CA practices.

4.2 New potential environmental accounting system

Changes to accounting for emissions are also being proposed by various parties internationally that will likely impact on the reporting process around the carbon accounting system. A new System of Environmental-Economic Accounting (SEEA) was accepted as part of the international statistical standard by the United Nations Statistical Commission at its 43rd meeting, held 28 February 2012. This means that the SEEA now has the same status as the System of National Accounts favoured by the IPCC. The Australian Bureau of Statistics (ABS) is looking at aligning their SEEA accounts and the Department of Climate Change and Energy Efficiency's Kyoto protocol based accounts. It intends for both account systems to be produced as part of the set of environmental-economic accounts. They are also considering looking at emissions in terms of final consumption. Therefore agricultural production will be attributed to the final consumer using environmentally extended 'input-output' analysis (Australian Bureau of Statistics 2012) (figure 2).

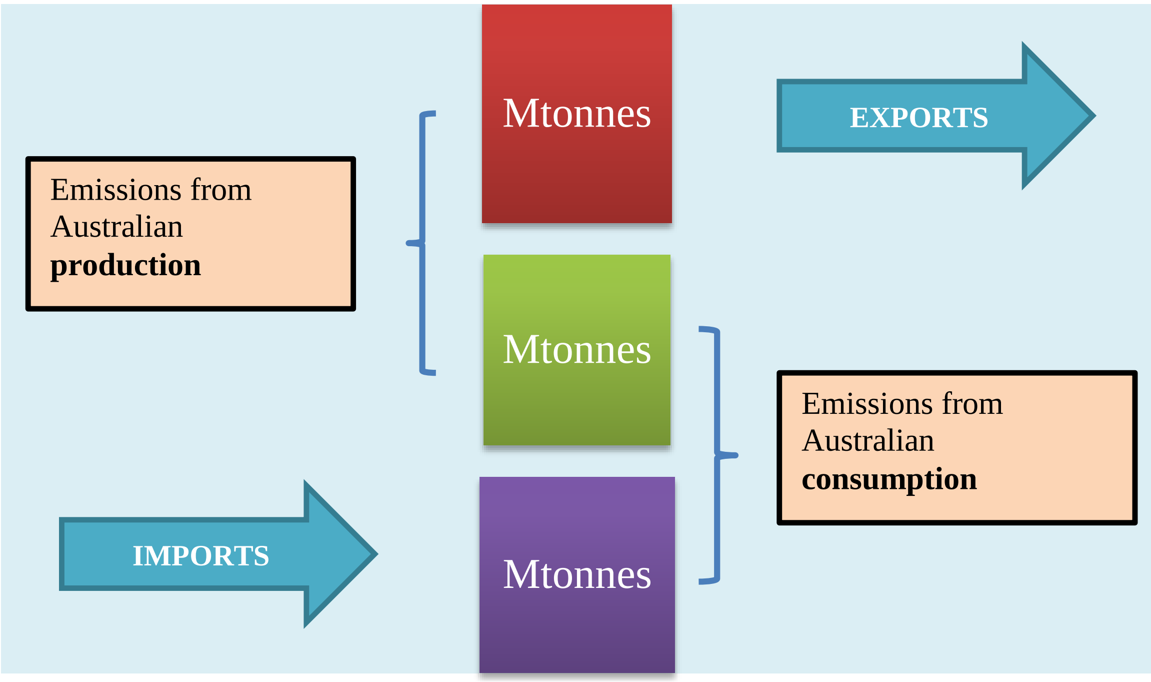


Figure 2 Production and consumption approaches to GHG measurements (adapted from The Australian Bureau of Statistics)

The proposed shift of focus to consumption reporting is based on the premise that ultimately industries exist to satisfy consumption in Australia and abroad. It is also intended to address issues of leakage by considering the environmental cost of a country by considering its environmental balance of trade.

In terms of the land sector it may lead to the use of carbon stock accounts from carbon carrying capacity (land stock) and land use history (depletion of stock) to consider:

- Depleting carbon stocks due to changing natural systems to agriculture

- Land restoration value versus food and fibre production
- Land uses that result in temporary carbon removal and storage

However the accounts are considered, different farming practices will result in different emissions and carbon storage profiles which is in turn influenced by the decisions the farmer makes on farm.

4.3 Farm Greenhouse Gas emissions and the need for policy intervention

With sunlight, grain crops take up atmospheric carbon dioxide in the process of 'photosynthesis' to produce oxygen to assimilate sugars, and then at night during 'respiration' the oxygen is combined with sugars or fat in living cells to release water, CO_2 and energy required by the plant. The cycle favours carbon based biomass and in the process produces an excess of oxygen. This process is one of the main ways in which atmospheric CO_2 moves into other carbon pools (Hartman et al. 1981). Plants are approximately 40% carbon sequestered from the atmosphere (Ho 1976) but the sequestered carbon is short lived in annual grain crops, and a only small fraction moves into the soil carbon pool (Wang and Dalal 2006). The policy implication of this is that plants are still the main pathway for removing atmospheric carbon over which we have some control (Miller 2005). The grain portion of the crop is used as an energy source for human or animal consumption.

In generating the grain, the farm can be both an 'emitter' in terms of fuel use, mineralisation of soil organic matter, applied fertiliser or the breakdown of crop residue. It can also be a 'sink' with the atmospheric carbon moving into the soil pool (pedosphere) via plant decay, noting that the atmospheric carbon moves into the soil matrix via microbial decomposition and assimilation into both resilient and labile carbon pools. The process of plant decay is then also a source of emissions. This balance can be influenced by farm practices and is the subject of policy consideration in terms of national carbon accounting.

If farms can be both a 'source' of GHG emissions and a 'sink' for atmospheric carbon; how can farms participate in mitigating climate change? Jonge (2010) interviewed farmers in South Australia and 50% did not believe in, or were undecided about, the necessity to respond to climate change and 90% indicated that if they were required to respond to climate change it would be easier if there were financial incentives to do so (Jonge 2010). On the premise that only a small percentage of farmers will voluntarily make changes to mitigate their emissions at a cost to them for a broader public benefit; I consider policy intervention by government as the main driver to creating change in behaviour. There are two broad policy directions that can be pursued to minimise the impact of farming on climate change; the first is to consider policy that encourage farmers to reduce existing emissions, and the second to encourage farmers to take up sequestration opportunities. This can be sought by means of regulation using legislation, market based instrument such as a ‘carbon offset’ market, incentive payments or education. All four instruments require some form of measurement from which to gauge the effectiveness of the policy. Governments often pursue a combination of these policy initiatives to manage the potentially long time frames and the likely uncertainty in outcomes (Hanley 2001; Horan and Shortle 2001; Lal et al. 2009). In the industrial sector, policy might consider supporting ‘avoided emissions’ by encouraging a reductions in emissions to below a *business as usual* standard, by for example: switching to renewable energy or participate in offset markets (Whittington 2002). Offset markets in turn can be based on ‘avoided emissions’ or sequestration (Ribon and Scott 2007).

Simple measurement of farm emissions is not always possible due to the inherent nature of farm emissions such as N_2O emissions being bio-chemically based and the need for specialised equipment to do the measuring (Smith et al. 2000; Schwenke et al. 2011). As a consequence it is not likely to be clear to farm operators what exactly is their emissions profile during their daily activities or indeed what it should be operating at. It is therefore not surprising that farm practices decision is based on factors such as input price, convenience or productivity. Without some form of policy intervention it is most likely that farmers will continue to operate simply on production goals. Although some activities such as reducing energy inputs may well have aligned goals with emissions reductions; their perceived value in terms of targeted management is also likely to be different. It may be reasonable to expect farmers to want to cut energy costs but other production factors may be more critical. The choice of farm machinery for fuel efficiency may not be as important as having sufficient power to get all the planting operations done within a window of opportunity dictated by the weather. Farmers may manage immediate individual risks (loss of crop opportunity) ahead of long term community risks (climate change).

Policy intervention is inevitably required to manage long term community risks since individuals will seek to improve their position by reducing their personal risk ahead of the community good. This was evident in the behaviour of wheat producers of the American mid-west during the 1930s when the price of wheat fell sharply due to reduced demand during an economic downturn (the Great Depression), producers responded by increasing production to make up their income shortfall and in the process increased available supply resulting in further decreases in wheat prices (Russell 1988). In current terms simply educating farmers about the long term risk associated with climate change is likely to be insufficient to create widespread farm practice change, especially if those changes are likely to limit their immediate opportunities. It will inevitably require some form of political intervention in terms of a Market Based Instrument or regulatory processes.

4.4 Emissions factors of farming operations and the need for a farming systems approach

Policy to manage the externalities of GHG emissions needs to consider how they were produced. Scope 1 emissions as a direct result of on-farm activities can be highly variable due to climate and bio-physical factors but also other operational factors such as the extent of the use of contractors that supply such services as spraying, harvesting and to a lesser extent planting. Contractors play an important role in farming, but the pattern of use is highly variable. Some farmers will have some operations (e.g. spraying) totally devoted to contractors and others will only use them when needed. From an emissions accounting point of view the use of contractors is a complex demarcation area because the type of machinery used by the contractor and its energy output is not under the control of the farm business, but the soil emissions from planting operation as performed by the contractor is at the direction of the farmer. Therefore clear demarcation lines on operational control relating to emissions can become a bit blurred under the IPCC carbon accounting system.

Furthermore emissions on farm can be concerned with farming ‘operation’ such as tractor operation or it can be viewed from a farming ‘practice’ perspective which incorporates a range of operations such as a ‘no-till’ versus a ‘conventional’ planting system. The value of perceiving emissions from a ‘farming systems’ perspective rather than simply a farm operation is that farmers have a diverse range of machinery and infrastructure but communicate between themselves around improving farming systems[15] (Allmaras and

[15] CSIRO farming systems research group. http://www.csiro.au/Outcomes/Food-and-Agriculture/Farming-systems.aspx

Dowdy 1985; Dent and McGregor 1994; Cornish and Kelleher 1996; Crawford 2004). The size of their planters may differ significantly but the way in which the machine is deployed to achieve successful plant establishment has common ground for discussion, therefore it is a much more engaging issue for farmers. The systems approach is more commonly used by agronomists and agricultural researches in their dealing with farmers. Policy can be concerned with influencing either 'individual farm operations' or 'farming systems', this research considers that policy influencing farming systems as a collective of operations provides a better option to engage farmers.

Emissions from the 'operational' component of the farm is more effectively analysed under life-cycle assessment analysis (Biswas and John 2009; Brock et al. 2012) or by the use of farming carbon calculators; whereas the 'systems' approach looks at a collective of operations from which the farmer perceives an outcome for his or herself. The differences between the two approaches is that 'operational accounting' provides a better emissions accounting framework by reducing overlap, but the systems approach is better suited to creating changes in behaviour given that is the preferred extension model of the industry. The major emissions from farming enterprises are outlined in Table 5.

Table 5 Major reported emissions sources from farm operation (Biswas and John 2009; Eckard and Armstrong 2009)

Farm operation	Emissions
On farm transport; tractors, trucks, vehicles	CO_2 (transport sector)
Tillage; tractor and soil emissions	CO_2, CH_4 and N_2O (sector mix)
Fertiliser application, Legume rotations, stubble retention and leaching of inorganic nitrogen	N_2O (agriculture sector)
Stubble burning	CO_2 , CH_4 and N_2O (agriculture sector)

Because many of the emissions from farm operations cannot be easily measured without complex scientific instruments; the IPCC also provides default guidelines of emissions factors to allow for calculation of certain emissions from various on-farm sources (Table 6). It is used primarily to estimate N_2O emissions as inputs into the global atmospheric pool operating as a simple box model (Smith et al. 2000). N_2O is the main emissions source for cropping agriculture and has a global warming potential of 310 relative to CO_2 (Forster et al. 2007). CO_2 from farm machinery is reported in the transport sector and CO_2 emissions from crop residue burning is much less than N_2O from soils in Australia and can be more consistently estimated.

Table 6 IPCC Default Method for Calculating N_2O Emissions from Direct Sources

Source	N content	Emissions Factor
Crop production – Synthetic N fertilisers	Amount of N applied – 10% NH_3 + N_2O loss	1.0%
Animal waste used as fertiliser & other organic fertilisers	Amount of N applied – 20% NH_3 + N_2O loss	1.25%
Biological nitrogen fixation	Amount of N is 2 – harvested crop biomass – N content (3%) for pulses and soybeans	1.25%
Crop residues	Amount of N is 2 – harvested crop – N content minus harvested parts (45%) minus fraction of crop residue that is burnt in fields < 10%	1.2%
Cultivation of organic soils (not prevalent in Australia)	Area of cultivated organic soils	Temperate regions: 5kg N_2O-N ha^{-1} y^{-1}

In 2006 the IPCC changed the emissions factor for N_2O to 1% based on more updated information (De Klein et al. 2006). Even with this change the default factors do not reflect conditions in Australia's cereal belt which experiences limited seasonal rainfall. If microbial activity is a driver of N_2O emissions than lack of moisture would be expected to suppress those emissions (Galbally et al. 2010). Barton et al. (2008) report that in Western Australia's cropping region the measured emissions factor for N_2O was 60 times lower (0.02%) than the new IPCC default value of 1% and they suggest that the default values are not appropriate for semi-arid regions (Barton et al. 2008; Galbally et al. 2008). Trials in Eastern Australia with slightly higher seasonal rainfall report slightly higher emissions values around 0.45% (Schwenke et al. 2011; Brock et al. 2012). In a review of N_2O emissions from Australian agriculture Dalal et al. (2003) report the range of emissions in grain cropping as varying from nil to 9.9% depending on a range of environmental factors. N_2O is the most significant emissions factor for Australian cropping in our national accounts and the current research suggests that Australia's semi-arid climate may well be over-reporting N_2O emissions if based on IPCC default factors for emissions from soils. From a policy perspective the grains industry has an emissions profile that is not readily measurable in terms of reporting (Dalal et al. 2003; Thamo et al. 2013).

At present agriculture emissions does not account for scope 3 emissions, and from a policy perspective attempts on reducing emissions into the future remains focussed on farm activities. If we take scope 3 into account than from a Life Cycle Analysis (LCA) perspective, a typical tonne of wheat has 45.3% of its emissions from pre-farm input production emissions (Brock et al. 2012). How reliable the energy of production figures are is difficult to say; input products such as herbicides are manufactured in different parts of the world and companies do not readily supply information on their energy cost of production or if they have offset the emissions liabilities of their product in some form.

In the current reporting context the extent of emissions from Australian agriculture accounted for 85.2 million tonnes CO_2e or 15.58% of the national inventory in March 2012 excluding Land Use, Land Use Change & Forestry (LULUCF). The Australian National Greenhouse Gas Accounts record emissions from cropping primarily as N_2O from Agricultural soils estimated at 15.8 million tonnes CO_2e or 2.8% of the national inventory. Field burning of agricultural residues is less than 1% of the national inventory for 2012 (DCCEE 2013). Machinery Diesel is accounted for under the transport sector and not included in agricultural emissions. The emissions of methane CH_4 and N_2O relate to the decay process of organic matter in the soil and is influenced by human activity including cultivation, the addition of organic as well as inorganic fertilisers and deliberate burning of crop residue (DCCEE 2013). The main factors to reduce scope 1 emissions in terms of Australia's national accounts require a reductions in the amount of tillage that involves the mineralisation of organic matter, a reductions in the demand for inorganic fertiliser that create fugitive N_2O emissions and to reduce the level of residue burning. Farmers are unlikely to respond to suggestions that they should reduce tillage, apply less fertiliser and stop burning crop residues without a sound business reason. Given the time and cost involved in tillage and fertiliser application it is reasonable to assume that farmers have business reasons for doing so, albeit those reasons may not necessarily be optimal, but it will continue if they believe it to be necessary (Vanclay

2004). Therefore the answer to changing practices would need to address the underlying agronomic and profitability issues for the practice. This needs to be pursued in a way that does not adversely impact on the farming sector or food production, hence the need for a ‘systems’ approach.

Cropping agriculture as a source of emissions is essentially dealing with two biological cycles; the carbon cycle and the nitrogen cycle. This increases the complexity of agricultural emissions as the two cycles are interlinked in a complex system. Increasing plant biomass required for increasing SOC requires adequate levels of nitrogen, phosphorus and sulphur (Lal et al. 2004a). However Cogle et al. also point out that adding carbon to a soil system can increase denitrification (Cogle et al. 1987b). Furthermore the cycles are both temperature and moisture dependent, which in the Australian context is highly variable. The pursuit of policy targeted at such complex systems has a risk of unintended consequences if aspects of the system being considered are not clearly understood. Beyond targeting emissions there are other environmental consequences such as salinity, land degradation, offsite pollution and loss of biodiversity that also needs to be considered as an important part of the landscape assets.

The reason for pursuing a system’s approach is to achieve a more in depth understanding of the factors that influence changes in farm practices that will reduce emissions from the sector. Systems approach has also been used to manage other forms of environmental externalities in agriculture such as chemical drift into waterways (Collins 2012).

4.5 Reporting issues for agricultural emissions

As previously outlined the major sources of emissions in agriculture are from non-mechanical sources such as the bio-chemical process that occur in soils or enteric fermentation in the gut of grazing ruminants. To better understand the inherent reliability and accuracy of reporting, the advantages and disadvantages of the means of calculating emissions are outlined by Russell (2011) in a working paper on Corporate GHG Inventories for the Agricultural Sector (Table 7).

Table 7 Approaches for calculating GHG emissions from non-mechanical emissions within the agricultural sector adapted from (Russell 2011)

Approach	Advantage	Disadvantages
Direct field measurements	Accurate with high levels of sampling	Technical capacity required, Determination of measurable variable, Expensive, Time consuming
Emissions factors quantified as a function of farming activity	Inexpensive, Easy to use	Low accuracy, Does not account for environmental changes
Empirical models constructed from statistical relationships between empirical GHG data and management factors	Inexpensive, Low to medium accuracy	Potential data gaps for all agro-ecological zones
Process-oriented models using mathematical representation of bio-geochemical processes that drive GHG emissions	Medium to high accuracy with good models, More flexible approach	Requires large data sets, Expensive with high technical requirements to establish

Non-mechanical emissions such as methane and nitrous oxide losses from soils are expensive and complicated to measure on a regular basis, which means that agricultural emissions are predominantly based on estimates. Countries can modify the IPCC Emissions Factor where they have data that suggest their condition differs. In the recent National Inventory Report (NIR) 2010 for Australia, The application of synthetic fertiliser and animal waste has been revised for Australian conditions. Since more than 75% of Australia's grain crops is located in low-rainfall regions (<550 mm annual rainfall) with porous soils where both nitrification and the denitrification potential is low; these areas are not regarded as having substantial background N_2O emissions rates. The government's National Inventory Report 2010 indicates that soil moisture as a result of irrigation or rainfall, and excess fertiliser application being predominantly responsible for the majority of soil N_2O emissions. Detailed studies of N_2O emissions over the entire cropping cycle is indicating that Emissions Factors (EF) in low rainfall areas that use traditionally less fertiliser are significantly lower than the IPCC default factor of 1-1.25%. Based on the research, the current EF for Dryland cropping has been reset to 0.3%. Whereas grains grown under irrigation or high rainfall areas have had their EF increased to 2.1% (figure 3) (Australian Government 2014) this is based on research carried out by the Australian Nitrous Oxide Research Program (Grace et al. 2010; Scheer et al. 2010).

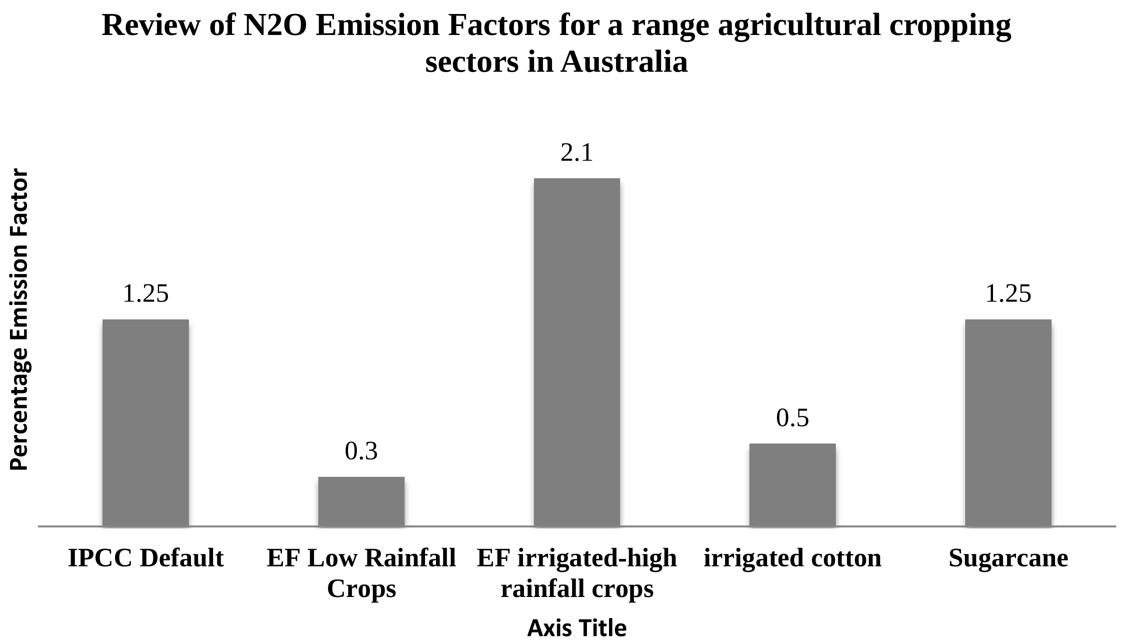


Figure 3 Australia's Emissions Factor for cropping have been revised based on new research to a selected range of EF based on rainfall and use patterns (adapted from DCCEE 2010)

Given that agriculture is the second largest emitter by sector (Figure 4), it is understandable that the Australian government is investing in research and policy initiatives to minimise GHG emissions from the sector despite the difficulties involved in measuring non-mechanised emissions. However the lack of a simple to use, inexpensive and accurate method of measuring the main GHG emissions of agriculture, makes it difficult to rely on market instruments such as Carbon Offset trading. Essentially the buyers in the market may be concerned about the validity of the offset even when using simple emissions factors and may shun agricultural offsets in favour of more reliable offsets from industrial processes (Walcott et al. 2009).

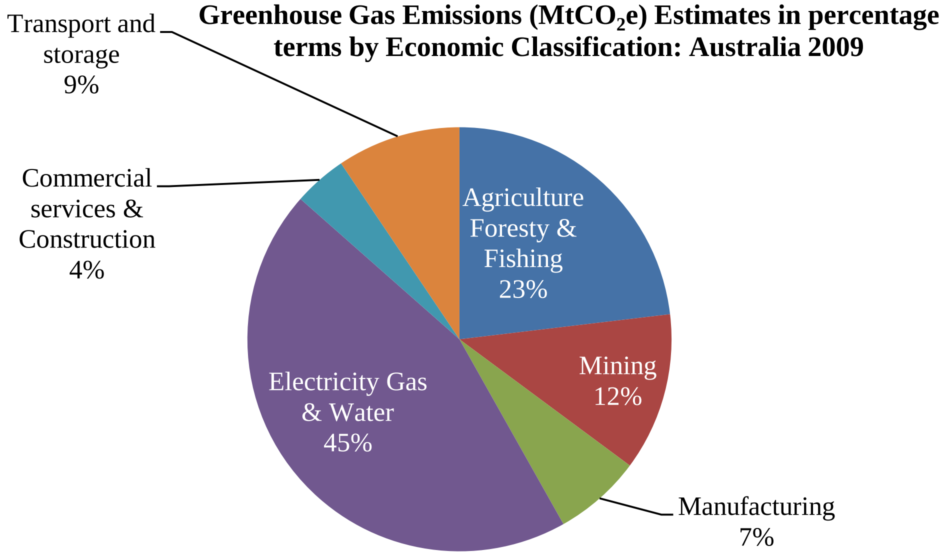


Figure 4 Greenhouse Gas emissions estimates by economic classification (ANZSIC Code) (source: Department of Climate Change and Energy Efficiency; Australian National Greenhouse Accounts, National inventory by Economic Sector, April 2011).

The government could link activities within the sector to estimated emissions and changes in activity would than correspond with reductions in emissions. The levels of activities such as the degree of stubble burning, tillage and stubble retention is measurable via surveys and remote sensors (satellite). Linking into farm data using proximal sensors is another possibility for collecting farm information for analysis. Therefore reductions in practices such as tillage or stubble burning would be expected to correspond to a reduction in emissions, barring leakage factors. Factors that are likely to limit such outcomes is the variability across agro-ecological zones based on soil types and climate, so robust models are required to equate activities and emissions reductions by regions. Furthermore at the farm level, farmers will make different choices on practices based on soil type, seasons and their world view of farming, which makes it difficult to support carbon offset trading for individual farmers (Thamo et al. 2013). A possible option at the policy level is to support changes at a more fundamental level using a farming systems approach. The Farming System's paradigm looks primarily at improving farming productivity and as an added outcome it can also reduce GHG emissions or demand less energy. What may be of interest to farmers in this approach is that farming systems operate from an agronomic perspective. Since farmers are not under the threat of a penalty for their emissions, they may well be less interested in reducing emissions for its own sake. Where there is also a production benefit such as the option to improve fertiliser efficiency than essentially emissions can be clearly linked to unwanted waste from the system which makes participation more likely. Encouraging a self-induced incentive (reducing cost) may be more effective and cost efficient from a public expenditure perspective than an externally applied market instruments. This will depend on the drivers for change and the timeframe involved, which is discussed in the sections to come.

I acknowledge that any emissions reporting process in agriculture will have some degree of uncertainty and this is mainly due to the nature of the processes being reported on. In this instance I am concerned with policies likely to produce changes to on-farm practices that will have an outcome for reducing climate change impacts, accepting that the degree of emissions reductions may be uncertain (Freney 1997; De Klein et al. 2006; Omonode et al. 2007) .

4.6 Sequestration factors

On the other side of the balance sheet from emissions of GHG is 'sequestration' generally defined in climate change terms as the removal of carbon dioxide from the atmosphere for long-term storage in either soil, plants, geological formations, oceans or mineral carbonation[16]. The key point of such a definition in terms of climate change is the requirement for long term storage as opposed to short term processes such as the fluctuation that occurs between photosynthesis and respiration (Johnson et al. 2007). Farms have two potentially significant opportunities for sequestration, firstly via long term forest plantation on surplus land (Keating and Carberry 2010) and secondly via the soil, by increasing the levels of soil organic carbon (Baldock et al. 2009; Sanderman et al. 2010). While these potential exist they are nevertheless complex to manage in practice.

Farm Forestry is defined as forestry plantations on private land for commercial production as part of a broader farming system; they are predominantly of a smaller scale than industrial plantations and may have less emphasis on timber as the primary output (URS Forestry 2008). The potential for carbon sequestration on farms is based on the concept that farmers may want to permanently plant trees for other reasons than commercial harvest, such as managing salinity. From our interviews with farmers, concern was raised on the issue of permanence for projects under the Carbon Farming Initiative legislation; this means that

[16] Carbon sequestration as defined within the Australian parliament. http://www.aph.gov.au/library/pubs/climatechange/responses/mitigation/carbon.htm

plantations would have to be retained for 100 years plus to qualify for an Australian Carbon Credit Unit[17]. Such a long term liability is unlikely to be palatable to farmers especially if the carbon price is low. The subject of farm forestry is not within the scope of this inquiry, although it acknowledges its role on the farm.

The subject of soil carbon sequestration faces the same test of permanence if it is to participate in carbon offset trading. The potential role of increasing Soil Organic Carbon (SOC) has been reviewed by Sanderman et al. (2009). Grain cropping in Australia covers approximately 23 million hectares of production (GRDC 2012) dominated by light textured soils. Cultivated soils lose organic carbon at variable rates depending on the clay content and annual rainfall (Swift 2001). In a range of clay soils loses of organic carbon averaged 0.6% per year (Dalal and Chan 2001). The Limited rainfall of the cropping region in the range 300mmm to 800mm limits the opportunity to significantly increase the organic carbon content of these soils (Chan et al. 2008; Baldock et al. 2009). Under Australian conditions current practices have limited capacity to increase soil organic carbon, and in most situations they can only mitigate the ongoing loss (Wang et al. 2010). This would mean that much of the cropping soils would show only small marginal increases in soil organic carbon (Luo et al. 2010; Chan et al. 2011). Such small changes are unlikely to find sufficient offset units across the average grain farm to interest traders and would require some form of pooling to create the necessary economies of scale (Renwick et al. 2003). This is further complicated by the error margins associated with measuring soil organic carbon that emanates from variations in bulk density (Throop et al. 2012); samples being based on depth rather than equivalent mass across a heterogeneous soil types (Sanderman et al. 2010). Sanderman and Baldock (2010) also argue that predicted stock change data from agricultural trials may not truly reflect sequestration when the state of the soil carbon at the beginning of the trial is unknown; that is when there is no comparable baseline at the start of the field trials. Thus current IPCC accounting methodologies developed from some trial results may not be reflective of the true value of the carbon storage based on the management activities (Sanderman and Baldock 2010). This uncertainty is likely to affect confidence in the market allocation of carbon credit units for offsetting a unit of emissions using soil carbon sequestration.

[17] Carbon Credits (Carbon Farming Initiative) Bill 2011. Bills Digest Service No. 5, 2011-12 http://www.aph.gov.au/library/pubs/bd/2011-12/12bd005.htm

Measuring non-mechanical GHG emissions and the balancing of sequestration for a farm business for the purpose of trading 'Carbon Offset Credit Unit' is likely to be contentious when compared to the more simplified mechanical measurements associated with an industrial process. In policy terms, that leaves the government with introducing some form of estimated index based on management practices, which has its own inherent variability (Baldock et al. 2009).

4.7 Farm cropping practices and their impact on Greenhouse Gas emissions and carbon sequestration

The Australian National Greenhouse Accounts (ANGA) does not cover all potential GHG emissions associated with farm operations. They include ones that have some capacity to be measured; the following related to cropping are reported by the Australian National Greenhouse Accounts ANGA (updated quarterly at *climatechange.gov.au*) :

• *Rice cultivation* – methane emissions from anaerobic decay of plant and other organic material when rice fields are flooded.

• *Agricultural soils* – emissions associated with the application of fertilisers, crop residues and animal wastes to agricultural lands and the use of biological N fixing crops and pastures.

• *Field burning of agricultural residues* – emissions from field burning of cereal and other crop stubble, and the emissions from burning sugar cane prior to harvest.

Other farm emissions are either located in other sectors (e.g. diesel consumption - transport) or have no reliable way of being measured so are not included in the accounts. A comparison of these measured and unmeasured emissions is presented in Table 8.

Table 8 A comparisons of agricultural emissions that are accounted and not-accounted for in the national accounts

Accounted	Not accounted
CH_4 emissions from rice flooding	Loss of SOC from cultivation as CO_2
N_2O from Fertiliser application	Emissions from soil compaction
N_2O Planting of legumes	C Sequestration from crop residue
CO_2 burning of residues	Emissions from anaerobic soil conditions (water logging)
N_2O from retained residues	

The Australian government does however measure a number of farm practices for other purposes outside of ANGA. At present the major agricultural activities for cropping monitored by the Australian Government for Sustainable Agriculture include tillage, crop residue practices, ground cover management, fertiliser usage, and the incidence of soil acidity. They are measured for productivity reasons and each of these practices is under the control of the farm business unit. The practices previously mentioned also have GHG emissions and soil carbon sequestration implications and could play a role in reporting emissions where a direct correlation can be made between their emissions and the farm practices.

The types of CA practices that can be related to carbon accounting consideration include tillage practices, crop residue retention, control farm traffic, legume crop rotations, fertiliser application, the application of recycled organics such as animal waste and cover crop management. Some of those farming practices are well established in Australia and are already being measured for productivity reasons, whilst others are only just developing. I consider each of the current practices as a whole for all its potential emissions characteristics regardless of its current accounting position. This provides an option to consider future potential policy options targeting farming systems and how changes in farming system might contribute to reduced emissions.

As part of this examination on how farming systems practices might be operated to reduce emissions I consider in more detail some of the practices in the grain farming system and how those practices create emissions. This further examination is hoped to provide potential avenues for changing the practices to reduce emissions or actively remove CO2 from the atmosphere is a more permanent way.

4.7.1 A review of tillage practices and their emissions in broad-acre grain (PAPER)

This section is presented as a paper to the Journal *Agroecology and Sustainable Food Systems* on the 20th of September 2014

Notes

The following publications are presented in the format of the manuscript as sent to the relevant Journal publisher. The tables and figures are not listed as part of the thesis but follow the numbering pattern of the text in the publication. The figures have a border to distinguish them from figures in the main thesis. The bibliography has been removed and incorporated into the thesis bibliography.

A study of developing carbon offset projects using conservation tillage on grain farms in northern Australia

Jean-Francois Rochecouste and Paul Dargusch

Abstract

This paper examines the issues that affect the development of carbon offsets from farms in northern Australia using conservation tillage. Legislation is available for carbon farming in Australia, although there is no methodology for changing tillage practices at this time. Our analysis highlights that there are several issues constraining the development of carbon offset methodologies in northern Australia around tillage. First, tillage terminology as it applies to soil carbon is inconsistent within the literature and is likely to complicate the development of practical methodology. Second, our analysis of regional farm soil tests shows no significant correlation between local tillage practices and levels of accumulated carbon. This suggests that more-intensive individual farm soil analysis may be required, which would lead to a substantial increase in transaction costs. Third, leakage factors indicate an emissions benefit in fuel consumption but an unknown impact from herbicide use. Herbicide use and bioaccumulation is highly variable depending on seasonal rainfall. The general literature seems to indicate that reducing tillage reduces carbon loss and may account for small levels of carbon accumulation in Australia. However, we conclude that the measuring process required for verification of a carbon credit unit at current prices is likely to be cost prohibitive at farm level and poses a risk to aggregators.

Keywords

soil carbon, carbon sequestration, herbicide emissions, Emissions Reductions Fund, Carbon Farming Initiative

1.0 Introduction

The Australian Government is examining opportunities for the agricultural sector to play a role in reducing greenhouse gas (GHG) emissions and sequestering atmospheric carbon. The previous Labor Government introduced specific legislation to support this on 8 December 2011, with the *Carbon Credits (Carbon Farming Initiative) Act 2011* (CFI Act)[18] and the supporting Carbon Credits (Carbon Farming Initiative) Regulations 2011 (CFI Regulations)[19]. The CFI Act allows for land managers to develop projects to remove carbon dioxide (CO_2) from the atmosphere and to avoid emissions of GHGs associated with agriculture, principally nitrous oxide (N_2O) and methane (Australian-Government 2011; Browne et al. 2011). The scheme was designed to help farmers and land managers earn additional income by reducing emissions and sequestering carbon in vegetation and the soil

[18] CFI Act 2011 - http://www.comlaw.gov.au/Details/C2012C00417
[19] CFI Regulations 2011 - http://www.comlaw.gov.au/Details/F2012C00466

through changes to agricultural and land management practices (DCCEE 2012). The major challenges to producing carbon offsets from Australian agriculture are that emissions from agriculture are not easily measurable, emissions come from a wide range of small operators and the factors causing emissions are linked to biophysical and socio-economic factors (Freney 1997; Walcott et al. 2009; Parnell 2010; Chan et al. 2011; Brock et al. 2012). The Liberal/National Coalition Government of Australia, elected to federal office in the September 2013 election, appears committed to supporting the production of carbon offsets from agriculture under its 'Direct Action' climate policy plan. This is outlined in the Emissions Reductions Fund Green Paper which summarises the government's consultation with business and the community (Australian Government 2013b). Reducing tillage has been linked to the production of carbon offset units in other jurisdictions, such as Alberta Canada. The process uses a 'deeming' method based on agro-ecological soil zones by deeming those farmers who implement a practice change to conservation tillage systems as having produced a prescribed level of carbon offsets specified by the protocol (Alberta-Environment 2009). There is no current methodology of reducing tillage practices in Australia that might account for the production of carbon offset units (Harper et al. 2007; DCCEE 2012).

Practicing conservation tillage as an abatement option is listed in the Carbon Farming Initiative Handbook as worthy of evaluation, tillage having been one of the main contributors to the loss of soil organic carbon (SOC) in Australia's cropping land over time (Sanderman et al. 2010; Chan et al. 2011; DCCEE 2012). It has also been referred to in the 2008 Garnaut Climate Change Review to the Australian Government and is listed as part of the Australian Greenhouse Gas Abatement Cost Curve in a report by McKinsey & Company Australia (Garnaut 2008; Lewis and Gorner 2008). In this study we explore the feasibility of deriving carbon offset units from conservation tillage within the grains industry. The grains industry is Australia's largest cropping sector and has substantially changed its tillage practices towards conservation tillage over the last 40 years (Thomas et al. 2007c; Llewellyn et al. 2009; Agbenyegah et al. 2014).

The loss of carbon due to tillage results from the mineralisation of soil organic matter from soil disturbance and the amount lost is highly variable depending on soil type, moisture and temperature (Chan et al. 2003; Chan et al. 2011). The feasibility of a soil carbon sequestration project depends on farmers' ability to permanently maintain the SOC they have sequestered (Dalal and Chan 2001; Baldock et al. 2009). Research is ongoing into the carbon cycle of cropping soils and the development of baselines for measuring changes in SOC; cropping also directly emits GHGs as N_2O during tillage (Barton et al. 2008; Sanderman and Baldock 2010; Antle and Ogle 2012).

Farming systems around Australia are complex, spatially extensive and regionally variable. We have therefore focussed this paper on the emissions characteristics of conservation tillage and farmers' operation in Australia's northern cropping sector to determine the feasibility of producing measurable carbon offsets. The northern grain region is subtropical with highly variable rainfall; both summer and winter cropping are dependent on stored soil moisture to maintain growth during the growing season (Dalgliesh and Foale 1998). The overlapping sequence of winter and summer crops had been heavily dependent on cultivation to prepare for planting until conservation tillage techniques were adopted over the last 40 years (Thomas et al. 2007c). Reducing tillage is generally argued as having an impact on reducing GHG emissions in comparison to continuing 'business as usual' cultivation (Lee et al. 2009; Hobbs and Govaerts 2010; Labreuche et al. 2011). Others have argued that the emissions benefits are negligible after accounting for leakage factors (Maraseni and Cockfield 2011).

2.0 Definitions of conservation tillage and greenhouse gas emissions from soil

Here we consider what conservation tillage means and how it is likely to impact on farm GHG emissions if adopted by farmers in the northern cereal belt. Tillage is a practice of soil disturbance that prepares the soil for planting or controls weeds and refers to the 'number of passes' and 'the percentage area of surface soil disturbance' in land preparation and seeding. The amount of soil disturbance from tillage is directly linked to soil carbon loss and soil emissions (Valzano et al. 2001; Choudhary et al. 2002; Reicosky 2002). One difficulty facing policymakers is the high degree of variability in the way farmers till their soils and how this might be linked to a method for measuring carbon offsets. Although relevant factors such as soil type can be determined 'in situ', the general definition of tillage in relation to the degree of soil disturbance appears to be highly variable and dependent on a number of farm management factors.

The area of cultivation required for seed placement will depend on the requirements for crop row spacing. In northern Australia, winter wheat row spacing is approximately 25 to 35cm and for the summer crops sorghum and corn may be as much as 90 to 100cm (Caldwell 2009; Queensland-Government 2011; GRDC 2014). In addition, local definitions of tillage do not deal with depth and often only infer a seeding depth of 50 to 100mm; however, this does not account for weed control needs. This variation in defining tillage practices in terms of its impact on soil disturbance is accepted by farmers and consultants at the level of farm production. However, in a GHG accounting system the lack of a precise international definition around tillage practices and tillage-related SOC changes is likely to create uncertainty in developing a carbon offset framework for the market. Therefore, when reports refer to 'abatement opportunities from conservation tillage' it is not well understood what this means. Below is a review of terminology used in Australia (Ugalde et al. 2007) (Table 1).

'Table 1 A review of tillage terminology and potential greenhouse gas (GHG) implications

Tillage practices in Australia	Terminology	Author	GHG implication
Full tillage: multiple passes (>3) across 100% of a field to a depth greater than 100mm +	Conventional tillage	(Gajri et al. 2002)	Highest level of soil CO_2 emissions and mineralisation of SOC. Highest fuel consumption with first ploughing operation, and with additional amounts from each pass.
The number of tillage passes is reduced to <3 operating at planting time across 100% of the field with depth not specified	Reduced tillage	(Gajri et al. 2002; Mitchell et al. 2009)	An unclear terminology that is simply less than conventional tillage. Hence there is likely to be some emissions reductions but the amount is unclear.
	Minimum tillage	(Chang and Lindwall 1989; Baker and Saxton 2007; Anderson 2009)	Depth of the implement has significant impact on fuel consumption; this potential variation is not captured in GHG terms.
Tillage only occurs prior to planting and is limited to the plant row using various points or tine (area of field and depth not specified)	No-till or no-tillage	(Gajri et al. 2002)	CO_2 emissions from soils are reduced by minimising soil disturbance and so is CO_2 from diesel operation but the relative quantity is uncertain.
Tillage only occurs at planting using either disc or tine for seed placement	Direct seeding	(Baker and Saxton 2007; Butler 2008; Ashworth et al. 2010)	The area of soil disturbance is considerably reduced, soil emissions are also expected to be low. Energy requirement at the drawbar is also significantly reduced. To manage weeds more passes for spraying is required, but energy use of sprayers operating across the paddock is low.
Tillage only occurs at planting using a disc to open soil for seeding	Zero-till		

In a review of planting operations in northern Australia from grower organisations, we note considerable variation in practices, input and equipment (Table 2). Such a range of practices demonstrates the diverse equipment choices that can be made by farmers in response to similar regional conditions.

‘Table 2 Planting operation of farmer in northern Australia.

Number of farmers	Tillage system	Various planter types
8	Zero-till using disc system	• Gyral AgBoss – double-disc system • NDF-disc Planter & Orion for deep sowing • homemade • Austil Disc • Rogro Parallelogram
7	Combined options - no-till and zero-till systems on the farm, includes tines and disc options depending on crop	• AFM with tines • Gyral and Shearer with Stealth point tines • Inverted T, 5mm points or disc planter for summer crop • Kinze and Flexicoil tine • Gyral, Mason for broadacre planting and John Deere Maximerge for summer
13	No-till system using tines	• Universal Shearer with tines • Flexicoil with tine • Universal Shearer cultivator with Peter Points • Converted tine opener • John Deere Cultivator, primary sales-inverted T points
3	Minimum-till	• BigRig • AlFarm 420 • Alfarm or Janke
1	Uses contractor	• Not specified

(Source: unpublished – Conservation Farmers Inc. used with permission, January 2012)

The snapshot provided in Table 2 highlights the significant differences in the equipment used by farmers to manage their soils; it suggests that tillage practices are likely to be very difficult to standardise. This in turn limits the ability to correlate tillage practices and soil emissions with the degree of accuracy that may be required for an offset scheme methodology at a farm level. There is no information on the way farmers operate disc machines, and the degree of soil disturbance can be highly variable depending on the set angle of the disc; narrow angles disturb less soils than wide angles (Ashworth et al. 2010).

Tillage terminology traditionally relates to machinery set-up, crop establishment and moisture requirement; it does not consider GHG emissions that emanate from soil disturbance. As indicated in Table 1, applying a GHG management methodology to tillage practices is limited by the observed inconsistencies in the way a tillage operation is performed. In the literature, recent comparisons of full tillage and some form of reduced tillage most commonly record a degree of significance in GHG emissions between conventional and no-till systems, but a detailed description of the tillage operation in terms of the degree of soil disturbance is rarely provided (Mummey et al. 1998; Desjardins et al. 2001; Landers et al. 2003; Six et al. 2004; Venterea et al. 2005; Lee et al. 2006; Elder and Lal 2008; Ahmad et al. 2009b; Smith et al. 2011). To estimate the value of changing farm practices for a carbon offset, a baseline of current practice based on the level of soil disturbance and potential emissions should be available to compare emissions with farm practice change over time at a local level. The lack of a standardised definition for no-till was identified at the 5th World Congress of Conservation Agriculture as problematic for researchers in this field (Derpsch et al. 2011). This may become even more relevant if the adoption of conservation tillage is to be considered as a means of generating carbon offsets as was initiated in the province of Alberta Canada (Alberta-Environment 2009).

3.0 The impact of conservation tillage and measuring soil carbon

Tillage refers to the disruption of the soil to varying depths using metal farm implements with the aim of loosening the soil in preparing the seedbed before depositing seed and fertiliser and also as a follow up to controlling weeds (Phillips and Young 1973). In the process of shearing the soil, the general structural integrity of the soil is changed and affects the bulk density, drainage and organic carbon content (Unger and Jones 1998; Dalal and Chan 2001; Swift 2001). Opening the soil mineralises organic matter, provides available nutrient to the crop and releases carbon dioxide (Reicosky 2002). Traditional tillage practices in Australia involve considerable soil shearing from a number of cultivations (4 to 10 passes) to manage weeds, incorporate previous crop residues and in the preparation of a seedbed (Ugalde et al. 2007). This type of conventional tillage resulted in extensive soil erosion and is thought to have caused approximately 20 to 50% of historic carbon losses (Lal 2004c; Sanderman et al. 2010). Conservation tillage has significantly reduced soil erosion and the associated carbon loss (Lal 2004a; Thomas et al. 2007c; Barson 2013; Ryan 2013). In the last 200 years, agriculture expanded in an effort to meet world food demand and in the process caused a net shift of carbon from the soil carbon pool to the atmospheric pool (Lal 2007b). This is not entirely replaced by growing crops, because the carbon derived from the atmosphere in the harvested grain moves into the food chain and the waste produced is generally not recycled, at least not in Australia (Scott et al. 2010). Therefore, agricultural soils in Australia have suffered a net loss of SOC requiring inputs of highly energy-intensive nitrogen, in the form of inorganic fertilisers, to feed the crop (Liu et al. 2006; Bell et al. 2007; D'Haene et al. 2009).

Recent international papers report savings in soil carbon and emissions (CO_2e) from reducing tillage. In a study of SOC in the sub-alpine meadow of China Shang et al. (2012) reported an increase of 1.73 tonnes of soil C/ha over a ten year period using conservation tillage. Hillier et al. (2012) report a reductions in emissions of 0.02 tonnes of CO_2e/ha/year by reducing tillage over a 50-year period. Following the adoption of conservation tillage in Spain, Gonzalez-Sanches et al. (2012) report significant variability in the reductions of emissions with a maximum of 0.85 tonnes of CO_2e/ha/year. Not all regions can be directly compared due to cultural variations in how farmers interpret 'conventional' and 'conservation' tillage, so international reports may not be relevant to local conditions (Wang et al. 2010; Gonzalez-Sanchez et al. 2012; Hillier et al. 2012; Shang et al. 2012). The Alberta Government in Canada operated a tillage reductions offset scheme from 2007 to 2011 where farmers were able to generate carbon offsets based on pre-set data by agro-ecological zones based on farm change practices (Alberta-Environment 2009). In a review of Australian conditions, Lam et al. (2013) conducted a meta-analysis of published data from 1984 to 2012 on the responses of soil carbon to improved agricultural practices. The dataset was compiled from 56 studies with 172 comparisons for the effects of conservation tillage and reported the relative gain in SOC was in the order of 139kg C/ha/year and 62kg C/ha/year for the associated residue retention (Lam et al. 2013). This should only be taken as an approximation given the variability of Australia's grain production areas.

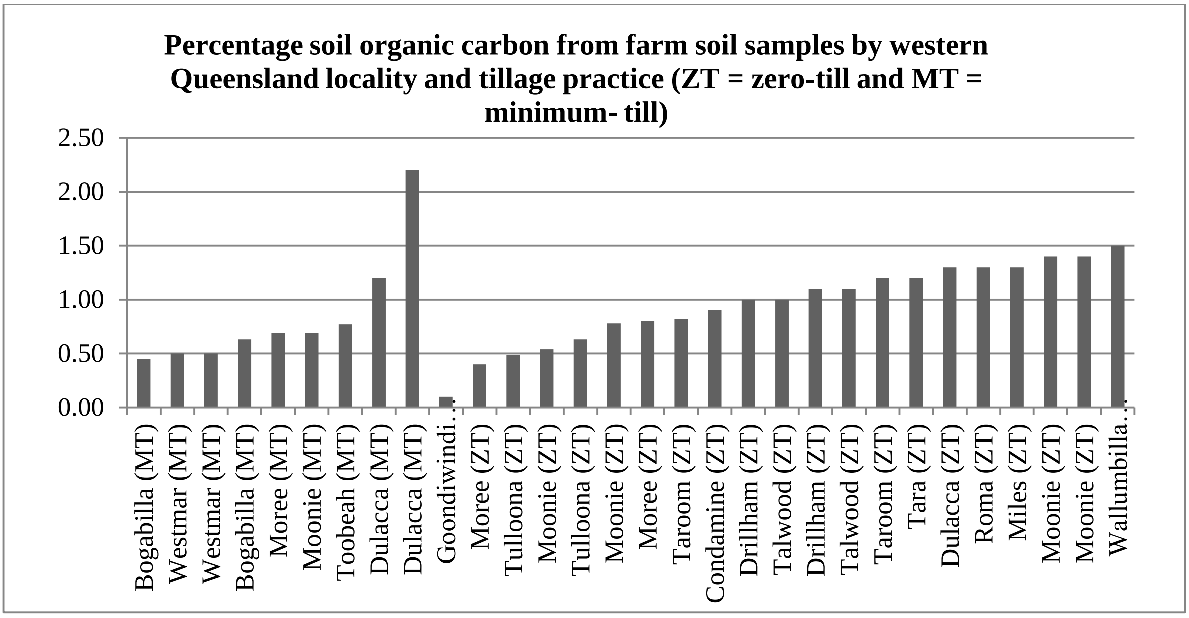
Researchers have also supported the concept that an important part of soil fertility is related to carbon as part of soil organic matter (SOM) (Dalal and Chan 2001; Loveland and Webb 2003; Bell et al. 2007; Manlay et al. 2007). SOC makes up about 50% of SOM depending on soil type (Pribyl 2010). A number of studies comparing native woodland and agricultural land in Australia have indicated a reduction in SOC caused by land clearing for agriculture (Riezebos and Loerts 1998; San Jose et al. 2003; McHenry 2009). It became apparent in the latter part of the 20th century that continuous tillage in Australia was reducing SOM and SOC, leading to a depletion of soil fertility (Lal 2004a; Liu et al. 2006; Luo et al. 2010).

The loss of SOC from cultivated farming soils is variable but based on international studies is generally in the range from 0 to 2.5% SOC (Omonode et al. 2007; Beheydt et al. 2008; Luo et al. 2010; Sanderman et al. 2010; Buragiene et al. 2011; Omonode et al. 2011). The loss of carbon and nitrogen from disturbed soils is mostly in the form of GHG emissions such as CO_2 and N_2O (Reicosky 2002; Olson 2010; Regina and Alakukku 2010). As the major portion of the organic matter content is in the surface horizons, using aggressive cultivation practices at depth means that the loss of SOC is likely to occur across both A and B soil horizons (Bauer et al. 2002; Heckrath et al. 2005; VandenBygaart et al. 2007; Alvarez et al. 2009).

The level of N_2O emissions relates more closely to fertiliser application to the in-situ crop than the practice of tillage (Regina and Alakukku 2010; Venterea et al. 2011). Ormonode and others (2007) reports a significant amount of CO_2 and small amounts of methane (CH_4) emissions from traditional tillage operations (Omonode et al. 2007). Soil emissions are also affected by biophysical factors such as soil type, moisture content and temperature (Unger and Jones 1998; Buragiene et al. 2011; Morell et al. 2011). Therefore, the ability to routinely quantify soil emissions from such a farm operation is very complex and costly to put into commercial practice, thereby limiting the policy opportunities to support verifiable emissions reductions units into a carbon offset market such as the CFI (Sanderman et al. 2010).

Changing practices by applying conservation tillage on its own does not significantly rebuild SOC in Australia's arid-zone systems, but can reduce its net loss (Kirchhof and Daniels 2009; Varvel and Wilhelm 2010). Additional biomass in some form is required to increase SOC (Liu et al. 2006; Gaiser et al. 2009; Govaerts et al. 2009; Fuentes et al. 2010; Iqbal et al. 2011). In policy terms, any reductions in unnecessary tillage will reduce soil emissions to some extent and halt the loss of SOC. The problem is that the emissions reductions benefit from changes in practice to cropping soils is not readily measurable, so estimates of emissions factors are required. The only reliable emissions data in relation to reducing tillage operation is going to come from mechanical emissions such as fuel savings. In relation to sequestration of atmospheric carbon in soils, Chan et al. (2003) and Luo et al. (2010) conclude that the amount of SOC accumulation in Australia is unlikely to be significant in the low rainfall cropping areas in the short term.

Measuring increases in soil carbon baselines is also likely to be difficult. We compared 30 soil test results collated from local agronomists for western Queensland farmers practicing some degree of tillage (minimum-till) and zero-till to identify any trends evident in SOC (Figure 1). zero-till (ZT) refers to tillage with only one pass for seeding and minimum-till (MT) refers to some degree of cultivation not specified. The practices were consistent for at least the previous three years. The region was experiencing a number of dry years during the sampling period with little organic matter input from crop residue. Some of the sample farms had also been including an animal manure treatment when the product was available and this was reflected in a higher than average SOC for some samples. The soils in the sample area had low clay content on the surface horizon, annual rainfall ranges from 550 to 630mm and were mostly alkaline with pH ranging between 7.5 and 8.5.



'Figure 1 Farm soil samples supplied by agronomists and farmers. (Source: Adapted from data collected by Dave Hall Consulting and Conservation Farmers Inc., January 2012 used with permission)

The 30 samples suggests that no easily defined correlation exists between stated current tillage practices and their levels of SOC, there is simply too much variability. Although not a rigorous analysis, it does indicate that industry information alone is not going to be sufficient to make a case for obtaining a verifiable carbon sequestration unit on comparative regional farm practices. A system requiring extensive data collection to confirm changes at farm level is going to significantly increase the transaction costs of any project and would have to operate in addition to standard soil testing.

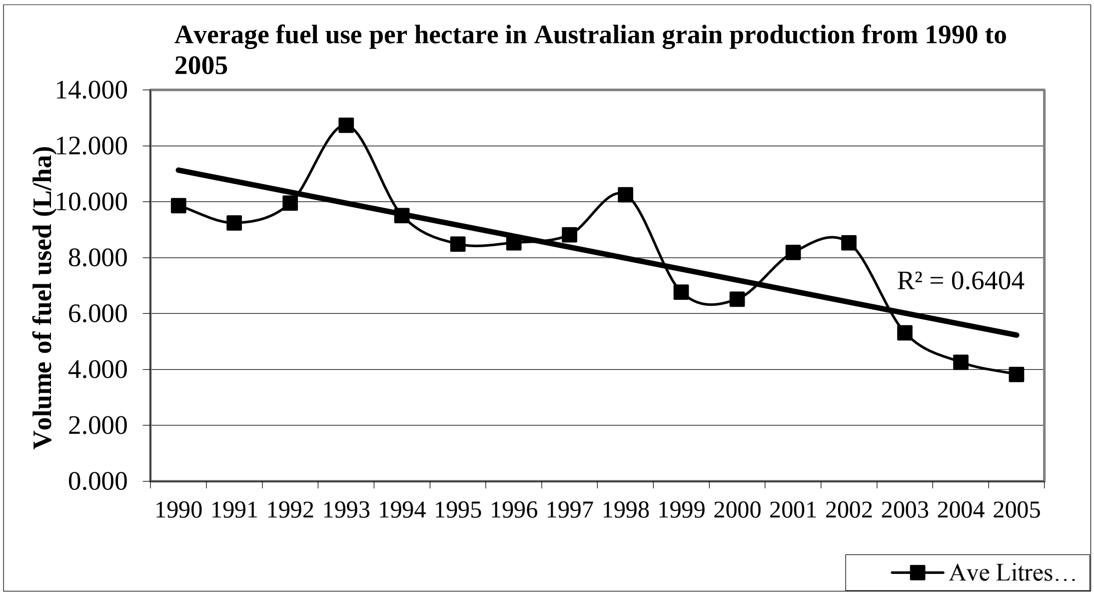
Adopting reduced tillage practices may improve organic carbon or reduce its loss. However, in the more arid-zone farms, the tillage practices that a farmer undertakes are unlikely to record easily measurable improved SOC levels based on existing soil sampling techniques. Significantly more detailed studies would be required to ascertain the factors leading to changes in SOC levels. Using serial time sampling of the soil to measure on-farm soil carbon accumulation over time for a particular change in farm practice, for example to reduced tillage, is likely to be confounded by the seasonality of biomass production and from other farm activities such as the importation of manure. Given the low values of soil carbon and the variability, it is unclear that a 'deeming' method as previously mentioned in regards to the Alberta scheme can be supported in Australia. We suggest that for farmers to demonstrate carbon sequestration from changes in tillage practices is going to involve significant time and transaction cost for a series of small incremental gains in soil carbon. This is likely to be a dilemma for regulators trying to encourage farmers to participate in the CFI using a tillage reductions methodology.

4.0 GHG leakage factors from conservation tillage

Conservation tillage operations produce CO_2 emissions from tractor fuel combustion and from the manufacture of the herbicides required to replace tillage as a means of weed control. Changes in farm practice can result in sideline emissions in other industry sectors and those 'leakage' factors can be positive or negative. For example, diesel use is reduced under conservation tillage and emissions can be easily measured by the farm industry, whereas herbicide use is greatly increased and emissions factors are not readily accounted for by farmers. In this section, we consider the two main emissions leaks that result from a change of tillage practice to conservation tillage; the direct reductions in diesel consumption reported under the transport sector and the required increase use of herbicides as indirect emissions from manufacturing (scope 3).

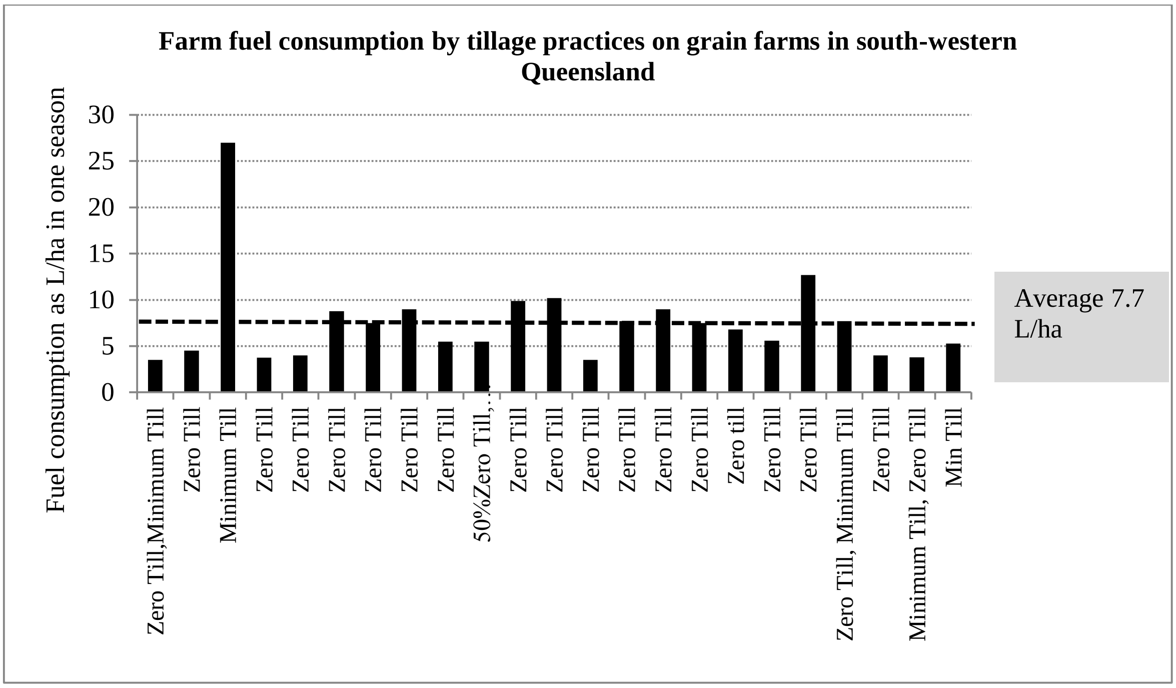
4.1 Farm fuel consumption

The most direct impact of abatement from reducing tillage is the reductions of on-farm diesel consumption. Although this is not accountable as part of agricultural emissions, it is still part of the national accounts within the transport sector (Nationmaster.com 2005; Australian Government 2014). Whether it should be included as part of agricultural emissions is a matter of process, but its impact is not insignificant. As tillage requires energy, reducing tillage proportionally reduces energy requirements. A review of fuel consumption estimates using figures from the Australian Bureau of Agriculture and Resource Economics and Sciences (ABARES) shows a decline in the volume of fuel used in the grains industry from 11L/ha in 1990 to below 6L/ha in 2005 (Ugalde et al. 2007) (Figure 2).



'Figure 2 The trend in average fuel use per hectare by grain farmers for the period from 1990 to 2005. (Source: A. Umbers, Umbers Rural Services, used with permission)

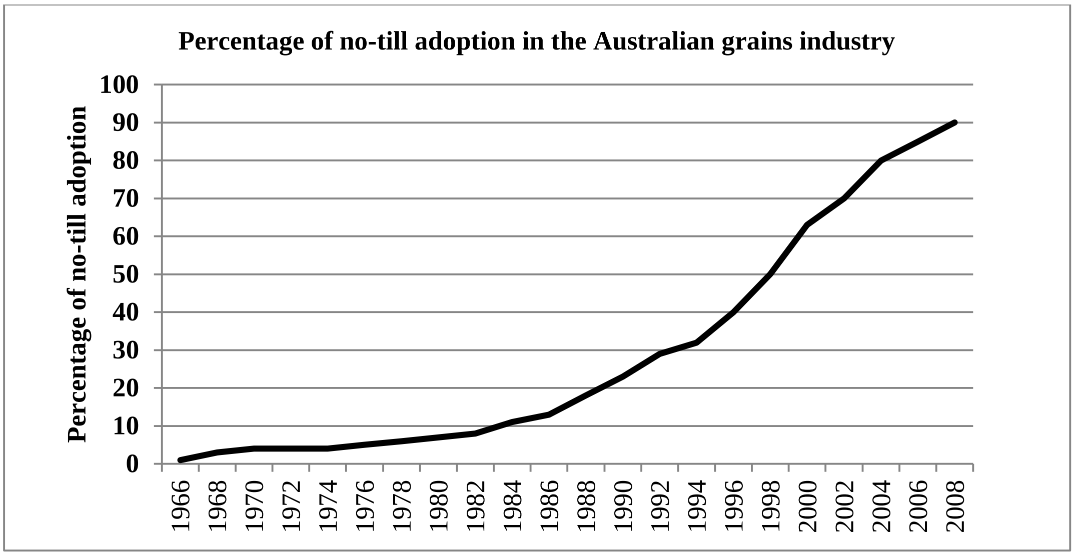
A survey commissioned by Conservation Farmers Incorporated and conducted by the author of farmer's fuel consumption in the cropping areas of south-western Queensland for the period 2005 to 2007 indicated that the national ABARES data was supported at the regional level with an average across 23 farms of 7.5L/ha (excludes harvesting).



'Figure 3 Farm fuel consumption by tillage practices on grain farms in south-western Queensland per planting season. (Source: Adapted from unpublished survey data - Conservation Farmers Inc. used with permission.)"

The survey data is slightly skewed by a farmer who included an exceptionally deep ripping operation to manage sub-soil constraints that used 27L/ha. If this entry is discounted this provides an average of 6.6L/ha which is more consistent with the national average of 2005 (5.5–6.0L/ha). The fuel reductions as a result of reduced tillage would indicate that grain farmers as a whole are using about 36% less diesel than they did in 1990.

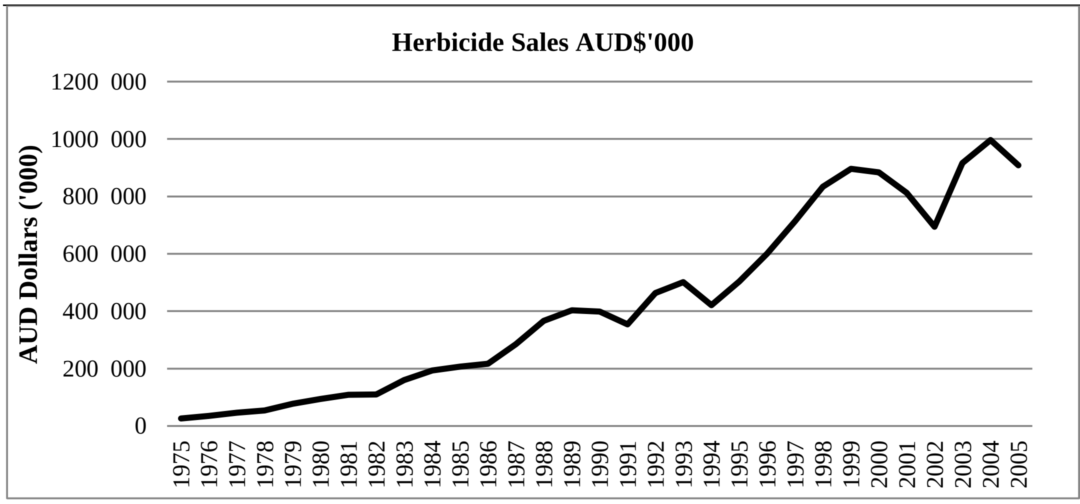
This general decline in diesel consumption in cropping operations could result from a number of contributing factors. The most significant contributor to the decline is likely to be the sharp increase in conservation tillage adoption between 1990 and the mid-2000s as reported by (Llewellyn et al. 2009).



‘Figure 4 Australian no-till adoption (Llewellyn et al. 2009). (Source: Adapted from data by R. Llewellyn 2009, used with permission.)

4.2 Herbicide products

Another indirect emissions factor that is a consequence of reducing tillage is the need for increased herbicide use to control weeds. When cultivation is removed as a weed control option, the most economical alternative is herbicide, predominantly glyphosate in Australia. The energy consumed in the manufacture of herbicides should be considered as indirect ‘scope 3’ emissions which is additional to the function of reducing tillage (i.e. it would not have occurred if using cultivation). During the period from 1990 to 2005 when the adoption of zero tillage was on the rise, we also noted a corresponding increase in the sales of herbicides in Australia (Figure 5). Although it may not be the only factor involved, the increase in reduced tillage would have necessitated a demand for more herbicides for fallow weed control.



‘Figure 5 An increasing trend in the use of herbicides in Australian agriculture.
(Source: Australian Bureau of Agricultural and Resources Economics and Sciences)

To date the carbon footprints (or energy profile) of commonly used herbicide is very limited. The last published data for the Australian farming context on the energy requirement for the manufacture of herbicides appears to be by Helsel (1992). The data in Table 3 (extracted from Helsel, 1992) includes energy inputs of commonly used herbicides for grain production in South-west Queensland as well as energy conversions to diesel equivalent and corresponding estimates of GHG emissions (Table 3).

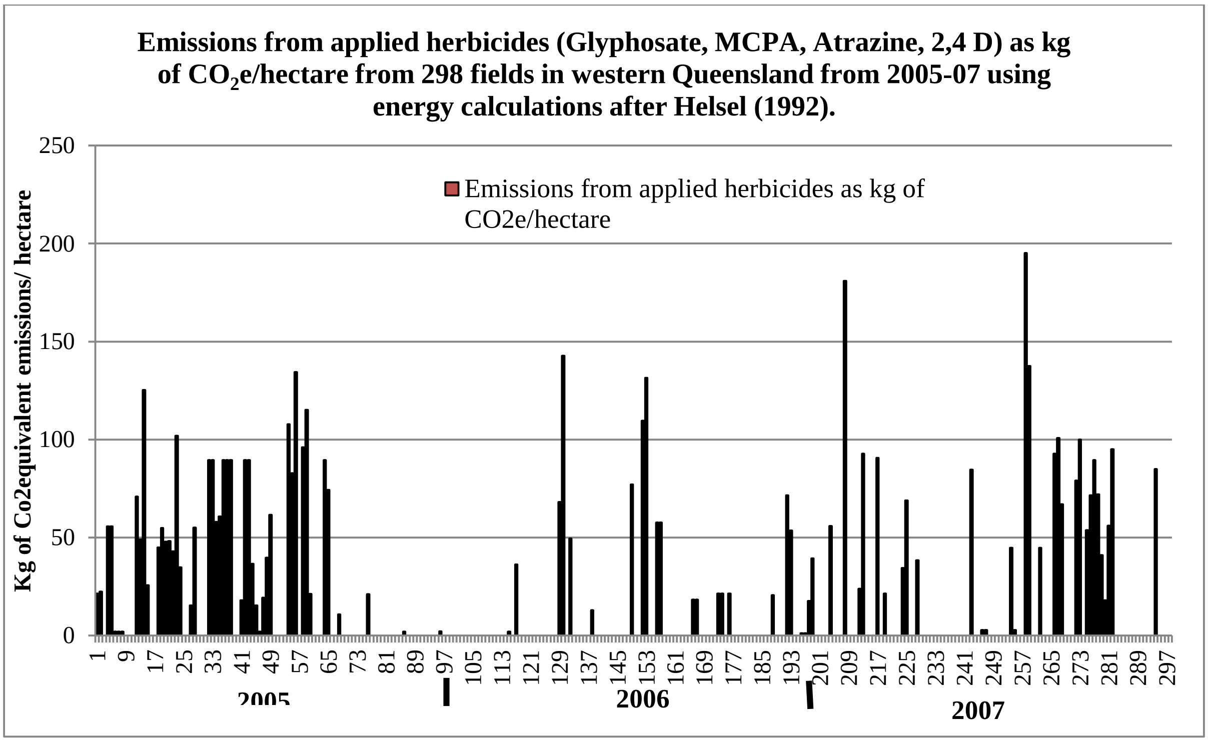
‘Table 9 calculation of GHG emissions for common grain herbicides based on energy of manufacturing (Helsel 1992).

Herbicide	Energy inputs Gj/mt of a.i.	1L Diesel energy Mj	Diesel equivalent per kg of a.i.	Formulation (Aust. Labels)	Average rate/ hectare (Label)	rate of a.i./ hectare	Diesel (L) equivalent per hectare	Emissions Kg of CO_2/hectare
RoundUp	454	43.1	10.5	0.45	1.4	0.63	6.6	17.9
MCPA	130	43.1	3.0	0.5	0.5	0.25	0.8	2.0
2,4-D	85	43.1	2.0	0.5	1.0	0.5	1.0	2.7
Atrazine	190	43.1	4.4	0.9	3.0	2.7	11.9	32.1

Although the above data is likely to be out of date with improvements in manufacturing, it provides an example of the importance of characterising the energy values of herbicides where a life cycle analysis is being considered. The type of herbicide can have significant emissions characteristics and a number of authors exclude the use of herbicides in describing the benefits of reduced tillage or where it is included it is not clear if the actual calculated energy data comes directly from the manufacturers (Zentner et al. 2004; Maraseni and Cockfield 2011). According to Cowie et al. (2012) in a review of GHG accounting in the land-based sectors the energy associated in producing herbicides is covered under the manufacturing sector (Cowie et al. 2012). This scope 3 factor is significant in determining the overall benefit of reduced tillage in terms of emissions accounting, but data on energy of production of herbicides is simply not readily available to farmers to account for their emissions. In April 2008 Monsanto, the manufacturer of the most widely used herbicide in cropping announced the planned expansion of its Roundup™ (glyphosate) facility in the United States to be completed in 2010 where the company implemented a hydrogen-recovery project to reduce natural gas cost (Jany 2008). The Monsanto Company is claiming that it is expected to reduce its

GHG emissions by an estimated 58,000 tCO_2e annually. The plant is likely to constitute more than 10% of the world’s production of glyphosate and is a major supplier to Australian farmers. What manufacturers may be doing in terms of reducing the GHG of their products is not directly available to farmers at the purchase point.

Moreover, use patterns for herbicides are highly dependent on the needs of individual farmers and prevailing seasonal conditions. A survey of herbicide use pattern by farmers in South-west Queensland shows a high degree of variability in energy profile relating to herbicide use by farmers and herbicide practice base on local seasonal conditions (Figure 6). Some farmers varied in their pattern of use from 0 to 5 sprays in preparing their ground for planting. This means that individual farms can have a high degree of variability in their emissions leakage profile in any one season based on the weed load.



‘**Figure 6** Herbicide emissions patterns from the history of 66 paddocks across various seasons in Queensland from mid-2005 to 2007[20] (source: Adapted from unpublished data - Conservation Farmers Inc. used with permission, January 2012)

In figure 6 we note that at the start of the survey in the second half of 2005 farmers applied a lot of herbicides prior to the summer crop with diminished use in the 2006 winter season. This indicates that

[20] Herbicides are Glyphosate, MCPA, Atrazine, 2, 4 D, as kg of CO_2e/hectare from 66 fields by quarter in western Queensland from 2005-07 using energy calculations after Helsel (1992).

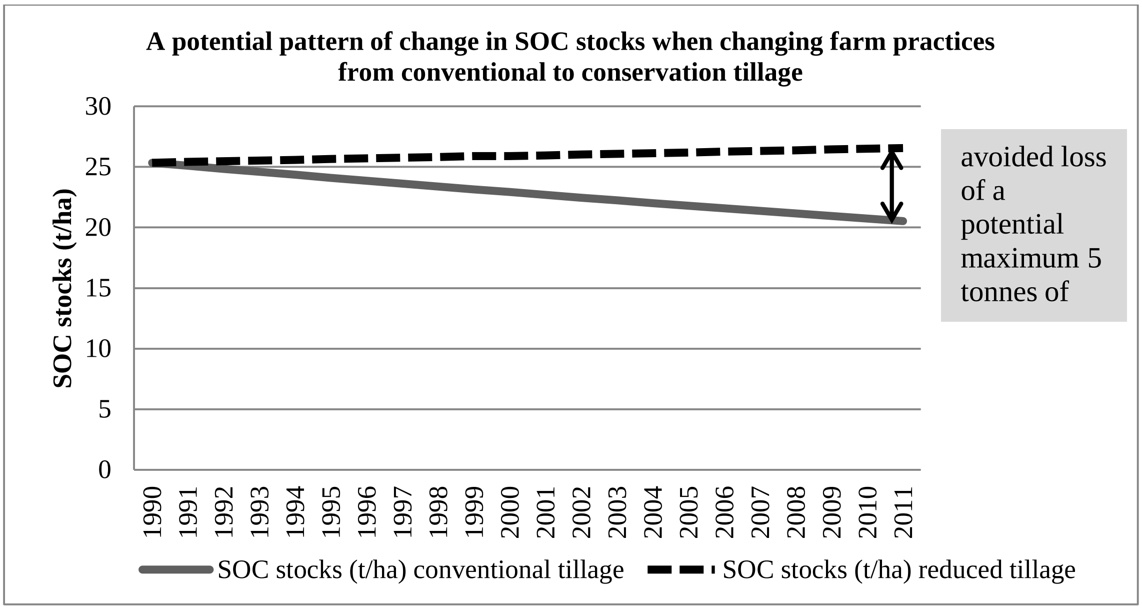
if we take into account leakage factors of scope 3 emissions there is going to be significant background variation in emissions depending on cropping choice and seasons.

It indicates that accounting for agricultural emissions in any detail from a change in practice as might be required by a carbon offset market is going to hold considerable uncertainty. It suggests that some broad industry based assumptions may have to be made as farmers may not want to be involved in collating the data required to verify emissions. It may be the reason that to date there has not been an established CFI methodology for soil carbon in the cropping sector involving tillage practices. The compliance requirement and transaction cost are likely to be prohibitive in terms of the current low price of carbon. However at a macro-level farmers are still looking to reduce tillage activities. This means that the agricultural sector is contributing to reducing emissions but is doing so as a co-benefit to production efficiency.

5.0 The implications of reducing tillage in Australian climate policy

Australian grain farmers in Northern Australia have been reducing their tillage practices since the 1970s but the most significant change occurred from around the 1990s when only 20% of farmers had adopted some form of reduced tillage practices, to over 80% in 2008 (Llewellyn et al. 2009). The opportunity still exists to further reduce the degree of tillage over another 10 million ha of land in Australia (Edwards et al. 2012). It should be noted that it has taken nearly 40 years for the process to occur without a direct external policy or carbon market incentive.

It should also be acknowledged that quantifying and monitoring emissions from tillage at farm level is very costly and likely to be impractical for a farm based project (Sanderman and Baldock 2010; Sanderman et al. 2010; Wang et al. 2011). Tiessen et al (1981) in a review of the literature suggests that grain operations using conventional cultivation lose about 1% of their SOC stocks per year (Tiessen et al. 1981), which is also discussed by Slattery & Surapaneni (2002). A number of studies have indicated that under Australian conditions reducing tillage achieved little in the way of increasing SOC but did significantly reduce the depletion of SOC stocks (Dalal and Chan 2001; Chan et al. 2003; Wang and Dalal 2006; Luo et al. 2010). A soil baseline measurement of Carbon stock (C_s, t/ha) for Eastern Australian vertosols in 1994 by Young was recorded at 25.35 t/ha (average of A & B horizon) and 6 years later recorded 25.9 t/ha under reduced tillage (Young et al. 2009a). Based on this estimates, we could speculate that a farm in Eastern Australia under a business as usual case since the 1990s that continued to use conventional tillage would have incurred a depletion of SOC of about 5 tonnes per hectare more than Conservation Tillage over a 21 year period. This is likely to be much lower on the non-vertosols in the dryer parts of Australia. These amounts do not correspond to commercially significant volumes on a per farm basis, but in national terms with 20+ million hectares of grain production the potential soil carbon loss even with some degree of discounting for soil types, would be in the order of 50 million tonnes of SOC over that 21 year period since 1990. In figure 7 we have plotted two scenarios based on the continuing decline of soil carbon stocks from ongoing conventional tillage to maintenance of soil carbon stocks with possibly a slight increase as indicated by Lam et al. (2013).



'Figure 7 Potential savings in soil carbon from Business as usual conventional tillage versus the adoption of Conservation tillage

6.0 Conclusion

Although the Australian government is seeking to encourage agricultural projects that will reduce emissions and increase carbon sequestration, the means of establishing a market ready project is proving difficult in some sectors. The concept of incentivising farm practice change using a Market Based Instrument can only function where a clear carbon credit unit can be demonstrated from the adoption of such practices. Although conservation tillage has been considered in various reports on agricultural emissions reductions, there is no approved carbon farming methodology available at present in Australia. We studied the opportunity for carbon offsets in the northern Australian region where conservation tillage is well suited to grain production as indicated by Thomas et al. (2007b). The indications are that farmers operate their production systems in widely different ways so it would be difficult to establish uniformity in practices that can be correlated to emissions reductions or carbon sequestration. Further changes in farm practices like reducing tillage create complex leakage factors that can shift the emissions to other jurisdictions, but information on those factors are not always readily available to the farm manager making on-farm decisions. We have also noted that seasonal conditions can strongly influence these leakage factors like the use of herbicides.

We conclude that due to the inherent variability in the way that individual farms operate, the means of demonstrating clear and reliable carbon offset generation at farm level is unlikely to be efficacious. The main reason being the volume of carbon offset units capable of being generated on a typical grain farm is relatively small given transaction cost required to verify those units (Lam et al. 2013). The costs of verification, aggregation and assuring for permanence would further reduce the gains. The concept of an individual farm credit system in relation to reducing tillage reductions as per the Alberta model seems economically questionable in an arid zone context (Alberta-Environment 2009). It would seem preferable to recognise the benefit at an industry-wide level where perhaps a modest deeming rate could be allocated to support the co-benefits gained from reducing tillage.

Although carbon sequestration is not easily measured at a farm level there is evidence of a potential measurable mitigation benefit from reducing tillage on a regional to national scale. The value of having measurable soil carbon units at a regional scale, even allowing for some discounting for variability, should be considered in a positive light. Reducing tillage also brings with it considerable environmental co-benefits in terms of maintaining soil health for food production and reducing pollution of waterways from erosion containing sediments and pesticide.

Under the Australian Government Department of Environment's Emissions Reductions Fund (ERF) White paper released in April 2014, it was noted that some emissions reductions activities such as in the land sector is likely to be from smaller-scale actions that would need to be implemented through some form of aggregation to be cost-effective. This would require the aggregator establish a project involving the support of a number of farms to conform to a specified activity and measurement reporting. At the time of writing soil carbon project methodology was still under development.

The Clean Energy Regulator will be responsible for the operation of the market through an auction process and the regulator will set a benchmark price for each auction, above which bids will not be considered. The auctions will begin after June 2014, and will be run quarterly, and the government's preference is that contracts will be for five years. As the bidders will need to guarantee payment for the future delivery of emissions reductions, it will be important for aggregators to have surety of supply of carbon offsets from farmers. As we have noted previously farm practices are highly varied and subject to climate and operational needs. The aggregator will be severely exposed if farmers cannot deliver due to climate factors impacting on soil carbon accumulation.

4.7.2 Stubble management and their emissions in broad-acre grain

The primary benefit of stubble retention from a production perspective was to improve infiltration, retain valuable moisture, reduce soil erosion, impair weed growth and protect the emerging seedling (Jacobson et al. 1992; Unger 1994; Malinda 1995; Lal 2008; Anderson 2009). Stubble as a source of organic material also contributes to the nutrient cycling of soil micro-organism and increases soil organic carbon, with typical wheat stubble consisting of approximately 40% Carbon, 0.58% Nitrogen, 0.05% Phosphorus, 1.42% Potash and 0.19% Sulphur and decay of the crop residue releases about 55-70% of the carbon to the atmosphere as CO2 (Schomberg et al. 1994; Tan 2009). Microbial biomass take up about 5-15% of the C and the remaining 15-40% is partially stabilised in soil as new Humus (Jenkinson 1971).

In terms of greenhouse gas balance; the retained stubble releases N_2O as its breaking down and leaves a residual carbon fractions in the topsoil layer (Howden and O'Leary 1997; Jorgensen and Jorgensen 1997; Chan et al. 2003; Robertson and Thorburn 2007; Baldock et al. 2009; Liu et al. 2009; Wang et al. 2010). The level of carbon returned to the soil is variable depending on the stubble type, soil characteristics, environmental conditions and management practices, and at present there is no consistent regional data for Australia (Chan et al. 2003; Wang and Dalal 2006; Robertson and Thorburn 2007; Liu et al. 2009; Luo et al. 2010). A number of models have been developed that consider the influence of Temperature, soil moisture deficit and the inorganic Cation Exchange Capacity (CEC) of the soil on the general degradation of crop residue (Jenkinson 1990). Whether these models can be applied to Australian conditions is still being researched (Howden and O'Leary 1997; Liu et al. 2009; Li et al. 2010; Luo et al. 2011). Some of the capacities for Australian soils to accumulate organic carbon have been reviewed by Baldock et al (2009), but it is still difficult to determine the fractional component of stubble that will turnover into stable soil organic carbon to the degree of confidence required for a soil carbon offset market. Hence there is a balance of emissions factors involved (Table 9). If the stubble is burnt than it emits a known estimate of carbon dioxide, methane and N_2O based on the level of biomass. If the stubble is retained than the N_2O emissions associated with the microbial nitrification associated with breakdown of organic material is counted as an emissions. However the carbon input is uncertain so is not include in the equation. If it is to be considered it must be accounted via an addition of carbon over time based on a standard measure taken at the start of the period.

Table 9 Comparative emissions in tonnes of CO_2 equivalent for the management of wheat residue per 100 hectares, based on IPCC guidelines and the Grains Greenhouse Accounting Framework version 6 by Eckard & Armstrong (2009).

Action by Farmer	Emissions t CO_2e /100 hectares	Sequestration	Net emissions t CO_2e accounted
Stubble burnt	12.5 (methane & N_2O)	nil	12.5
Stubble retained	4.4 (N_2O)	unknown	4.4
Stubble removed	Nil (moves to another system)	nil	0.0

The lack of a sequestration figure undervalues the basis of stubble retention in the system and its contribution to soil organic carbon. The issue is understandably complicated by the variability and fluctuations in the carbon cycle from the decomposition process of crop stubble to stable humus fractions (Cogle et al. 1987a; Cogle et al. 1987b; Scharppenseel et al. 1992; Tan 2009).

From a national policy perspective it is possible to consider initiatives that are targeted to farmers with the aim to retain stubble since there is an associated production benefit. In a broader agricultural sense it is also possible to broadly estimate carbon inputs since crop residue is estimated to contain approximately 40% carbon, and considering the ratio of grain yield and vegetative yield, than using the harvest indices of the major cereal crop we can make an estimate of the volume of stubble retained (Donald and Hamblin 1976). Using the estimate of a general harvest index of 0.4 for the major cereals; wheat, barley, oats and triticale (Kemanian et al. 2007), the 2010 Australian crop harvest returned 37,741,000 tonnes of grain (GRDC 2012) and left a potential 56,584,500 tonnes of stubble after harvest prior to burning or grazing, of which the 40% carbon component equates to 22,633,800 tonnes of carbon. On a national area basis we could divide the tonnages of stubble by area of production (23 million hectares) that tells us that in 2010 Australia averaged approximately 2.46tonnes of fresh grain stubble per hectare (0.984 tonnes of carbon). In 2007-08 the Australian Bureau of Statistics survey indicated that only 43% of crop farmers (all sectors) left their stubble intact, although this may not equate with area of production. Another 33% ploughed the crop residue into the soil and 34% baled or grazed the stubble, covering 90% of all land managed (Pink 2009). The area of stubble burnt from surveys suggest about 20% of the median area of cereal stubble was burnt (Llewellyn et al. 2009). Some attempts was also made to estimate areas burnt using satellite technology to detect fire hot spots, but on the whole accurate records of practices are not collected (Scott et al. 2010). Some states like Western Australia and Queensland are less likely to use fire to remove residue (Pink 2009). As the areas of production are highly variable, it is at this point that due to the margin of errors in estimation that we lose track of the stubble impact on carbon inputs at the regional scale without more consistent local data. The degree of the degradation of the stubble into the more stable humus fraction of the soil carbon is another uncertainty that makes it difficult to consider the carbon input into the soil system.

The burning of crop residue is only a small fraction of the national emissions (0.025%), however it is a practice that can be changed for more beneficial agronomic reasons as indicated previously, along with environmental benefits from reduced soil erosion (Malinda 1995; Govaerts et al. 2007; Anderson 2009; Scott et al. 2010). Stubble has a nutrient value that can be returned to the farming system and can contribute to the soil organic matter in the more productive years as oppose to an emissions liability from burning (Whitbread et al. 2000; Dalal and Chan 2001; Hulugalle and Weaver 2005; Bell et al. 2007; Dalal et al. 2011) (figure 5).

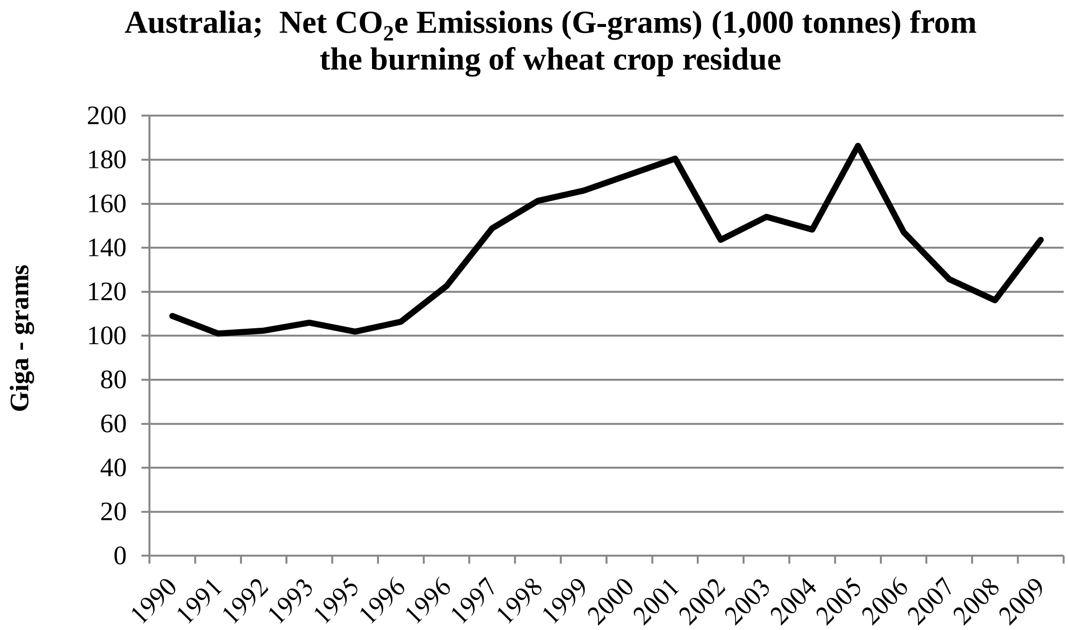


Figure 5 the pattern of emissions from stubble burning of wheat stubble. (Source: Australian Greenhouse Emissions Information System, Department of Climate Change and Energy Efficiency).

Policy aimed at stubble retention needs to also consider the issue of pest and disease carry-over in stubble which is an important agronomic consideration. An example that highlights this issue is the yield impact of wheat following wheat rotations by such diseases as Yellow Leaf Spot (*Pyrenophora tritici-repentis*), Crown Rot (*Fusarium pseudograminearum*) and Take-all (*Gaeumannomyces graminis* var *tritici*) which can be a significant incentive for stubble removal and this is one of the recommendations of the Grains Research & Development Corporation (Scott et al. 2010; GRDC 2011a).

In summary grain stubble left after harvest will emit a measurable estimate of GHG emissions as it breaks down, but it will also leave a component of carbon that is not easily measured in the soil dependent on the volume of biomass. Grain stubble burnt emits predominantly CO_2, CH_4 & N_2O, and leaves small amounts of mineral carbon but does not contribute to labile organic carbon, but will contribute charcoal to the inert carbon pool. Grain stubble grazed or taken off as feed transfers to another sector and reduces the contribution to organic carbon except as manure from grazing animals which comes with a component of N_2O from enteric fermentation.

At present there is a need for measurable information on the value of stubble residue in the carbon cycle and its role in the build-up of soil organic carbon. In dryland conditions it would appear to be a slow cyclical process with potentially small gains over time.

4.7.3 Fertiliser management and emissions in broad-acre grain

Fertiliser application is the second largest emitter of agricultural GHG emissions as N_2O, accounting for 18 % of Australia's agricultural emissions in 2012 (figure 6).

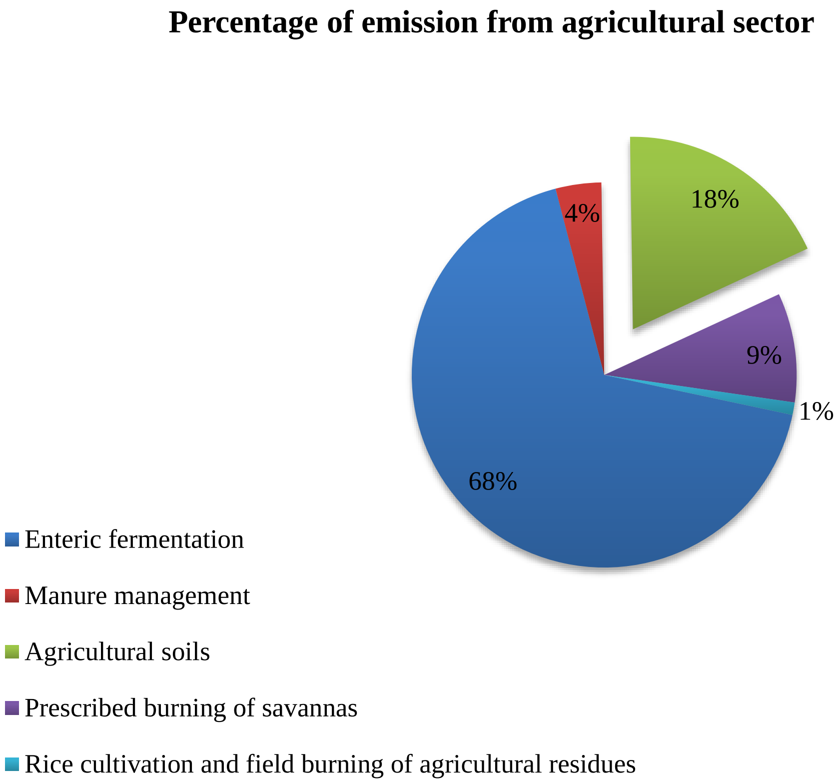


Figure 6 The percentage of emissions from the agricultural sector as accounted by the Australian National Greenhouse Accounts in 2012.

Following fertiliser placement in the soil in the form of ammonium compounds the product is transformed by urease bacteria to ammonia and ammonium; than to nitrates and N_2O which is released as a gas (Dalal et al. 2003; Addiscott 2004; Venterea et al. 2011). Fertiliser includes both organic and inorganic sources and is predominantly centred on the nitrogen cycle. Early farming practices involved a significant degree of cultivation and in doing so caused a reduction in soil organic carbon, hence a net loss of nutrients, predominantly nitrogen, phosphate and potassium (Dalal and Chan 2001). To manage the loss of nutrient in early farming systems, cropping areas were spelled and rotated with other crops such as legumes, new areas were exploited or manure was brought in. The advent of the manufacture of inorganic fertiliser by means of the Haber-Bosch process for ammonia synthesis saw a more cost effective way of replacing lost soil nitrogen (Addiscott 2004).

$$CH_4 + H_2O \quad \text{(superheated at 750 - 850°C, over a nickel catalyst)} = \quad CO + 3H_2$$

$N_2 + 3H_2$ (Nitrogen added via heat exchanger) = $2NH_3$

(after Addiscott 2004)

The process was energy intensive, but the price of energy was cost effective relative to the value of the product. The process saw an exponential increase in inorganic fertiliser from less than 10 million tonnes of production before 1950 to approximately 80 million tonnes during the next 50 years (Addiscott 2004).

This was followed by the mining of non-renewable phosphate rock deposits which is blended into fertiliser products (Cordell and White 2010). Potassium is also mined from potash deposits and imported (Johnston 2012). Mineral fertilisers provide the equivalent nutrient to 20 times the levels found in organic fertilisers on a tonnage basis, but does not include an organic carbon component (Drew 2010). Australian farmers have become dependent on manufactured and blended fertiliser as a more economical means of replacing the loss of soil nutrient and this is reflect in the increase in demand (Figure 7).

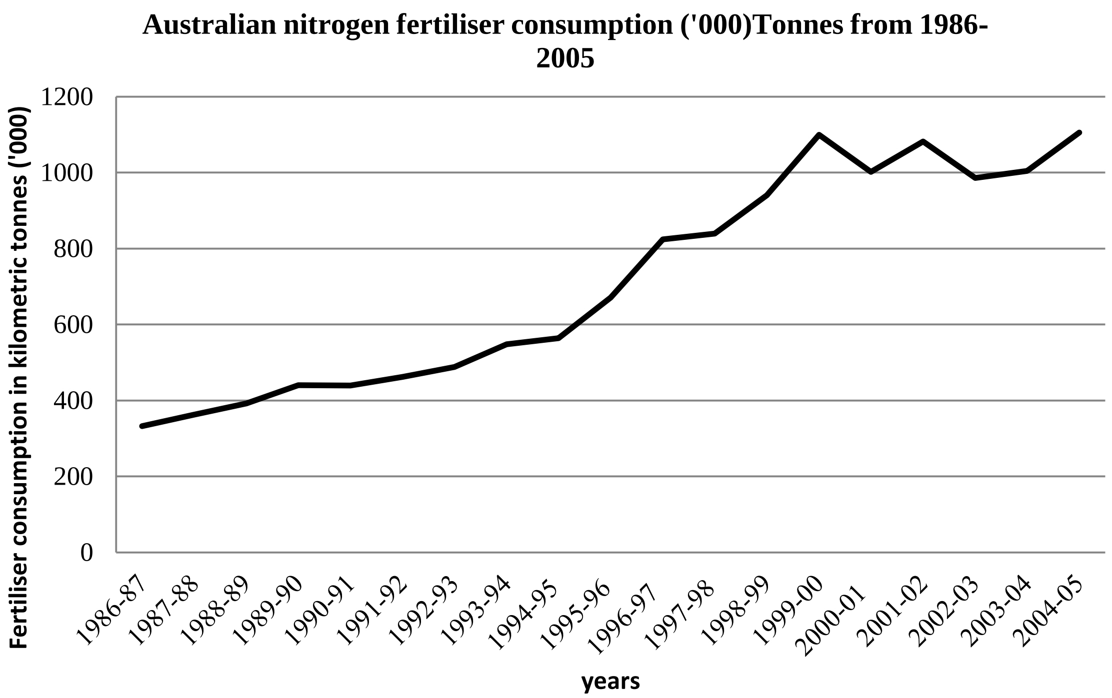


Figure 7 Volume of Nitrogen based fertiliser used by the farming sector over time (Source: ABS, Australian National Accounts, National Income and Expenditure, cat. No. 5204.0, Canberra; ABARES).

Inorganic fertiliser does not include organic carbon; the expectation is that farmers will incorporate the organic carbon from the biomass produced. However with a predominance of early cultivation, drought conditions and removal for animal feed, the levels of organic matter in many cropping soils have dropped significantly from the original native soils (Young et al. 2009a; Chan et al. 2011). A study by Conservation Farmers on the Organic Carbon (OC) content of 33 farmers in Western Queensland indicated an average of 0.92% OC in a range from 0.01 to 1.9% (n=33)[21] (Conservation Farmers Incorporated 2010 data used with permission). Native soils typically range from 1.15 to 2.2% depending on soil type and rainfall (Sanderman et al. 2010).

Fertiliser is a significant input in Australian grain production, but it is the application of Urea N that is the main source of emissions in the form of N_2O (Freney 1997; Dalal et al. 2003; Barton et al. 2008; Eckard and Armstrong 2009). The degree of N_2O emitted per rate of nitrogen fertiliser applied varies on the soil's environmental conditions but has been set a default figure by the United Nations Framework Convention on Climate Change of 1% where local estimations are not available (UNFCCC 2007). The UNFCCC takes advice on emission factors from the working party on EF data base. It is the responsibility of countries to determine what the best EF's are for their crops and environments. Australia has done this through the research programs and a culmination of nitrous oxide data over the past 10 years. This has been revised from a previous version of 1.25% established in 1996 (Dalal et al. 2003). Another factor that impacts on N_2O emissions is the pH of the soil; Australia has 90 million hectares of agricultural land that is acidic and at risk of further land degradation (Land Water Australia 1999). In current research Begum et al (2011) report a significant decrease in N_2O emissions by up to 70%, with a corresponding increase in CO_2 emissions by increasing pH from 5.0 to 8.0 (Begum et al. 2011).

The application of farm fertiliser can also be highly variable by region and does not always result in a yield response. In a study of 35 paddocks in western Queensland I obtained unpublished data from Conservation Farmers Incorporated to look at fertiliser application and the associated yield responses that indicated significant variation in use patterns (figure 8). The emissions of N_2O were calculated using the Grains Greenhouse Accounting Framework

[21] Data obtained from farmers soil test by Conservation Farmers Incorporated as part of GRDC research project CFI00009; used with permission

(GGAF) version 6 after Eckhardt & Armstrong (2009) showed that emissions did not correlate well with yield response from applied fertiliser.

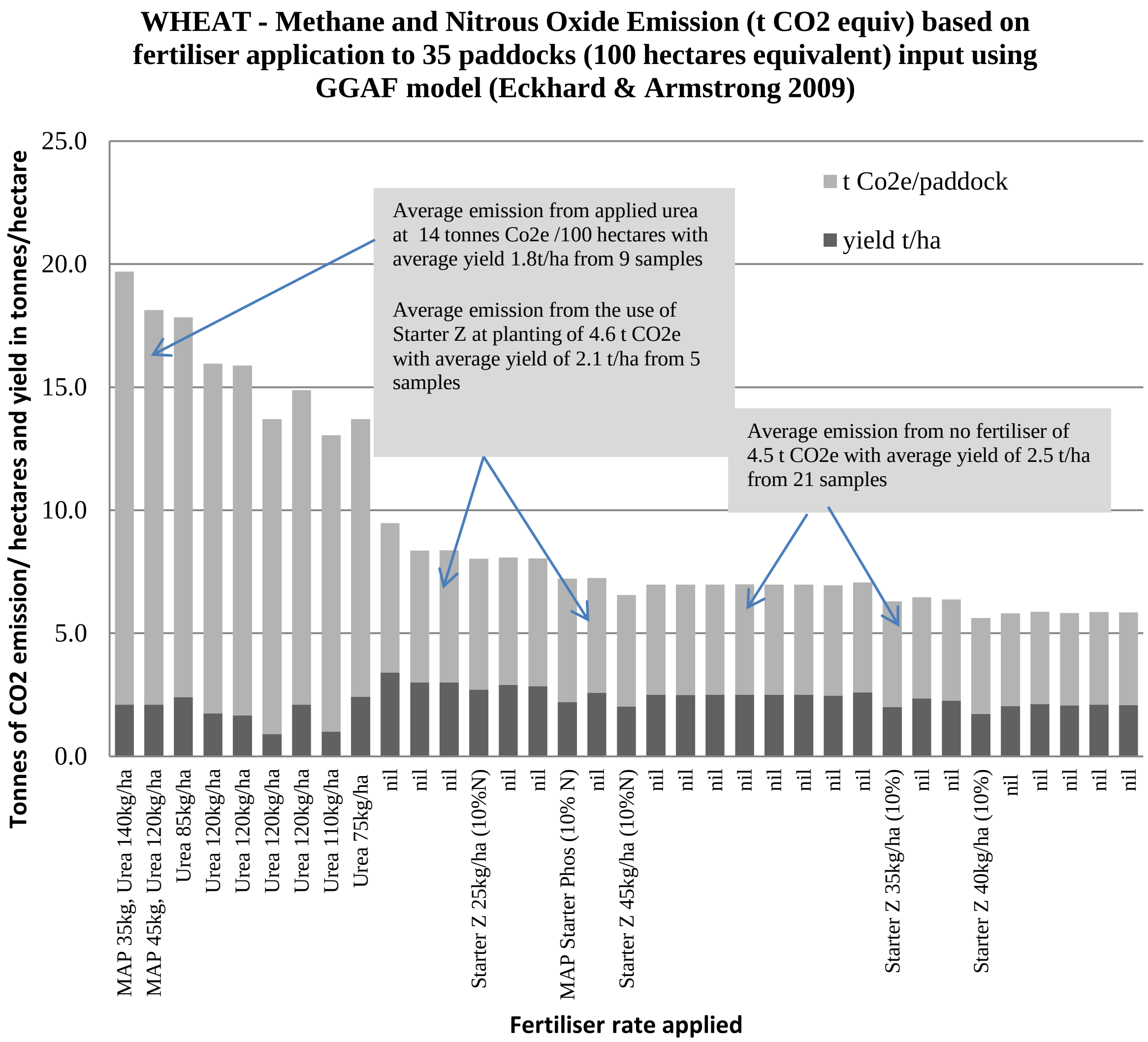


Figure 8 Fertiliser application data relative to yield from a sub sample of farms in Western Queensland in the period 2005-07 (source: unpublished data from Conservation Farmers Incorporated) analysed using Grain Greenhouse Accounting Framework V6 (Eckard and Armstrong 2009).

It would suggest that applications of urea can be lost with no benefit to the crop and that fertiliser management still has considerable room for improvement, being a source of emissions with no guarantee of a corresponding yield gain. Fertiliser application is also one of the higher inputs costs of farmers, although the emission profile of producing industrial fertiliser is standardised and measurable, its emissions characteristics on application to the soil is highly variable.

The second main source of nitrogen input is from the use of manure, both composted and raw. During the 2008-09 season industrial fertiliser prices increased dramatically in line with oil prices at the time and farmers turned to manure from intensive livestock production in their area as an alternative. The logistical cost of cartage and spread was being trialled and farmers were encouraged with some increases in yield. The Australian Bureau of Statistics estimates that farmers apply approximately 2.2 million tonnes of animal manure annually over 717,500 hectares (Australian Bureau of Statistics 2007). The increase in the application of animal manure as a source of nutrient was sparked by the sharp rise in fertiliser prices in 2008-09 which saw a subsequent decline in nitrogen consumption (Figure 9).

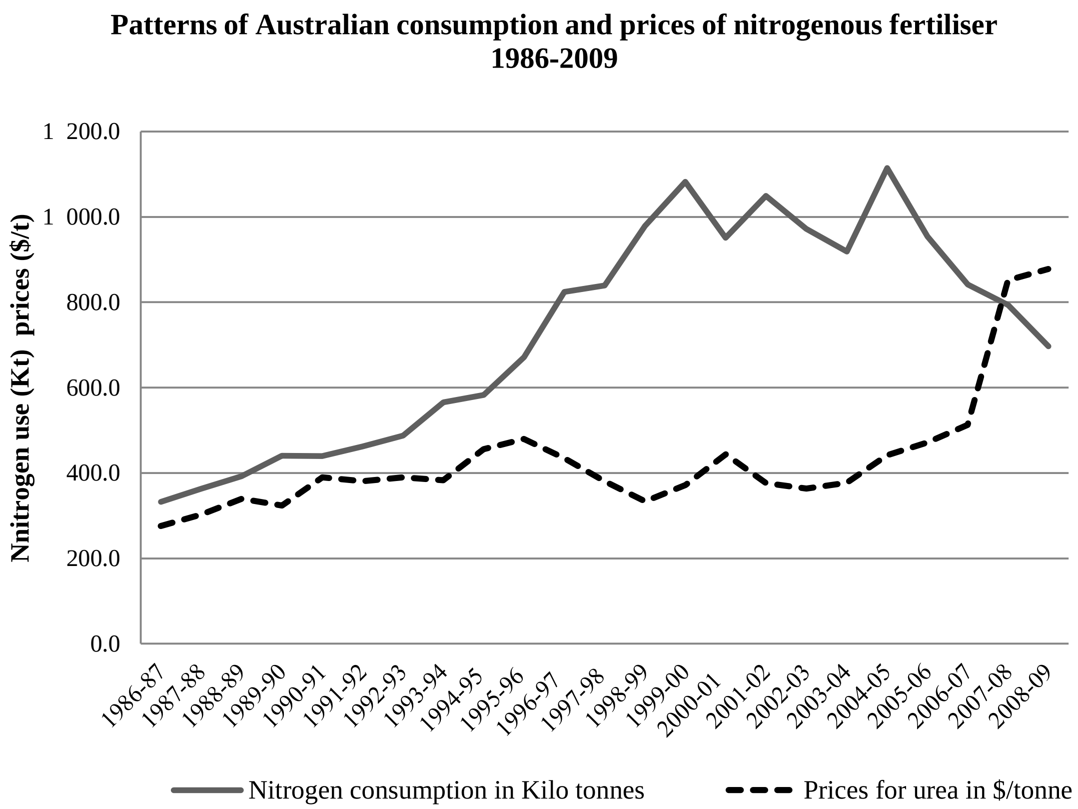


Figure 9 The consumption and price profiles for nitrogen fertiliser in Australia from 1987 – 2009 (Source: ABARES: Australian Commodity Statistics 2010).

Apart from N_2O emissions as a result of microbial de-nitrification of Nitrates (NO_3^-) and the nitrification of ammonium (NH_4^+), nitrogen plays an important role in building the necessary biomass for conversion to soil organic carbon (Herridge 2011). The interlinking of the two cycles means that nitrogen is important to the uptake of carbon in plants and that penalising nitrogen consumption could reduce biomass accumulation which is required in building and maintaining SOC (Lam et al. 2013).

4.7.4 Controlling machinery traffic on cropping soils

Limiting wheeled traffic on cropping soils achieves one very important agronomic benefit; it reduces sub-soil compaction so that roots can exploit more of the soil environment (Tullberg et al. 2007). Compaction not only limits the extent of root development, but also negatively affects the population of macro-fauna such as earthworms (McKenzie et al. 2009). The presence of flora and fauna also acts as a carbon sink in the soil environment and with less compaction the activities of macro-fauna increases soil aeration, thereby limiting anaerobic conditions (Krupenikov et al. 2011). Having the tractor wheels limited to a compacted lane also reduces the tractors energy requirement compared to driving on soft soils. The use of Control Traffic Farming (CTF) has been reported to reduce fuel consumption by a further 50% from Zero-Till systems (Tullberg 2009). At present the main measurable benefits of CTF to reducing emissions involves a reductions in tractor energy requirements and hence diesel consumption. The relevance of fuel consumption to emissions may also be significantly altered with fuel switching to a source of biofuel. The indirect impact of CTF to the exchange of soil GHG gases is less certain. Current field trials (unpublished) by Tullberg comparing compacted planted areas and non-compacted areas indicates that significant differences in emissions do exist in N_2O emissions with a ratio of 5.5 (compacted) to 1 (non-compacted) for 42 days after planting (J. Tullberg personal communication 2012). It is hoped that future research may provide more information as to any direct correlation between CTF systems and reduced N_2O emissions from cropping paddocks. Given the agronomic benefits of CTF; a direct emissions reductions benefit would indicate that a policy initiative targeted at increasing the level of CTF within the cropping sector would provide sustainability benefits to the industry given that less than 22% of crop farmers are operating on CTF (Edwards et al. 2012).

4.7.5 A return to crop rotations

Rotating crops by growing different types of plants sequentially in the same paddock has been a long term practice of agriculture to reduce the build-up of pathogens and manage the nutrient demand of different crops (Bailey 1996; Feller et al. 2003; Korstanje and Cuenya 2010). Under modern market pressures it is sometimes difficult for farmers to grow alternative crops that have poorer cash returns despite the potential risk of carry-over plant diseases (Godsey et al. 2007; Thomas et al. 2011). Legume production crops are widespread components of rotations as a means of increasing nitrogen inputs or minimising the demands from inorganic fertiliser (Whitbread et al. 2000; Lindemann and Glover 2003; Peoples and Griffiths 2009; Herridge 2011). Farmers will also move from one crop to another depending on market price; they will seek more profitable crop options if they are confident that they know how to grow the crop (Thomas et al. 2011).

From an emissions perspective the main benefit of crop rotations is the option to grow crops with larger biomass and the introduction of legume crops to reduce the demand for scope 3 emissions from synthetic nitrogen production. A larger biomass would also allow for a greater level of carbon capture to increase organic matter if the stubble is retained (Roldán et al. 2003; Schwenke 2005). Nitrogen is an essential element of plant nutrition but nitrogen needs to be transformed to nitrate and ammonium before it can be taken up by the plant (Jacobson et al. 1992). The value of legumes is that they can convert elemental nitrogen to nitrates using a nitrogenase enzyme (Herridge 2011). This is a much slower but more energy efficient process than the industrial Haber-Bosch process which requires a great deal of energy, mostly generated by fossil fuel (Roldán et al. 2003; Addiscott 2004; Dalal and Wang 2010; Huth et al. 2010).

The value of legumes in supplying soil nitrogen for following crops is well known to farmers but the economics of introducing a legume crop is not always acceptable when grain prices are high and pulse grains from legume crops low (Lindemann and Glover 2003). Grain seasonal prices have varied as much as 200% since 2004-05 with some legumes having similar variations not necessarily in tandem, resulting in variable production volumes and a gradual decrease in the area planted to pulses in general over the last decade (O'Connell 2010). Some of the more effective legume crops for fixing nitrogen are not always the most economical from a production point of view (Lindemann and Glover 2003; Thomas et al. 2011).

A policy option that supports the introduction of legumes to reduce nitrogen demand below standard application can significantly reduce N_2O and methane emissions which are potent greenhouse gases (Eckard and Armstrong 2009). However choice of crops based on emissions is not the same as crops chosen for profit maximisation or risk management; it is introducing another element in the choice process. Managing agricultural emissions by influencing the choice of crops would require some form of incentive in competition with the grain market. I suggest that the demand for a grain crop has limitations and incentivising growers to grow legumes could create an oversupply and destabilise the pulse market. There would be less market consequences to return the crop to the ground as a cover crop since legume residue breaks down more easily than cereal stubble (Herridge 2011; Zhou et al. 2012).

4.7.6 Cover cropping to protect and restore fragile soils

Cover crops are defined as crops which are not harvested, but grown during a potential fallow phase. The crop, sometimes referred to as a green manure crop is sacrificed to protect the soil from erosion, to build up organic matter or as part of an integrated pest management system (Dabney et al. 2001). The added benefits of cover cropping are similar to crop residue retention in improving soil structure and infiltration; most of which relate to the increase in organic matter (Jacobson et al. 1992). Soil condition, Temperature and moisture play an important role in establishment of cover crops (Dabney et al. 2001).

From an emissions perspective the main benefit of cover cropping is the potential increase in soil organic carbon from the addition of organic matter (Veenstra et al. 2007). The amount of organic carbon would depend significantly on the quality of the cover crop chosen, available moisture and nutrients (Herridge 2011; Zhou et al. 2012). There is some uncertainty in a greenhouse gas budget evaluation as to the final benefits given the N_2O and methane emissions from vegetation decay when balance against the carbon sequestration component (Baggs et al. 2000; Bavin et al. 2009; Gomes et al. 2009). Fertilisers to produce the cover crop will increase respiration and N_2O emissions (Eckard and Armstrong 2009). Where the cover crop involves a legume, some of this risk is mitigated with an increase in total soil nitrogen thereby reducing demand for inorganic nitrogenous fertiliser (Gomes et al. 2009).

From a farming perspective cover crops have a number of conflicting considerations; involving the long term soil management benefits versus the cost of implementation (Butler 2008). As there is no harvestable produce, there is no resulting cash flow. Subsequently the level of cover crop adoption is limited as farmers are likely to consider potential returns on investment (Dabney et al. 2001). In policy terms if the value of cover cropping is arguably beneficial from an emissions perspective, which is not yet clear, than there is an option for operating an emissions reductions scheme on the basis of 'additionality'. The major issue will still involve a measure of the units of emissions as the main benefit would be carbon sequestration not emissions reductions in the form of N_2O or methane. I noted that the perceived value of soil organic carbon is increasing amongst farmers and in parts of the US the use of cover cropping has increased from 62,000 acres in 2008 to 301,000 acres in 2013 (Myers et al. 2013).

4.7.7 Emerging Precision Agriculture technologies

Precision Agriculture (PA) involves the application of Global Navigation Satellite System (GNSS) to the deployment of farm machinery. Often other software are integrated to locate position for specific operations such as fertiliser or herbicide application (Cook and Bramley 2000; Mayfield and Trengrove 2009). Mostly farm operations are set as a series of paddock management zones; where each paddock is a crop portfolio based on physical landscape or historical consideration. Traditionally paddock zones are treated uniformly from a machine operation perspective, ignoring soil type, moisture conditions or weed populations. The ability of being able to integrate proximal and remote sensors on a farm map to gain detailed paddock information so as to deploy farm inputs more accurately has interested farmers in managing increasingly expensive resources such as fertilisers (Cook and Bramley 2000; Chanet et al. 2005; Rochecouste 2009; Bloomer and Powrie 2011). The value of the technologies aggregated under the name 'Precision Agriculture' to emissions reductions is their capacity to report on current practices and that opens the way to improve farm efficiency (Cook and Bramley 2000; Bloomer and Powrie 2011). Part of the aim of PA is to reduce the input cost of resources by placing only "*what is needed, where it is needed*"

(Bloomer and Powrie 2011). I believe that improving fertiliser management in particular can have a significant and measurable reduction in N_2O emissions given its correlation with N_2O emissions. It is not about simply 'more' or 'less' fertiliser but reducing fertiliser waste and maximising plant uptake; thereby using less fertiliser per unit of production (Whitlock 2006; Whelan et al. 2009).

Agronomic advisors have been supportive of supplying case examples of fertiliser efficiency that can be achieved on the farm. The expanding role of Geographic Information Systems (Sappington 2000) are increasingly being used for:

1. Automation of processes previously managed by hand or other technologies
2. Cartography the production of more informative and detailed maps
3. Decision planning – where maps are created for planning purposes in order to visualise and analyse data for planning purposes
4. Inventory of natural resources assets such animals, vegetation, water supplies
5. Modelling of scientific concepts

The yield from any crop can be obtained using the on-board yield monitor and with several seasons of historical data, it can be averaged to give the mean normalised yield data for that field (Figure 10).

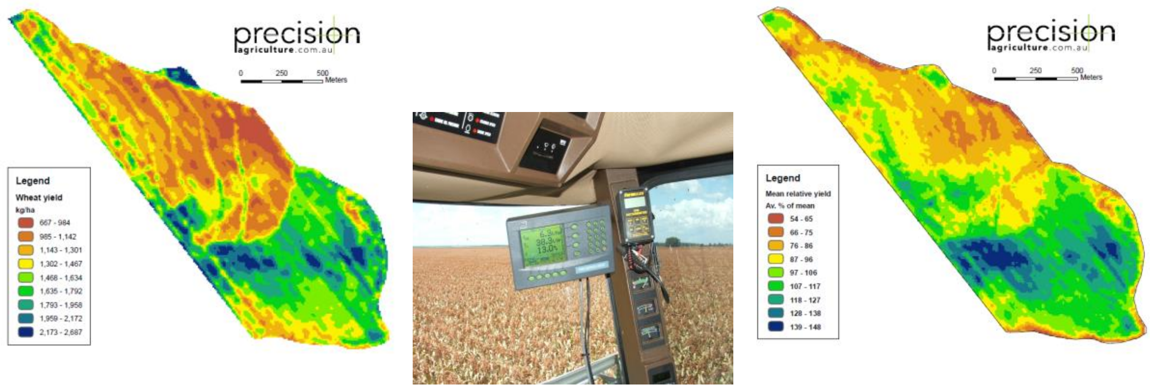


Figure 10 (Left) yield data collected at harvest from in cabin yield monitor (centre). Several years of data can be averaged to provide a normalised yield map of the field (right). Red-orange low yields (< 1.5 tonnes/ha), blue high yields > 2 tonnes/ha). (Source T. Neale Precisionagriculture.com.au used with permission)

In the example shown above the red orange area is consistently showing below average yield while the bottom blue-green area is more consistently producing better yields. The reason for this variation can be explored further for the likely problems associated with this response.

This level of detail is designed to match fertiliser requirement to the production capacity of the field. If the on farm trials (Figure 11) indicate that the more consistent higher yielding areas can deliver higher yields, this would indicate there is value in adding more fertiliser; if low yielding areas fail to respond to higher applications than it is more efficient to minimise the levels of inputs (Figure 12). Since nitrogen fertiliser is proportionally linked to N_2O emissions than any fertiliser not taken up by the plant ends up as an externality to the system by either polluting waterways or the atmosphere. Such a waste can be regarded as avoidable emissions.

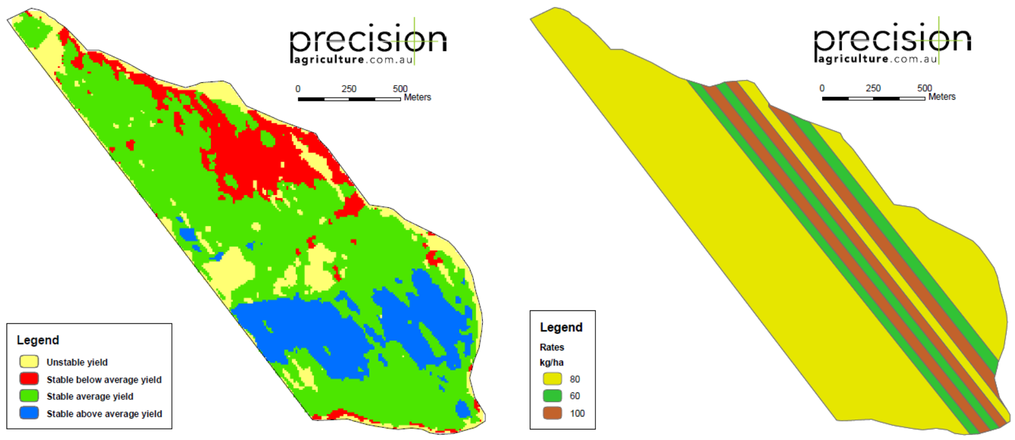


Figure 11 (Left) The degree of variability in the yield history can be analysed to determine the degree of stability in the data to predict stable areas of 'below average', 'average' and 'above average' yields. (Right) A range of fertiliser rates can be applied in trial strips to determine response. (Source T. Neale Precisionagriculture.com.au used with permission)

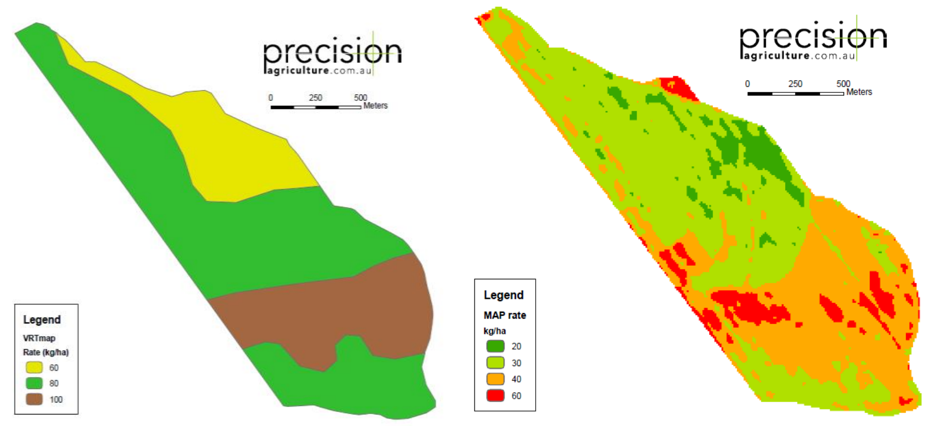


Figure 12 Prescription maps can be produced based on the trial results that will operate the fertiliser applicator to vary the amount of fertiliser to be applied to various parts of the field. This can deployed to different levels of accuracy such as a simple three zone system (Left) or a more complex system that delivers fertiliser to more exacting requirements (Right). (Source T. Neale Precisionagriculture.com.au used with permission)

It was evident from figure 8 previously in section 4.7.3 that the addition of fertiliser does not always result in yield increases and an average application of 100 -120Kg urea per hectare could create approximately 140kg of CO_2e /hectare and cost the farmer about $84 AUD/hectare for no discernible benefit in grain production. Any practice that can reduce the wastage of fertiliser can make a worthwhile contribution to emissions reductions per tonne of production; which is not the same as a net reduction in fertiliser use. However the more fertiliser is taken up by the plant, the less is left to go into the atmosphere and the more biomass in increased that can contribute to SOC.

The cost of entry into a PA system is variable depending on where a farmer is in the purchase of machinery cycle, but new equipment such as yield monitors, have been incorporated as a standard feature of new harvesters. This simplifies the entry process of using new technology as it is no longer an after sale add-on system. Farm efficiency can also refer to a reduced requirement for diesel fuel as operational logistics are reorganised to manage fuel savings. Where less fertiliser or chemicals based on more accurate crop demands is required, the amount of tractor hours is reduced.

A PA system also has important consideration from an emissions management perspective; apart from the direct energy management side, they introduce the means to provide reports for monitoring and evaluation purposes. Indeed one of their primary commercial function was to collect activity data in digital format for farm reporting, analysis and planning (Rochecouste 2009). That digital capacity could also be used as a monitoring and evaluation tool in reporting to market investors for abatement projects. At the research level the combination of proximal sensors combined with a geo-referencing technology can provide detailed spatial recordings of soil profile changes (Adamchuk et al. 2004).

In summary digital technology combined with a spatial referencing system can help improve the efficiency of resource deployment.

4.7.8 Rediscovering the role of manure (recycled organics)

Recycled organics is a general term for products derived from garden and food waste, biosolids, animal industry effluent; the product is either as a raw product (waste or manure) or as a composted material (recycled organics)(Gibson et al. 2002; GRDC 2010). Composted quality is defined by an Australian standard (Standards Australia, 1999[22]). The artificial composting process is a shorter more controlled process than the natural decomposition and decay of organic material (Epstein 1997). Many agricultural soils in Australia have depleted levels of soil organic carbon in comparison to their natural states, and therefore it is perceived to have a potential capacity to sequester a significant amount of carbon (Dalal and Chan 2001; Chan et al. 2003; Chan et al. 2008; Kirchhof and Daniels 2009; McHenry 2009). Another option to stubble retention and green manure crops is to introduce soil organic carbon to the field from recycled organics (Gibson et al. 2002; Calcino et al. 2009). The process of recycling waste streams has been used as part of agriculture for centuries. In the last two centuries with the growth of cities it became more efficacious to dispose of waste stream in central locations, rather than disperse the waste across a multitude of farms over large areas. Modern cities and industrial processes also introduced industrial contamination such as heavy metals to waste streams which was problematic from an agricultural perspective (Chen et al. 2010; Pritchard et al. 2010). These contaminants compounded with potential health issues of transferring diseases would have required extra costs to sanitise waste streams as well as allowing for transport and spreading (Barry and Bell 2006).

[22] Standards Australia 1999. Australian Standard AS 4454-1999. Composts, soil conditioners and mulches.

This change in old world practice means where a significant proportion of farm produce (food waste) ends up in non-recycled waste streams is common to most cities. Recent research has being undertaken to look at the capacity of agriculture to take biosolids from the urban areas (Barry and Bell 2006). The major issue of concern is soil quality being compromised by heavy metal contamination and the cost of transport and spreading material that has a low value with a high water component. The value is limited by what farmers can afford in competition with inorganic fertilisers.

In recent times local government are increasingly creating other waste stream in the form of modified green waste to reduce the rising cost of landfill. The green waste has low nutrient value but can be bulked with biosolids to produce alternative product options (Barry and Bell 2006). Most commonly waste stream from animal industries, including cattle feedlot, piggeries and poultry sheds areas being diverted to cropping agriculture as an alternative to synthetic fertilisers (Figure 13).

Figure 13 Manure being loaded on spreader for field application (left) and spreading process (right) (source: Conservation Farmers Inc.)

Only a part of the applied recycled organics actually remains as soil carbon but there is limited data available in Australia on the fraction retained based on various recycled waste material (Gibson et al. 2002, Slattery et. al 2002). Manure prior to a composting process emits a number of greenhouse gases including methane and carbon dioxide. From an agricultural emissions management perspective, recycling organic material does provide an opportunity to increase soil organic carbon despite the uncertainty on measurements (Sanderman et al. 2010).

4.8 Policy consideration

Whilst farmers may willingly change farming practices such as reducing tillage of their own volition, this will usually take decades for the practice to be commonplace (Llewellyn et al. 2009). In some instances, the policy agenda may require a shorter cycle based on the emissions reductions commitments of a government to climate change targets. In circumstances where the time frame for change in practices is likely to be too long to meet committed targets, some form of policy intervention will most likely be required to accelerate changes. A policy consideration when encouraging changes of farm practices to reduce emissions in cropping is that both the carbon and nitrogen cycle in plant production needs to be considered. In such a complex system a careful examination of consequences is required to consider whether policy intervention is needed or even possible, and if so where it might be most relevant to intervene. There are circumstances where farmer's goals are in line with carbon policy such as yield maximisation and biomass (carbon) accumulation. The government is looking to increased soil organic carbon in long term carbon pools but needs biomass to initiate the process. Since biomass is a function of yield; farmers most often seek to maximise yield in the expectation of realising a profit. However there are also some potential conflicts; grain being a commodity product means that farmers are likely to base their decision of crop choice and input requirements on the anticipated return for the commodity, not the volume of biomass it produces. Also growing of big biomass crops means that there is a large amount of stubble to sow into with the next season's crop. Dealing with big stubble loads is an on-going issue for conservation agriculture farmers who often rely on old practices (e.g. burning) to alleviate the problem and deal with slugs and crop diseases in wet years.

The degree of uncertainty of agricultural commodity prices and seasonal weather influences also results in unpredictable profit risk for a producer, therefore it is likely that farmers are not focussed on reducing GHG emissions of the inputs required, but are more focussed on increasing yield (biomass) at the lowest input cost. While the farmer's goals and policy agenda may at times have similar direction (figure 14), farmers are less likely to be concerned about the emissions implication and more concerned about profitability. However as previously reported emissions are often a by-product of inefficiency and certain farming systems by reducing waste and associated costs are also reducing emissions. This is evident in the CA systems where reduced tillage, reducing soil compaction, stubble management, legume rotation, introducing cover crops, and precision delivery of inputs with aim of improving long term soil health is also reducing emissions (Butler 2008). A question for consideration is whether such an integrated system is capable of delivering improved agricultural production and emissions efficiency in line with government policy.

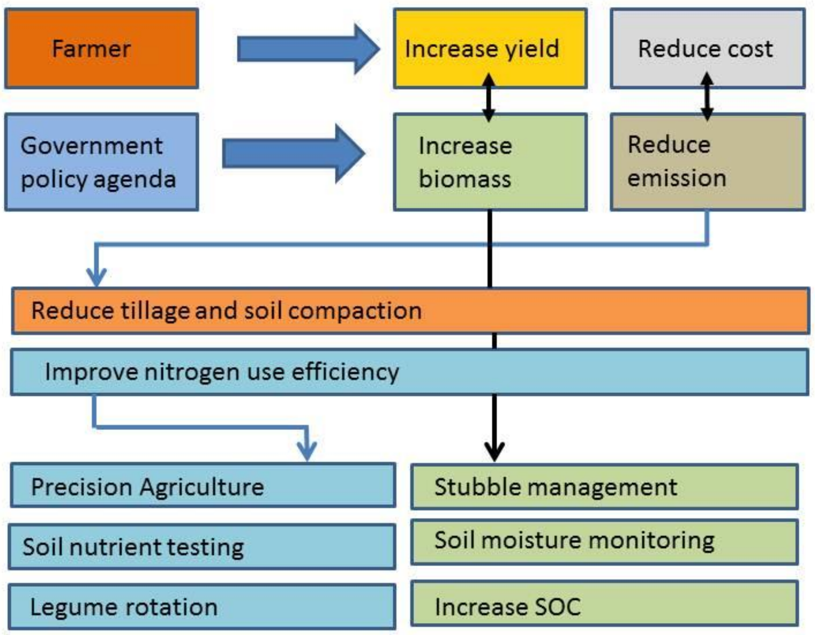


Figure 14 Alignment of government and farmer interest in outcomes and the farming practices that might be considered supportive of both outcomes.

Another factor for policy consideration is whether to apply a direct or an indirect policy instrument. A direct policy instrument seeks to make changes in practices directly at the source of change required and may use a 'command and control' process such as penalising a pollutant source (taxing fertiliser) or incentive payment for taking up a product such as fertilisers with urease inhibitors (Horan and Shortle 2001). Other policy alternatives are more indirect and can also be either a penalising process on incentivising process. The introduction of an additional tax offset for reduced tillage equipment is an example of an indirect incentive on an input to tillage practices. In this instance the policy is seeking to introduce an incentive for taking up reduced tillage by offering a financial reward. Reducing tillage is not the same as reducing emissions but indirectly reducing tillage is accepted as reducing organic matter mineralisation leading to soil emissions. The accepted linkage is deemed to be sufficient that an uptake of no-till equipment will lead to a reduction in tillage, which will in turn lead to a reduction in emissions. Such an indirect process can apply to a range of farm practices but needs careful consideration to avoid unintended consequences.

The issue of applying a direct policy penalty is that it is generally unpopular and needs to be enforceable which can also be expensive and be difficult to implement (Cocklin et al. 2007). Indirect intervention in the market is another option; in the state of Victoria the government has taken on the role of providing farmers access to accurate guidance (RTK correction) for farm practices, which is required to be commercially purchased by individual farmers in other states. In doing so Victorian farmers are able to take up Precision Agriculture at reduced cost in comparison to their interstate counterpart (Millner et al. 2007).

The government has a range of options to interfere in the market place, however doing so often has social consequences and can be costly. In a democracy, negative social impacts tend to have an impact on potential re-election, so the impact of any policy or legislation is usually thoroughly considered through consultation with stakeholders (Gourley and Ridley 2005). Financial incentives are likely to be more popular but must be affordable. A breakdown of policy framework is considered in Table 10. Whatever approach or drivers are used, the policy should be measureable and accountable for the outcome being delivered.

Table 10 Policy approaches and drivers to influencing farming practices

		Approach	
		Direct	Indirect
Driver	Penalty	Taxes, Levies on emissions directly	Taxes on contributing inputs or markets

	Incentive	Rebate and subsidies on emissions reductions	Rebates and subsidies on selected inputs. Levy on markets to support output.

Policy development can be further complicated by policy initiatives that are in place for other outcomes by either another government department or a different level of government. It is possible for policies to be in some degree of conflict that reduces the outcomes anticipated. This is evident when production goals and environmental goals do not account for each other (Abler and Shortle 2001).

Climate policy options might explore areas where farm efficiency would also result in a potential reduction in emissions. Options for consideration might include a range of practices for nitrogen use efficiency leading to a reduction in N_2O emissions relative to grain production (figure 15 & 16). Production is still an important consideration so crop input efficiency is the outcome in this instance, rather than a direct net decrease in fertiliser consumption.

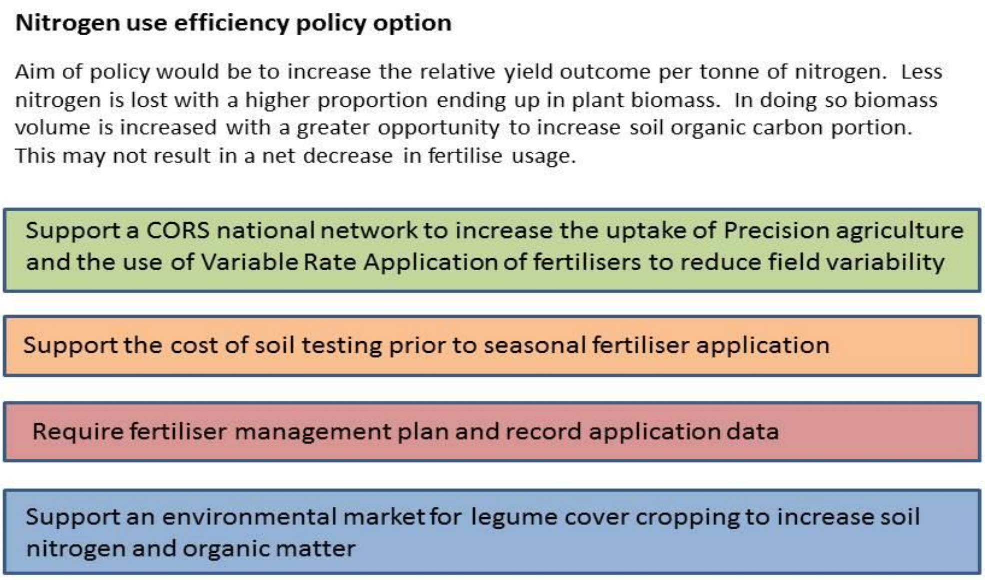


Figure 15 Some policy consideration for reducing nitrogen waste by improving nitrogen efficiency

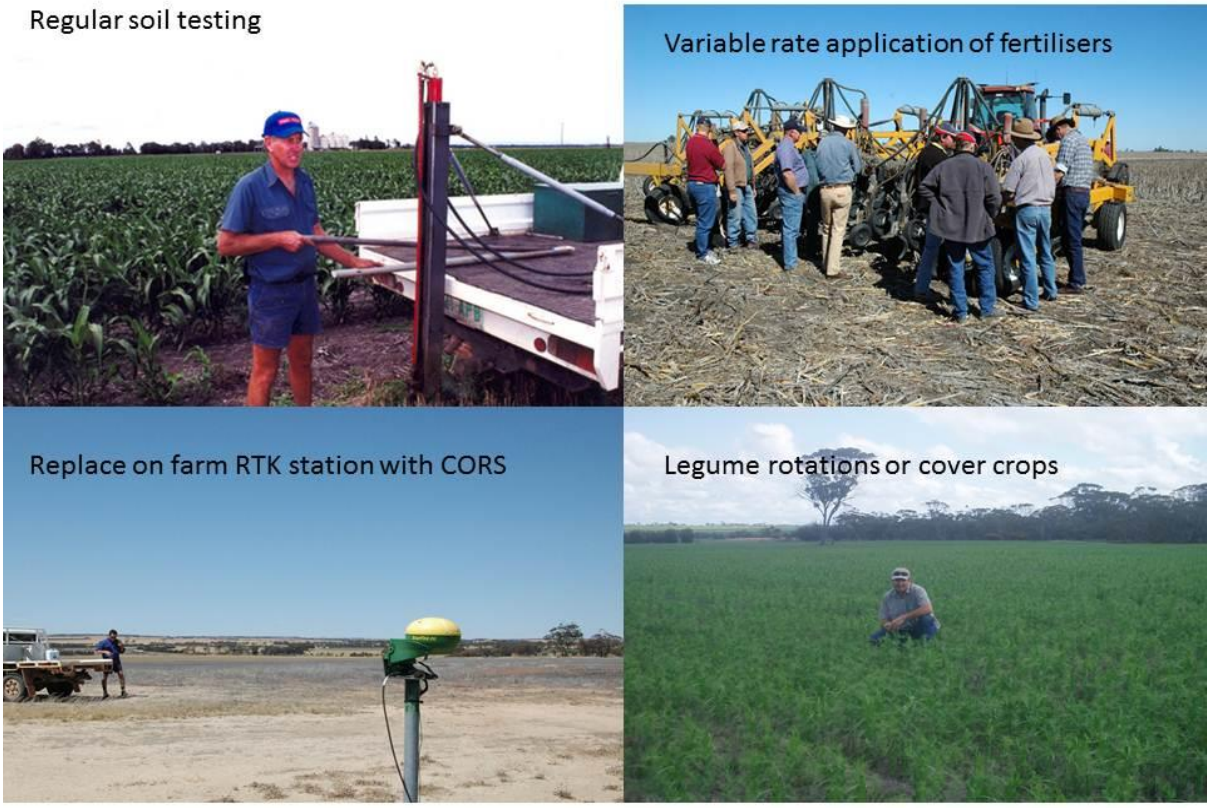


Figure 16 Some potential farm practices for improving nitrogen efficiency include regular soil testing, the use of Variable Rate Application, supporting Global Navigation Satellite System with correction station for highly accurate guidance and legume crop rotation. (Source photos J. Rochecouste)

4.9 The issue of data variability and the potential policy implication

Policy development is largely dependent on the quality of the data supporting the argument for intervention. Where such data is not directly or easily available some forms of estimates and proxies may be used with risk that it may draw erroneous conclusions. Agriculture is highly variable and the grains industry exemplifies this degree of variability (Malcolm et al. 2009). Both soil and climate can dictate the farming practices that are available to a farmer. The soil environment which is one the main factors driving GHG emissions and sequestration, is highly variable in terms of its physical, chemical and biological capacity (McKenzie et al. 2000). Such variability makes for a very unstable base from which to develop national policy. Across the grains industry this can vary from the high clay content of the vertosols on the Queensland Darling Downs to the mostly sandy loams of Western

Australia; therefore policy that is seeking to uniformly change a practice has to accept a high degree of variability in outcome. It is therefore problematic for policies such as increasing soil carbon to have equal opportunity across such a variable environment. Another important factor of the grain growing regions is moisture; its availability, timing and intensity. Grain production is predominantly reliant on incidental rainfall rather than irrigation, and available moisture has significant impact on biomass accumulation, soil biomass decay, emissions of gases and carbon retention. Another significant factor in variability is climate cycles, such as 'la Nina' and 'El Nino' which determines temperature, evaporative index and retained moisture. Drought years will have little opportunity for biomass accumulation, while wet years will drive high biomass accumulation but also increase the incident of disease carry-over that requires burning of residues.

Beyond the variability of the biophysical factors of the farm, an individual farmer's practice is inherently variable, based on local conditions and their own view of farming (Vanclay 2004). While such things as fertiliser may fit within a range, agrochemicals such as herbicide and fungicides rarely do and can vary significantly based on seasons and local conditions. In an analysis of scope 3 emissions from herbicide use for 30 farms across South West Queensland, using energy values reported by Helsel (1992) indicated variations from 0 to 195.1 KgCO_2e/hectare (see chapter 7). The policy implication is that creating environmental markets for emissions that are mostly reliant on non-mechanical processes in a highly variable environment is unlikely to produce the type of certainty that markets expect (Kimble et al. 2002; Antle and Stoorvogel 2009; Walcott et al. 2009; Sanderman and Baldock 2010). This leads to the problem of what other alternatives can policy development take, knowing that a number of assumptions are going to have to be made. Developing policy under these types of interactive complexity is perhaps best considered by using a systems thinking approach (Checkland 1999; Sherwood 2002; Bosch et al. 2007). 'Systems thinking' recognises that complexity is an inherent part of dealing with wide ranging policy areas like climate change. It attempts to consider the issue as a whole so as to avoid conflicting isolated silo mentalities, where fixing the problem in one area may simply push the problem to another area (Sherwood 2002). In the following chapters I will examine emissions from the cropping system as a whole and consider the various drivers influencing emissions from the CA practices as sub-systems.

4.10 A review of CA practices and potential for emissions reductions from dryland agriculture

If CA practices have potential for reducing agricultural emissions than it is worth considering to what extent it is already part of normal agricultural practice. In terms of abatement projects, under the IPCC guidelines which have been adopted by the Carbon Farming Initiative, projects cannot claim carbon credits if it involves a change of practice that is considered ‘common practice’ within the industry. Abatement projects are expected to go beyond ‘common practice’ under what is termed an ‘Additionality’ test to standard practice (Woodhams et al. 2012).

The proposed ‘common practice’ framework recommends that a practice that falls below 5 per cent of activities by farmers may be deemed ‘additional’; if the level of adoption is above 20 per cent then the practice is deemed to be ‘non-additional’ (Woodhams et al. 2012). This was drafted to give the market confidence that they were not paying industries for what is deemed commercial interest activities. This means that abatement projects could not apply to changing agricultural practices that are already at levels of 20% adoption or above and effectively rules out a carbon market initiative for the adoption of most CA practices. Depending on the likely emissions reductions value of the change it seems that foregoing a further 80% in the short term seems somewhat premature given the difficulties getting practice change in agricultural industries and the statement by the UNFCCC for action sooner rather than later. The key to evaluating the validity of this rule in regards to the climate change imperative is perhaps to put a carbon emissions reduction value on the remaining percentage not adopted (Table 11).

Table 11 Percentage uptake of practice within the grains industry in 2011 (Edwards et al. 2012) and the potential abatement value of changing farming practices.

System	Estimated uptake	Potential abatement value based on 23 million hectares (m ha) of production
No-till (<25% *soil disturbance*) *The balance reflects a combination of*	60% (13.8m ha)	In terms of carbon (C) loss from tillage using a conservative estimate of 0.139 tonne C ha^{-1} /year (Lam et al. 2013). Of the remaining 9.2m ha, this would provide an estimated potential of 1.2m tonnes of carbon net loss from mineralisation per year.

minimum till, direct seeding or conventional tillage		
Full stubble retention (*Defined as stubble retained to next planting but may include some grazing*)	60.5% (13.9m ha)	The Australian grain crop produces about 22.6m tonnes of carbon or 0.98 tonnes of carbon per hectare as crop residue. Only a small fraction of this carbon potentially stabilises to a humus fraction (excluding biota). Figures from the NSW DPI AgNote DPI – 464 suggest that retaining stubble rather than burning it can sequester 70–90 kg C ha^{-1}/year. A more recent meta-analysis by Lam et al. (2013) suggests a figure of 62 kg C ha^{-1}/year. For the balance of 9m ha, this would equate to a potential 558,000 tonnes of carbon that needs attention. It is not clear from the percentage land area where stubble is not fully retained to planting, how much carbon is lost, but at least 3m ha was burnt in 2011.
Legume rotation	6.8%	It is not suggested that cereals be replaced by legumes but the inclusion of legumes in a 1:4 year rotation would add 0.25 of the estimated 110 kg N/ha (Herridge 2011) and equates to about 28kg of N per year across 23m hectares and represents 0.635m tonnes of Urea/year that is otherwise produced from fossil fuel as a scope 3 emissions. The exact abatement potential is uncertain as legume production is limited by the market volume from export demand. NSW DPI AgNote DPI – 464 also suggests that legumes can sequester up to 150 kg C ha^{-1}/year. If only 0.25 of the full cropping area was planted to legumes once in every four years that would represent about 862,500 tonnes of carbon per year.

Controlled traffic farming (CTF) (*It is unclear if this represents all farm machinery or only some of the machinery, noting that a single pass creates compaction*)	21.1% (4.85m ha)	There is indication that compacted soils emit higher rates of N_2O than non-compacted soils and that CTF reduces overall soil N_2O emissions by limiting compaction to a small section of the field. The amounts involved are not able to be calculated at this time. CTF also reduces fuel consumption per hectare to about 50% less than non-CTF fields, noting that definitions of CTF are often perceived differently by farmers and surveys do not always pick up the variations. What this represents in abatement terms is still unknown without further research.
Precision agriculture use of variable rate technology (VRT) to fertilising operations	8.1% (1.9m ha)	Although the use of auto-steer guidance requiring precise GPS capacity is at 66.7% adoption, VRT use is still quite low. Efficiency gains are primarily measured in production terms of nitrogen use efficiency. This can represent an increase in the efficiency of fertiliser use, reducing waste of an intensive energy manufactured product. The value to abatement is still unclear without further research.
Use of recycled organics	unknown	According to the Grains Research and Development Corporation (2010). The annual volume of recycled organic fertilisers produce from industry waste is in the order of 5.21m tonnes. The carbon fraction is highly variable but represents about 35% dry weight. The N_2O emissions value of uncomposted manure brought on-farm is unknown. This represents a recycling of about 1.8m tonnes of carbon per year. There is a complex balance of emissions options associated with intensive animal industry.
Cover cropping* in rotation	<1%	Cover cropping is the addition of soil organic carbon inputs as a green manure crop. The amount varies

		considerably depending on the cover crop chosen. The introduction of a cover crop in the production cycle is limited by available soil moisture and cover crop produces no cash-flow for farmers.

* The following has not been included in any recent surveys and is not accepted practice within the industry. Only a very small number of growers practice cover cropping.

Table 11 is not intended as a detailed analysis of available carbon credit, indeed there are many complications in relation to the bio-physical factors existing on farms and the interaction of the Carbon-Nitrogen ratio. Nevertheless from a policy perspective it does ask the question whether excluding the balance of practice change is perhaps missing an opportunity for low cost abatement, given the land sector is still a key option for sequestering carbon. It seems the additionality framework is predicated on farmers acting as 'firms' and there has been some suggestions by sociologists that while farmers prefer to operate within an economic framework; they do not entirely fit the economic behaviour of a 'firm' (Vanclay and lawrence 1995; Vanclay 2004; Egan 2008). It is also evident that individual farms are unlikely to have sufficient carbon credits to warrant the required compliance effort; estimates for emissions from a typical grain farm is in the vicinity of 660 tonnes of CO_2e (Keogh 2007) from fertiliser, fuel, soils and stubble burning. Any decrease from that level as an abatement opportunity is not going to provide much in the way of returns when compared to grains. Their value is perhaps more as an industry sector than as individual enterprises.

Estimates by Tiessen et al in a review of the literature suggests that grain operations using conventional cultivation lose about 1% of their Soil Organic Carbon (SOC) stocks per year (Tiessen et al. 1981). A number of studies have indicated that under Australian conditions reducing tillage achieved little in the way of increasing SOC but did significantly reduce the depletion of SOC stocks (Dalal and Chan 2001; Chan et al. 2003; Wang and Dalal 2006; Luo et al. 2010). A soil baseline measurement of Carbon stock (C_s, t/ha) for an Eastern Australian vertosol in 1994 by Young was recorded at 25.35 t/ha (average of A & B horizon) and 6 years later recorded 25.9 t/ha under reduced tillage (Young et al. 2009a). If we consider the impact of tillage since 1990 when the date established for quantification by the Kyoto protocol, when conventional tillage practices in Australia was at about 20% (Llewellyn et al. 2009). A 'Business as Usual' case using conventional tillage would have meant a depletion of SOC of about 5 tonnes per hectare more than CA over a 21 year period (Figure 17). This is not significant on an individual farm basis, but in national terms the potential for reducing carbon loss from the soil can conservatively be estimated using 50% of the calculated estimated loses (i.e. 2.5 tonnes/hectare) over the Australian cropping area (23 million hectares) it could be in the order of 57.5 million tonnes of carbon depletion. These can only be broad estimates given the variability of biophysical factors across Australia. However it does point to the likelihood that at the national level there is some externality benefit to be gained by encouraging farmers to reduce tillage.

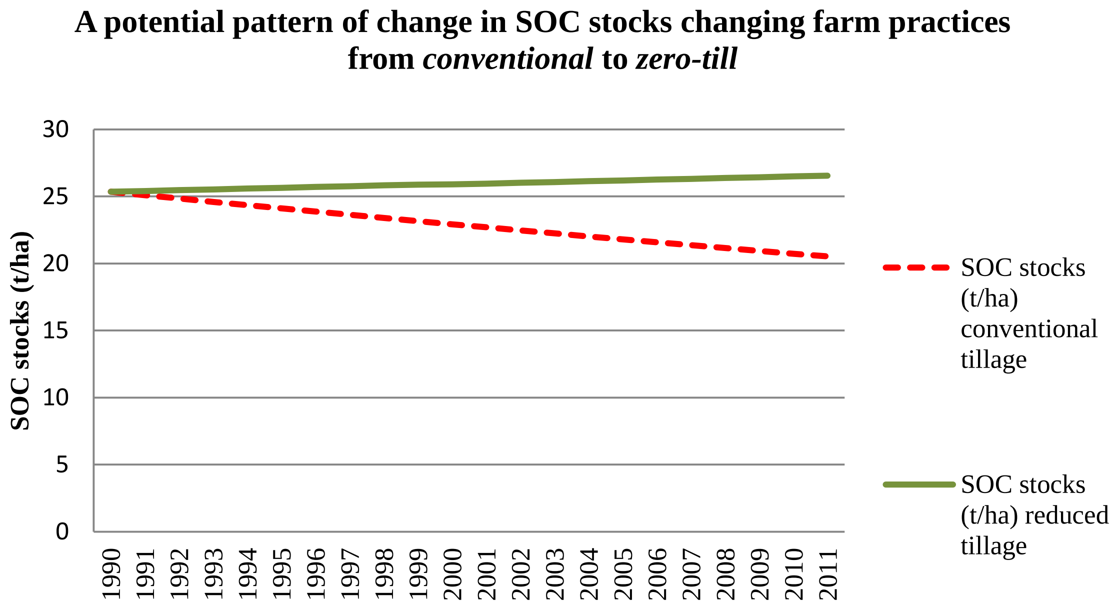


Figure 17 Estimated loss of carbon from conventional tillage over time (adapted from Young et al 2009a)

At present Australia is unable to include these abatement options in the national accounts in the national accounts as part of the Kyoto agreement. Under Article 3.4 of the Kyoto protocol which allows changes in practices such as going from conventional tillage to reduced tillage to gain credits it must conform to set accounting rules that compare net baseline values of soil carbon against future net values, after discounting for any on-farm emissions. As yet we do not have clear baselines of soil C stocks from 1990 across the various soil types. Australia is also subject to drought and bushfires that can significantly increase on-farm emissions relative to the likely increase in soil carbon and this was seen as too great a risk for Australian agriculture and Australia has therefore not previously signed up to Article 3.4 as part of its Kyoto obligation.

Given that farmers are not currently liable for their emissions and the continuing uncertainty around compliance, legal liabilities, low carbon price and transaction costs, it would seem that the most rational use of their limited time would be to be improving their production efficiency. The net result is that the majority of farmers under the current market condition are unlikely to participate as individuals in carbon farming opportunities.

Summary

In terms of a rural climate change policy target, the farm boundary is the scope 1 emissions emanating from the operational activities under the influence of the farm manager. We note that farms can be either an emitter of GHG or a source of sequestration for carbon depending on practices. They are not however, required to report their emissions liabilities; which are highly variable, based on bio-chemical processes and are difficult to record. The need for policy intervention is highlighted by the perception that farmers are more concerned with immediate production issues and less concerned about looking for ways to reduce climate change externalities. Emissions, predominantly CO_2 and N_2O come from a range of sources and are difficult to measure, relying on approximations (default factors from models). This creates reporting issues in terms of accuracy and linking policy with changes that will reduce emissions. Practices and the need for changes are better understood by farmers under a farming system paradigm. The opportunity for carbon sequestration is highly variable and cyclical in cropping systems, which creates issues with measurements and reporting of emissions. I note that only some emissions are accounted for by the National Accounts, the major contributions from cropping in terms of carbon loss to the atmosphere is from earlier land clearing, tillage of the soil, applied fertiliser and the burning of crop residues. CA practices advocates reducing tillage, retaining stubble, improving fertiliser efficiency and building soil health that is more resilient. These activities may reduce emissions and carbon loss. This tells us that CA practices reduce a certain degree of emissions even accounting for leakage factors, but it is difficult to measure at a farm scale. Adoption of CA practices would reduce an uncertain level of emissions and in the preceding chapter I consider the characteristics of the farming systems and what the drivers to adoption are.

It is acknowledged that CA practices like all farming operations will have variability and cannot provide a consistent abatement unit, especially at farm level. I feel that broad adoption of CA will contribute towards an emission reduction, albeit not directly measurable. We noted that the Canadian model operated on an approximation of emission reduction across region based on a farm practice change (see section *3.3.3*). Similarly, it may be possible to make a conservative estimate of the emission benefits associated with the level of practice change in Australian agriculture that would contribute to the national accounts.

5.0 A REVIEW OF SYSTEMS AND ADOPTION FACTORS IN AGRICULTURAL INDUSTRIES

The previous sections outlined the variables influencing GHG emissions in CA practices in Australia. Most of the focus on CA to date has centred on tillage practices and stubble retention (Murphy et al. 2011). However with many farmers having already adopted no-till and stubble retention, growers have turned their attention to other CA practices as outlined in section 4.7.4 to 4.7.8 (Tullberg et al. 2007; Butler 2008; Llewellyn et al. 2009; Robertson et al. 2012).

Where a practice change shows a net reductions in emissions it can be considered that adopting such a practice will contribute to an overall reduction in agriculture’s emission profile. The degree of emissions is likely to remain uncertain due to the variations in farming practices and the environmental conditions prevailing at the time as outlined in section 4.7.1. Some estimates can be made on a regional scale but is unlikely to be useful for accounting emissions on individual farms. From a market supply perspective the supply of units of abatement is more efficient from an aggregate of individual farms since typical family farms do not produce sufficiently large volumes of emissions in their own right to cover the cost of transaction (Keogh 2007). Even at this level the variability in accounting for emissions is likely to add to the cost of compliance. Knowing the emissions characteristics of a practice is only part of the equation in policy terms; policy needs to consider how such practices are likely to be adopted. I place a strong emphasis on adoption and drivers of adoption in this policy analysis since without adoption of practice change there is no resulting change in emissions.

I maintain that policy development intending to create changes in farming practices for whatever purpose needs to consider the system characteristics of the industry sector, what drives management decisions and activities within the system, the reaction of the actors and institutions in the system as well the resources and flows into and out of the system. In the following chapter I consider the theory of adoption and analyse the system characteristics of the dryland grain production sector.

This chapter draws its conclusions from the interpretation of Government data such as the Australian Bureau of Agriculture Resource Economics and Sciences, The Australian Bureau of Statistics, the literature and engagement from industry. For more details refer to research question 3 under Methodology in section 3.1.

5.1 Adoption theory in Agriculture

Adoption of new agricultural practices is regarded as a key aspect of reducing emissions; it is therefore relevant to understand how adoption takes place in the agricultural sector. The early theoretical and empirical literature on the adoption of agricultural innovations has studied how new farming technologies such as new crop varieties was adopted by farmers as part of the ‘Green Revolution’ (Feder and Umali 1993). The main focus of early studies was predominantly on increasing yield, rather than a balance of productivity and environmental outcomes. According to a review by Feder & Umali (1993) the diffusion cycle of innovations in agriculture is strongly impacted by the agro-climatic environment which is in some sense related to the likely responses that can be achieved given the conditions where the farm is operating. Their findings is supported by examples in the Australian broad-acre grain cropping sector by the greater pace of adoption of ‘no-till’ practices in the more arid conditions of Western Australia compared to the higher rainfall of Eastern & Southern NSW (Crabtree 2010) (Figure 18).

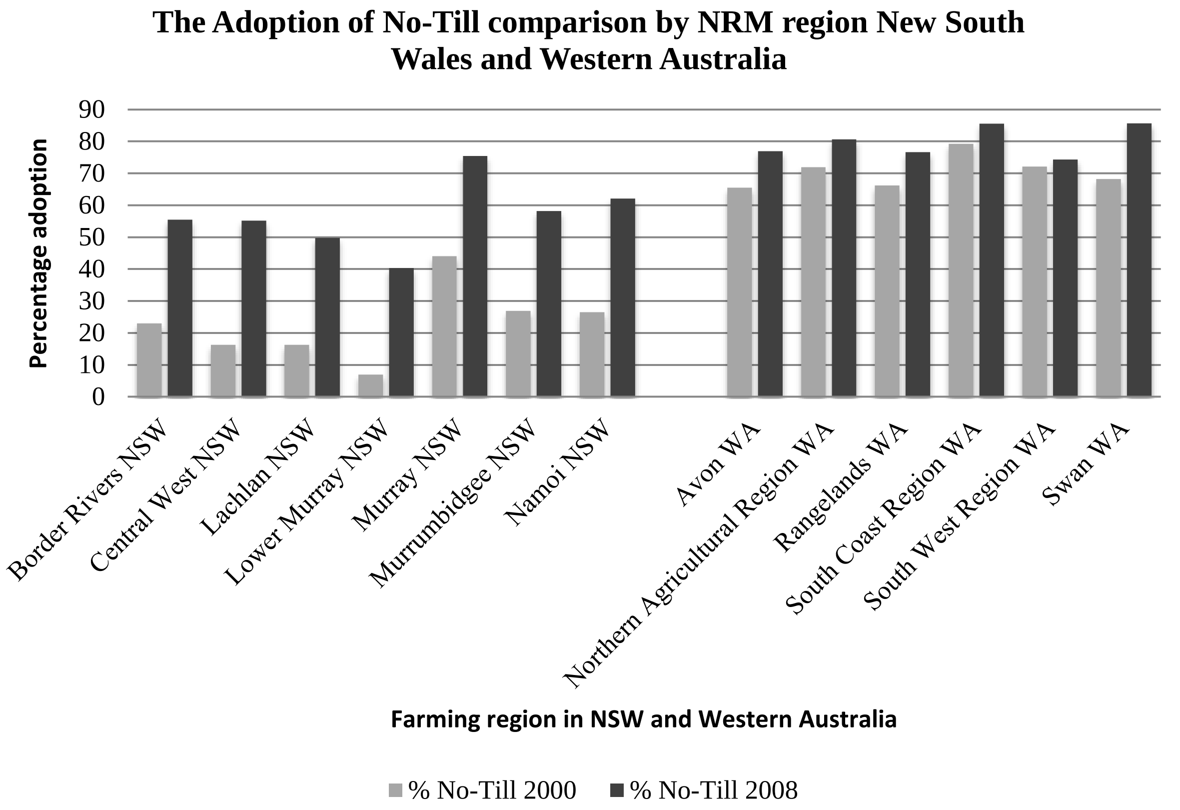


Figure 18 A comparison of No-Till adoption in the wetter and better soil areas of NSW versus the drier sandier regions of WA which is highly conducive to wind erosion (adapted from ABS reports June 2009 on agricultural practices).

The assumption is that farmers in less forgiving environments have seen greater returns from conserving moisture, than farms in better rainfall areas (Crabtree 2010). There is also a suggestion that the linkages between the step process of adoption and the aggregate diffusion process across the industry as a whole needs to be firmly established to achieve a clearer understanding of diffusion patterns (Feder and Umali 1993). That process can stall or take longer depending on a whole range of socio-economic conditions (Pannell and Vanclay 2011). Several studies showed that the impact of policy interventions to promote technology adoption depends on the type of technology, and how complex it is to put in place (Thomas et al. 2007c; Tullberg et al. 2007; Robertson et al. 2012; Tey and Brindal 2012). For example auto-steer on tractors first began to appear in the early millennium and was adopted by 48.6% of farmers in Australia by 2008, growing to 66.7% in 2011, this relatively quick adoption in Australia was attributed to the benefits being easily evident (reduce fatigue) to farmers, and the process was relatively straightforward being a purchased product (Edwards et al. 2012). Other technologies such as setting up a Control Traffic Farming system are considerably more complex to establish, requiring re-engineering of machinery and reshaping the landscape on occasions, so adoption has proven relatively slow with just over 20% of farmer adoption (Barson et al. 2012a; Edwards et al. 2012). Much the same story can be seen with reducing tillage in the early stages of adoption and with the need to take the time to demonstrate how the planter can be changed, but adoption significantly increased in the late nineties and early millennium with the advent of a range of commercially available zero-till planters (Crawford 2004; Thomas et al. 2007c; D'Emden et al. 2008). This also indicates that the market structure is relatively influential by providing economic signals in terms of the price to sustain the change process. When farmers could see the crop production benefit from retained moisture across their neighbour’s fence from practicing reduced tillage and stubble retention they were driven to make changes on their farm (Thomas et al. 2007c; D'Emden et al. 2008). Where the economic benefit has been limited or economically capped such as the market for legumes, than inclusion of legumes in the rotation is necessarily limited to a certain level. The nature and duration of the policy intervention is also relevant to the speed of adoption, whether it be in the way of market based incentive or an education program through agricultural extension (Miller and Tolley 1989; Feder and Umali 1993; Nicholson et al. 2003; D'Emden et al. 2008; Pannell et al. 2011). What is indicated by these examples is that adoption is affected by a range of factors such as the climate, how complex the technology is, the market forces operating and policy intervention. These impacts are useful to understand but do not give a good construct to accurately forecast how much is adopted and how long it takes for adoption to occur.

The adoption of CA practices has also shown a return on investment to the farmer and can be described as providing a productivity benefit (Kassam et al. 2009). If we consider the adoption trends for reducing tillage in Australia we find it does tend towards a logistic function curve or sigmoid curve for adoption of innovation as proposed by Rogers (2003) (Figure 19 & 20).

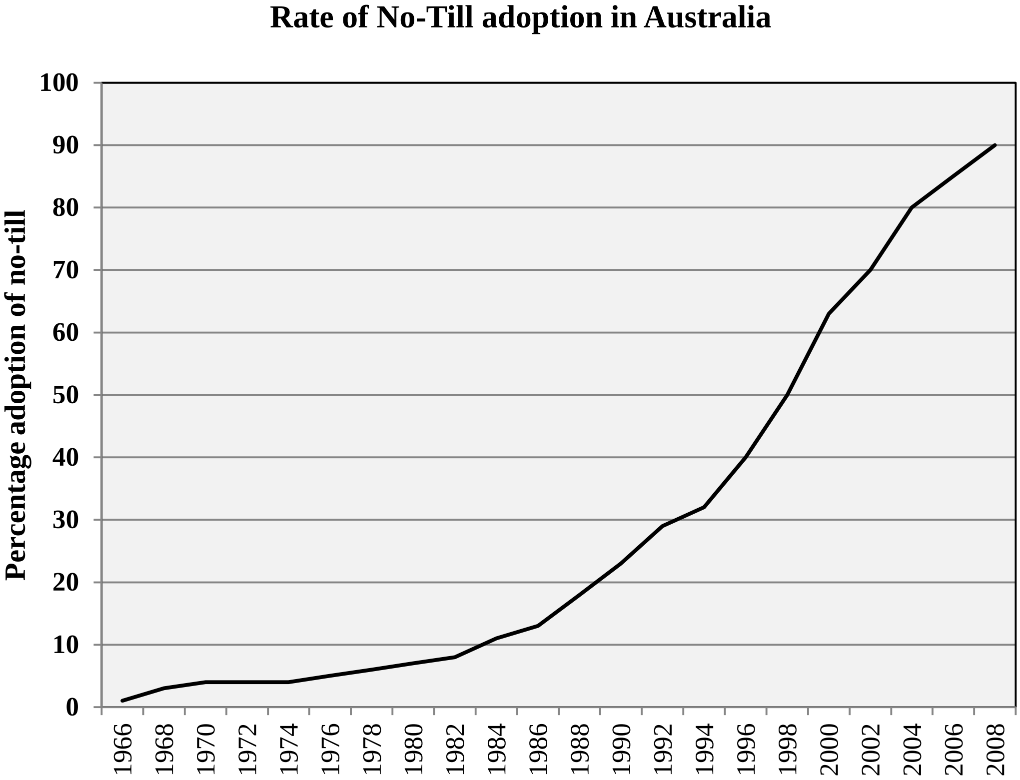


Figure 19 The adoption trend for reducing tillage in Australia adapted from (Llewellyn et al. 2009) aggregated for all states

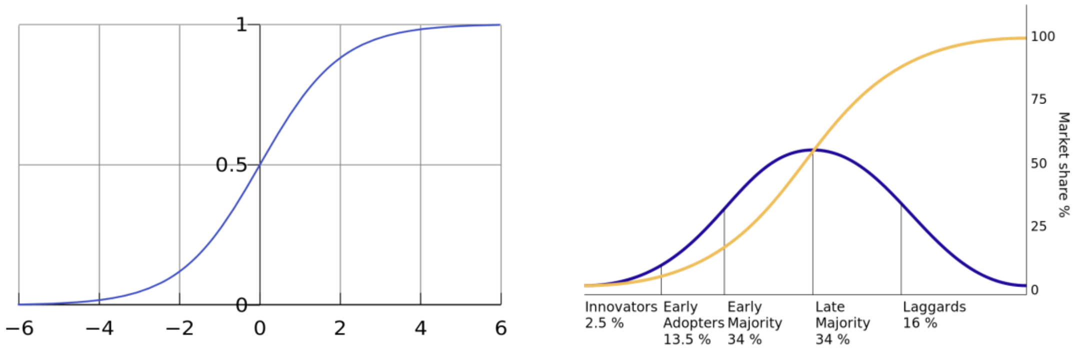


Figure 20 A typical logistic function curve on the left and Rogers Diffusion model with a sigmoid curve representing the adoption of innovation adapted after (Rogers 2003)

The elements of Roger's diffusion model can be applied to the adoption of reduced tillage farming practices in that the practices was regarded as new by farmers (innovation) and it was communicated by leading farmers in 'grower groups' and government extension officers in the early stages and private agronomists and machinery manufacturers in the latter stages (communication channels) (Belloti and Rochecouste 2014). The relative rate of adoption has been recorded for some practices (time) and there is a social system (agricultural community) that is motivated towards increasing production and saving resources (common goal) (Vanclay 2004). The diffusion process in terms of acceptance of new practices by the farming community over time is variable and in some instances such as ‘no-till’ adoption described by Llewellyn et al. (2009) follows a pattern similar to that proposed by Rogers (2003). Some others do not quite fit the profile such as legume rotation being constrained by the market size based on production figures from ABARES (2010). A number of other CA practices are still relatively new within the adoption cycle and it is not certain if they will follow the same pattern of adoption. I propose that if the innovation can be self-sustaining in an economical way than we would expect that adoption will follow a one way process and until we get a slowdown in adoption or even a slight reversal due to balancing economic factors. I therefore regard the ability of the innovation to provide a significant economic return to the farmer as an important criterion in sustaining practice change. This may seem evident in regards to innovations promoted purely on the basis of productivity but it is not necessarily the same for practices design to reduce externalities. The question of profitability is not an inherent characteristic of a practice designed primarily to reduce externalities given the goal is other than productivity.

In Roger’s theory of diffusion he outlines the likelihood of a practice being adopted based on five characteristics as perceived by the individual (farmers). I consider how the theory might apply to CA practices based on our experiences with the adoption of No-Till which has already been well documented (Freebairn et al. 1986; D'Emden et al. 2006; Thomas et al. 2007c; D'Emden et al. 2008; Llewellyn et al. 2009). The first important characteristic as perceived by Rogers was the relative advantage of the innovation in relation to current practices. The main innovation perceived by farmers in No-Till systems was increased soil moisture leading to more planting opportunities and reduced erosion of top soil (Thomas et al. 2007c). The second characteristic of the model was the compatibility of the innovation to the farmer’s paradigm and this was a barrier for some considerable time as it required farmers to significantly change their perceived view of how farming is normally carried out; which is by cultivation in preparation of a seedbed. However it is worth noting that the success of leading farmers in the application of this change in practice created a constant drive towards adoption (Belloti and Rochecouste 2014). Farmers established No-Till grower groups in the eighties and nineties to provide the means of demonstrating how the practice can be practically applied to suit their farms (Belloti and Rochecouste 2014). The third characteristic was the degree of complexity involved in the change and again this was initially slow but was more readily adopted in the late nineties and early millennium due to the increasing support of local manufacturers in supplying ready made No-Till planters as is illustrated by available commercial equipment (Figure 21).

Figure 21 Manufacturers offer of No-till planters facilitated the uptake of No-Till by not requiring modification to existing planters. (source: Excel website)

The fourth driver in Roger's diffusion theory was based on the requirement that the practice be 'trial-able' on a small scale to provide confidence for a complete change in practice. This is difficult where large machinery is concerned and may be part of the reason that No-Till took so many years to be taken up (Thomas et al. 2007c). This was in some way mitigated by demonstrating how some local farmers had managed to modify their current machinery to suit (Crawford 2004). The final characteristics of Rogers theory was how the new innovation could be readily observed in delivering benefits (Wylie and Moll 1998). Again this was very much a feature of grower groups holding farm machinery demonstration where farmers came to learn about how No-Till could be deployed and the resulting production benefits (Figure 22). Attendance at field days is a time consuming event and attendance is indicative of the relative value of the event to their thinking process of change.

Figure 22 Machinery field days (left) and crop walks (right) was a major feature of grower group extension promoting reduced tillage in the 90s and continues today (Photos courtesy of Conservation Farmers Incorporated & Gemma Elwell)

Despite the difficulties of machinery modification No-Till was adopted primarily because it could demonstrate a value return on their investment (see chapter 6). We can extrapolate that evolving farm practices such as Control Traffic Farming, Precision Agriculture and Cover Cropping may well follow a similar pattern of adoption. However there should be some caution as not all innovations have been accepted by farmers; the proliferation of computer based Decision Support System (DSS) made available for farmers have not been readily taken up by them in Australia despite available computing capacity. Lynch et al (2000) reviewed why such adoptions have not taken place along the lines of Rogers Diffusion model and points to the failure of many of the DSS tools to make themselves relevant to the way farmers make decisions. They point to a number of social considerations such as the lack of familiarity of farmers with computers, the need for data entry not normally collected by farmers and the uncertainty by farmers that the results being presented were real (Lynch et al. 2000).

Innovation adoption in farming was oriented around assisting farmers becoming more productive; therefore the number of farmers adopting as a percentage of the farming population is a relevant measure. However in emissions terms we are dealing with adoption change as the means of reducing an externality. The ‘number’ of farmers adopting a practice change is not entirely relevant unless all farmers are assumed to have approximately the same property size in terms of production, but they do not. According to ABARES data the range for farm size extends from 500 to 20,000 hectares of cropping (see also figure 28). We note that 10% of farmers at the smaller end of the property size scale are not the same as 10% of farmers at the larger scale. In managing an environmental externality other requirements come into play. The ‘area’ under change is more relevant than the number of farmers as emissions is more a factor of farm area and soil type than the number of farmers. Upadhyay et al (2003) indicated that farmers adopting multiple conservation tended to have larger farms, more financial resources and better education than non-adopters.

Another observation from looking at adoption theory in practice is that the process is governed by a range of factors that can act to slow the process such that it can take decades to get meaningful levels of adoption. In the case of No-Till, if taken from early appearances in the early 70s it took until 1998 (just under 30 years) to achieve 50% adoption (Llewellyn et al. 2009). Such a time frame may not be suited to externalities that is considered time critical such as climate change. It would suggest that if adoption of emissions reductions practices may need to be accelerated than the normal parameters of diffusion as suggested by Rogers (2003) may need to be modified in policy terms. In such circumstances there needs to be a clear understanding as to what are the drivers most likely to support practice change.

I believe that Roger’s Diffusion of Innovation theory can be a useful tool to examine the process of adoption and may suggest likely trends into the future. It should however be used cautiously as some of the parameters that support adoption can be negative, which is likely to result in longer adoption curves than is the ideal time frame for climate change mitigation. Some innovations have also been known not to have been successfully taken up because they did not fit the farmer’s paradigm and did not offer sufficient value proposition (Robertson et al. 2012). Environmental practices were not inherently designed for production benefit; but they may be beneficial as a by-product of the market (e.g. high energy price environment). In such circumstances applying the right policy choices that understand the value proposition for farmers is going to be important to reduce agricultural emissions.

5.2 A farming systems analysis of grain production for emissions policy

I will begin an analysis of the production system by seeking to better understand the main characteristics of the system that assists in interpreting the drivers for practice change. The geographical location of the system is located in the inland West, South and East of the Australian continent (Figure 23).

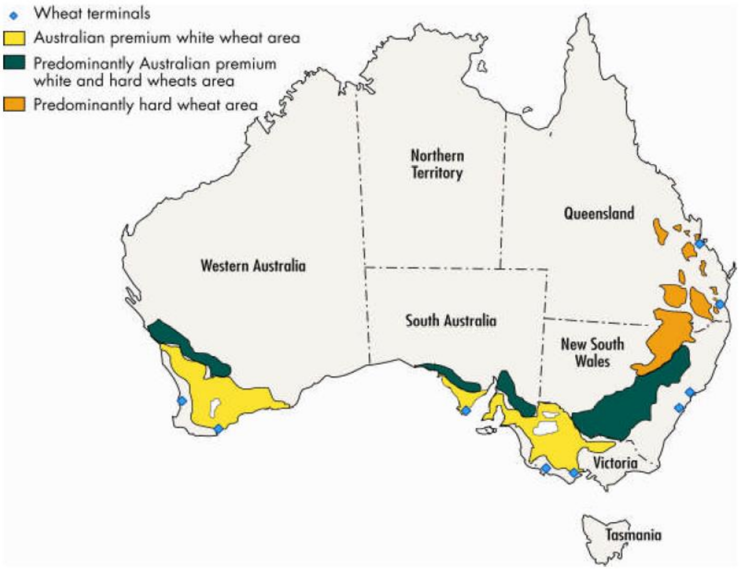


Figure 23 Australian grain cropping areas (source: ABARES at www.abareseconomics.com)

The boundary of the system includes the dryland Australian grain farms as a sector and the factors influencing the CA farming practices as sub-systems (Figure 24).

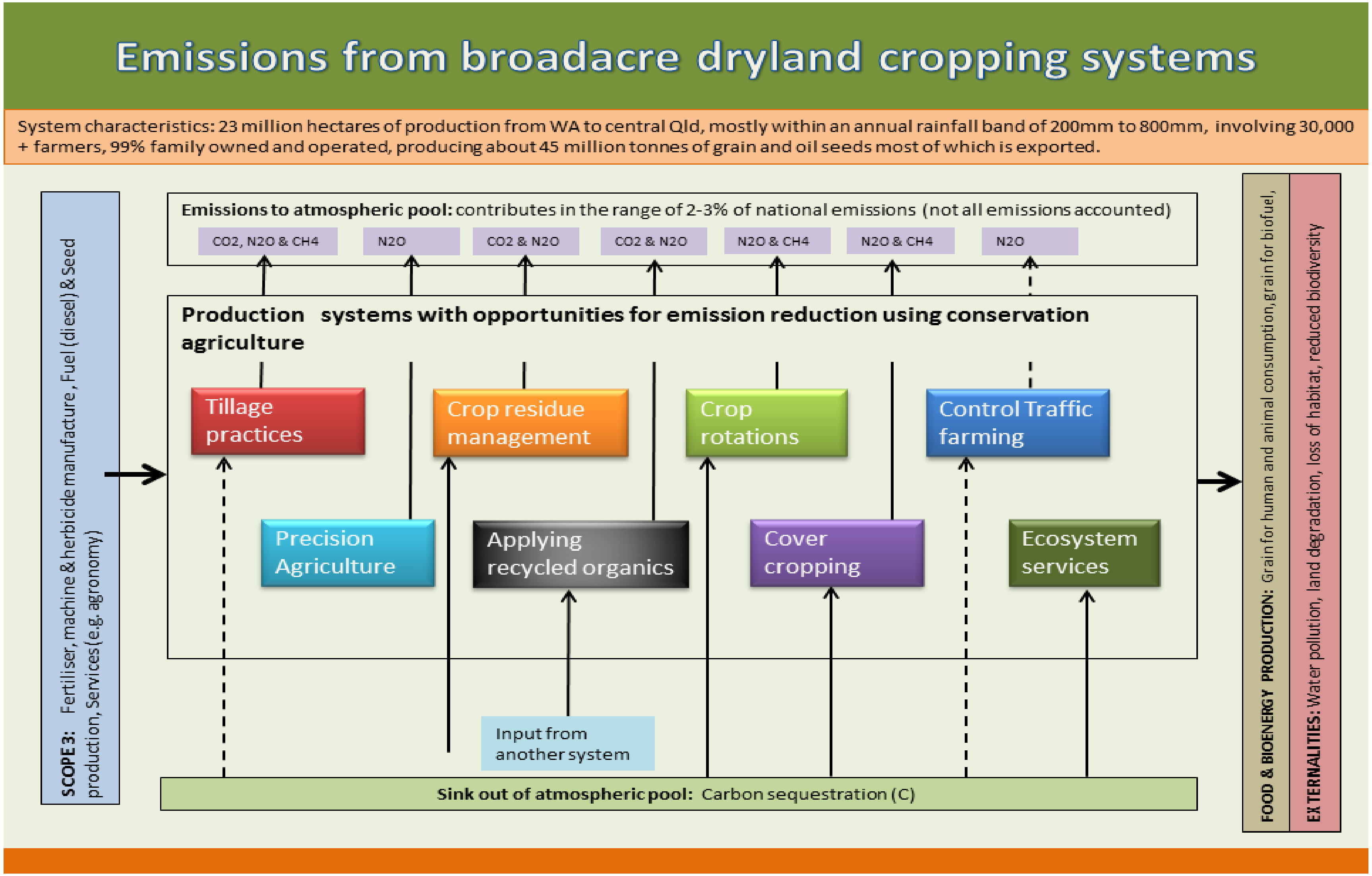


Figure 24 A systems framework with production systems and sub-systems creating emissions in the process of producing food and fibre.

The system in Figure 24 highlights the main characteristics of production, including input resources on the left and outputs of food and fibre to the right. The externalities in emissions terms are highlighted from the various sub-systems that are being considered for change. Some emissions factors are uncertain and need further research shown by broken lines.

5.2.1 Systems Characteristics of dryland grain cropping

In this section I source data from the Australian Bureau of Agricultural Resource Economics & Science (ABARES) and from industry; I have visited farms across different parts of Australia and held conversation with farmers, industry bodies and agronomists. The industry is able to share insight into the implication of structural and market changes on farm.

In production terms the dryland grain cropping system in Australia consists of approximately 23 million hectares of production operated by an estimated 30,000 growers in 2006, with 99% of farms being family owned (Australian Bureau of Statistics 2006). This indicates that the policy target audience includes a significant number of individuals. Production data from the Australian Bureau of Agricultural and Resource Economics and Science (ABARES) collected in 2005-06 indicates that in terms of distribution of impacts on land area resources; it is relatively even across the medium to larger growers; the medium to larger producers representing just over half of the total number of growers (53%) have a proportionally higher impact factor per farm unit accounting for 90% of production (Figure 25). The assumption is that they also account for the majority of emissions, although larger growers are more likely to take up new efficient farming systems.

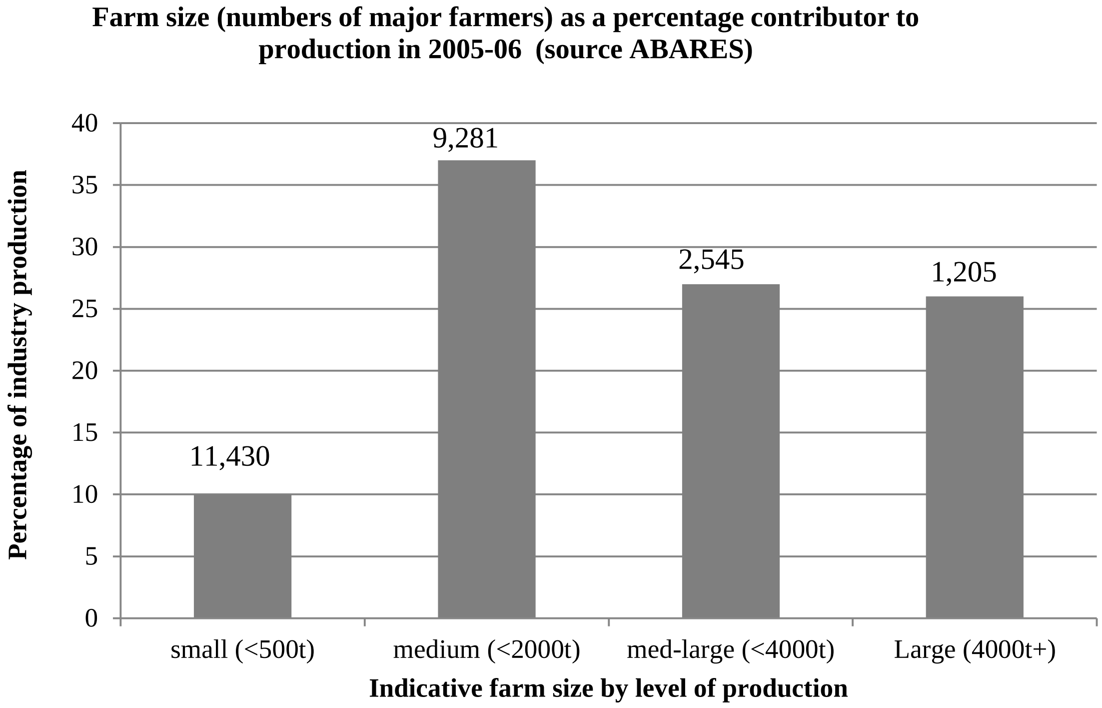


Figure 25 A comparative analysis of the policy target audience relative to their likely emissions profile. This indicates that 53% of farmers account for 90% of production. Mixed small farmers not included.

In climate terms the system is described as 'dryland' as most of the production is reliant on rainfall and sits within the 250mm to 600mm annual rainfall belt inland from the coast, but this can fluctuate with drought and flood years depending on the various climatic patterns of the Indian and Pacific oceans[23]. While the production areas are familiar with drought and flood years, they are nevertheless economically vulnerable to future climate change impacts on rainfall, evaporation, carbon dioxide concentration and temperature (Crimp et al. 2008; Howden et al. 2010). Of particular concern to crop yield in the short term outlook, are reductions in net rainfall and the timing of that rainfall, with the possibility of a trend to increases in rainfall intensity going to run-off and limiting infiltration (Stephens and Lyons 1998; van Herwaarden et al. 1998; Hope and Ganter 2009). The marginal rainfall of the cereal belt exposes future crop yield to potential losses from climate changes of reduced rainfall and higher temperatures (Crimp et al. 2008; Hennessy et al. 2010). Potential changes in rainfall will vary across regions but on the whole the trend is towards reduced rainfall across the cereal belt (-30% to +20%). With increasing temperatures in the range 0 to

[23] Bureau of meteorology. www.bom.gov.au

4°centigrade this will also impact on the soil's vapour pressure deficit reducing microbial activity and affecting soil fertility (Crimp et al. 2008; Pittock 2009). Cropping as a farming enterprise generally yields better profit than livestock production, but it is also more economically vulnerable to climate risk in dry years due to grain yield sensitivity to moisture loss (van Herwaarden et al. 1998; Day et al. 2010). Both risk conditions of exposure to reduce rainfall and crop sensitivity to that change is likely to have a significant impact on the future of farm profit if those risks are realized (Stephens and Lyons 1998). Although the outputs of research may provide future solutions that outcome is speculative, it therefore relies on the adaptive capacity of farmers to manage their production vulnerability through better farm management as a more immediate priority.

From a number of farm visits I have noted that the soils supporting the system are highly variable from sandy loams in the west and south to deep profile alluvial vertisols in the north (Figure 26) (ABS 1966). The rainfall totals and soil types have an impact on the capacity of the soil to store carbon; and the majority of heavier soils and better rainfall form the hard wheat production areas (referring back to Figure 23) (Baldock et al. 2009).

Figure 26 Varied soil types across the regions from black alluvial clays (left), red loams (centre) to sandy loams (right); which impacts not only on crop options but also the ability to store SOC. (photos J. Rochecouste)

In economic terms dryland farmers produce about 45 million tonnes of grain annually; a significant portion is exported and contributes to export earnings (GRDC 2013). Grains as a produce operates in highly competitive commodity markets and abatement policies likely to impact on input resources such as fuel and fertiliser need to take this into account. Farmers control neither the price of their product nor their input costs and are subject to fluctuating global commodity prices. In recent years there has been a strong increase in farm input costs relative to commodity returns driving the need for increased efficiency (ABARES 2010). This impact has been significant as two of the main staples of farming inputs, fuel and fertiliser have seen large increases (Figure 27). This high cost, with a series of drought years and slow growth in the gross value of product being produced has coincided with an increasing level of average broadacre debt nationally (Figures 28 & 29). This is relevant in emissions terms as I would suggest that policies promoting practice change will need to meet certain economic parameters to be accepted by farmers. From our interviews with farmers it seems unlikely that farmers will entertain increasing debt levels until they are sure of the return on investment.

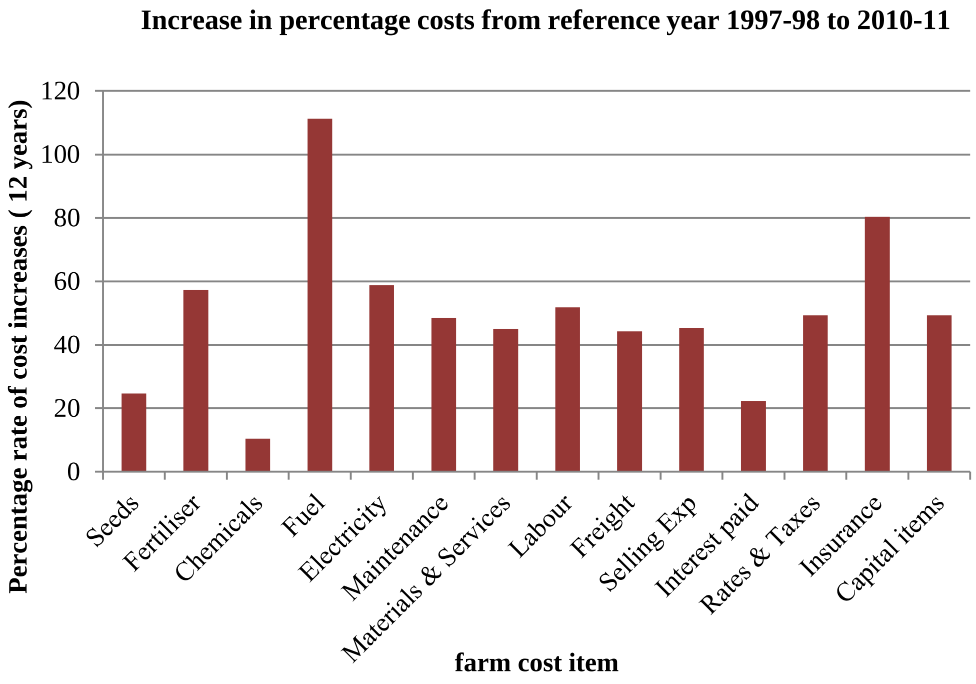


Figure 27 The percentage increase for the 12 years from 1998 to 2010, fuel fertiliser and electricity have seen the largest increases. Significantly the major farm inputs in budget terms are fuel, fertiliser & chemicals (source: ABARES)

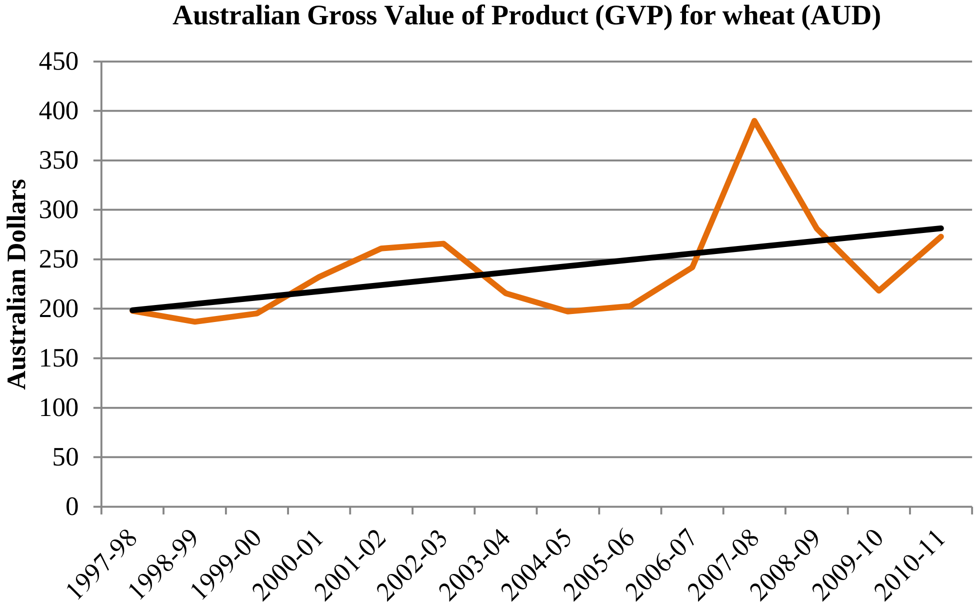


Figure 28 The gross value of product looks at the relative return per tonne which has been highly volatile in the last 6 years. The trend line indicates the average increase in the last 12 years (source ABARES)

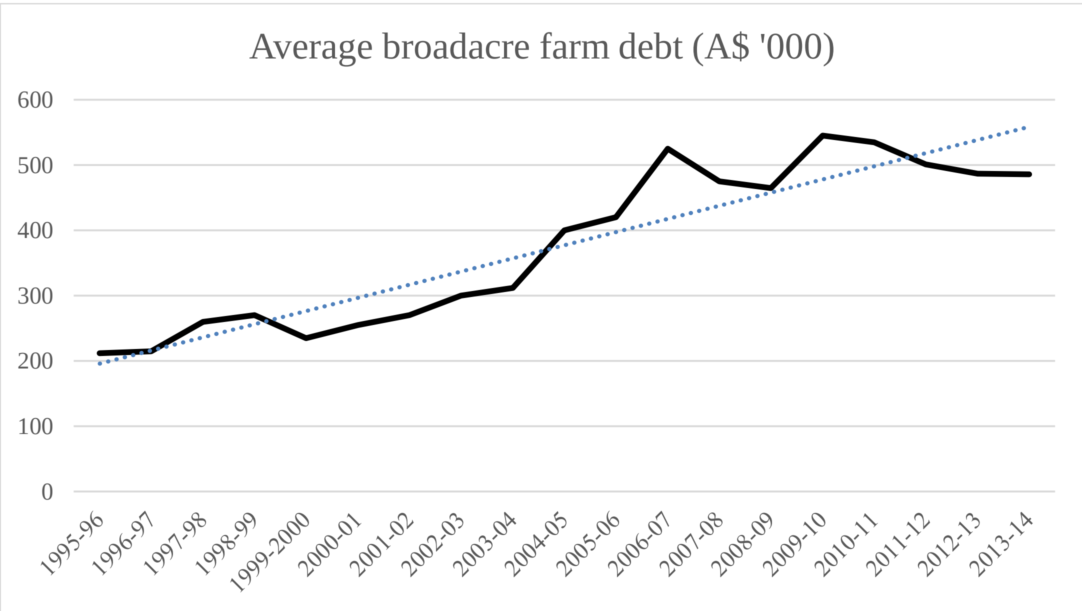


Figure 29 Indicates the increasing trend of broadacre farm debt in Australia with a slight flattening post 2008 and a reduction in the wetter years, currently regaining an upward trend sitting at $509k for 2015 (source: ABARES Outlook 2015)

In social terms the cost constraints has also impacted on the ability of the farm business to employ labour and there is also some indication that competition with mining in some areas is impacting on labour availability. Farmers seem to be doing more themselves resulting in increased time pressure with little capacity available to suitably assess farm system changes whose benefits are not clear from the start. This is likely to create resistance to engagement in reducing emissions if the objective is not perceived by the farmer as relevant.

In summary the dryland cropping system objective is geared to producing grain for sale in order to provide economic viability to the family farm. The management of externalities such as atmospheric emissions of GHG is perceived as one of the many risk management requirements of the farm. Others from media reports would include:

- Reducing chemical drift likely to damage neighbours crop
- Reducing runoff of sediments into rivers and streams
- Ensuring the Occupational Health & Safety of farm workers
- Maintaining rural community services (schools & sports clubs)
- Maintaining biodiversity

This indicates that there is a range of risk issues associated with externalities that is of concern to the farmer. They compete for time and resources away from the main objective of the system; the business of grain production. Externalities associated with GHG emissions and their potential long term impact may be accepted as relevant to the community, but it also has to compete for the time and resource of the farmer.

The use of a one dimensional agricultural policy aimed at reducing farm emissions may have difficulty in engaging the farmer amidst the many other competing factors. It suggests that policy may need to consider in more detail how emissions reductions can align with production issues. The development of CA was done with the support of farmers because they saw the opportunity to better manage input resources and deliver real economic gains (Thomas et al. 2007c) (Table 13). As CA practices continue to expand in an economically constrained environment; its potential emissions reductions profile provides a unique opportunity to align policy to a mutually positive environmental and economic outcome.

Table 12 Comparison of yield from two tillage systems at two locations in Queensland from trial conducted by the than Queensland Department of Primary Industries (QDPI) and presented to farmers in the publication *Opportunity Cropping 2nd Edition* produced by Conservation Farmers Inc. 1998

Tillage system comparison	Biloela 1989-92 Wheat yields Tonnes/Ha	Goondiwindi 1989-92 Wheat yields Tonnes/Ha
Conventional cultivated	2.5	1.6
Zero-till	3.4	2.2
Relative annual benefit value of Zero-till in today's dollar value (AUD) ($220/t) for a 1000 ha production property	$ 198,000	$ 132,000

It is profit that has supported the continual adoption process despite the negative parameters previously outlined under Rogers Diffusion of Innovation theory, suggesting that if the returns are sufficiently attractive farmers will eventually take up the required practice change. This may require further scrutiny from a policy perspective as simply outlining an overwhelming case for productivity increase may not realise an immediate response in the adoption of practice change. This is indicated by the data presented in Table 13 above where in the years 1995-98 advisors clearly outlined a business case for No-till but the majority adoption still took another 10 years (Thomas et al. 2007c; Llewellyn et al. 2009). Yet Auto-steer technology was widely adopted in a much shorter time according to the farmers interviewed, not for specific income benefit but more as a means of managing labour productivity and fatigue.

5.2.3 Management decisions and activities within the system

It is important to understand what influences the decision making process of farmers as adoption of practice change is what will create mitigation from the sector. The decisions made within the system appear to revolve predominantly around grain production. The farmer's objective is primarily about making a reasonable profit to allow them to continue farming as a business and lifestyle option (Vanclay 2004). In contrast I perceived from media reports that government is about increasing yields in order to expand the value of the industry in terms of export earnings. The commercial services industry is predominantly about increasing production that uses more commercial resources (e.g. herbicides & fertiliser) and other sections of government are about minimising the externality of this industry impacting on community assets (e.g. Great Barrier Reef Marine Park) and other industries (e.g. Tourism). I suggest that these various objectives are at time likely to coincide and at other times work in a counterproductive fashion.

In making policy to influence management decisions to reduce externalities, the type of policy applied will inevitably have supporters and detractors within almost any system. I believe it is important to understand the relative strengths of others to influence the farmer's decision process. It is reasonable to assume that management decision that does not support the relative economic objective of farmers are less likely to be supported by other players within the system who want to gain favour with farmers (e.g. agronomic advisers). For this reason policy development should have a strategy to manage the response of other players in the system, since all parties in the system are likely to work on the basis of self-interest. Other factors influencing decision making in the system may come from global forces. The concept that farmers should pay for managing their externalities is complicated by external forces. Competitive global markets for grain leading to low farm profits within the system means that farmers are not likely to have the capacity to pay for any significant environmental reconstruction or costly management changes (Gourley and Ridley 2005). Furthermore farmers may not see any immediate benefit to them for creating an unrecognised social benefit downstream (Vanclay and lawrence 1995). Given that most modern cropping agriculture are subject to global markets, in an open economy they become price takers for the goods they produce and have little option to demand greater profit in order to spend on legislative compliance (Pannell et al. 2006). The situation appears to have reached a potential 'impasse' attributable to "who pays?" and what can be afforded. Although farmers may still have some capacity to participate in environmental mitigation strategies given the correct extension framework, any attempt to shift the majority of the cost on to landholders is most likely to be resisted (Gourley and Ridley 2005; Jonge 2010). Therefore it is most likely to come down to some form of cost sharing across the whole community.

Ultimately all consumers of the grain produced have contributed in some way to creating the problem within the system. The market has not valued the maintenance requirement of the ecosystem services, considering instead the operating cost of the farm in the production of agricultural goods, and as a result we can observe a decline in the capital value of the ecosystem (see section 4.2 on new potential environmental accounting system). I propose that policy might recognise that the result of an economic framework which does not support the 'maintenance' of the environment will result in a decline in capacity to mitigate externalities such as excessive GHG emissions.

5.2.3 Actors and Institutions within the dryland grain cropping system

Other major influential actors within the farming system are other like-minded farmers with whom the farmer associates. This is not always a neighbour but is more usually a farmer who has similar issues and circumstances from which a shared discussion of practices can be supported (Vanclay 2004). Other farmers play a major role based on their credible experience having to deal with the same issues or because they share a similar degree of risk (Gianatti and Carmody 2007; Belloti and Rochecouste 2014). The degree of influence exerted by industry on farmers appears to be a function of the degree of working contact farmers hold with industry players (Kancans et al. 2014). Surveys reveal that the advisory agronomist is highly influential to the farm's practices, which is not surprising given the regular working relationship that advisory agronomist have with farmers (Ecker et al. 2012). In similar order, I suggest that supplier agronomists are also likely to have influence as do grower groups and specialist advisors (Kancans et al. 2014). Government advisory officers have become less influential as their degree of contact with farmers has dropped (Belloti and Rochecouste 2014). Trust is mentioned as a factor in farmers accepting ideas for change, but trust is slow to develop and to some degree is dependent on the level of inter-personal contact (Ecker et al. 2012). I note that many institutions have little inter-personal contact with farmers and the extension message they believe to be self-evident may in fact not be acted on without corroborating support from other trusted actors in the system. I perceive that the implication of this from climate change policy is that the climate change message is largely being driven by government and scientific organisations directed at farmers with little examination as to what support the climate change message is being given in the corroborating process. I have noted that institutional messages most often provide broad objectives and less often deal with the processes of how that objective can be logistically achieved within the local context (Belloti and Rochecouste 2014). A message that cannot be contextualised to the farmer's need is likely to be set aside as other priorities take over. I suggest that only where this message has a productivity context does the objective become more worthy of consideration. Corroboration by influential actors such the farm agronomist and financial advisor is a key process to adoption (Vanclay 2004; Ecker et al. 2012).

As in most systems I suggest it is not simply a one way flow of advisors influencing farmers; leading farmers that have a drive for experimentation in turn influence agronomists (Belloti and Rochecouste 2014). It is sometimes observed by farmers that their agronomist gain their experience from a range of other local farmers making mistakes (farmer, requested name withheld, interviewed 2013). Therefore leading farmers can influence local agronomists who in turn influence secondary adopters (Belloti and Rochecouste 2014). However all this can take time as more often there is a range of factors that is considered by the farmer and for which agronomists are well in tuned with.

It is also worth considering that farmers may not have the finance or the degree of skill required to take on a particular practice change. This has been a factor evident with precision agriculture; where a great deal of digital underpinning knowledge is required. Most often there is a generational gap in the operation of on-farm technology, with young farmers generally more comfortable with digital connectivity (Robertson et al. 2012). Targeting specific demographics in terms of practices uptake may be a consideration.

I believe this will have implications in terms of the need for aggregation of farms into a carbon market project. If the aggregators are from outside the community, they make take longer to get acceptance in creating the trust needed to create the type of project partnership required. If the agronomists were to be involved there is some question as to their underpinning knowledge in how to manage a carbon project. If the project were to engage the support of local agronomists they would need to consider a hire charge to cover their involvement which I suggest would in turn increase the transaction costs. The cost of engagement will come at a price whatever path is chosen and in turn this adds to the transaction cost and the likely viability of carbon offset project.

5.2.4 Resources & Flows within the dryland grain cropping system

In order to deploy a policy initiative within a system it is worth considering the associated resources and how they flow within the system. Cropping in a dryland system as mentioned previously is dependent on three main resources; rain, agricultural inputs (machinery, seeds, fertiliser and chemicals) and information. All can significantly impact on production and emissions by influencing the farm production system.

The variability of rainfall as a resource can particularly impact on policies related to sequestration of carbon into plants initially and ultimately the soil (Baldock et al. 2009; Walcott et al. 2009; Sanderman et al. 2010). Drought years are a common feature of Australian agriculture and limit the amount of organic material available to reduce erosion and feed the soil organic precursors (Chowdhury et al. 2013). In the wet years the opposite is true and this can have an impact on carbon projects related to plant sequestration, but it can also impact on any methodology likely to be considering soil sequestration. These fluctuating conditions cannot be planned for and can seriously impact the viability of a project where a project goes into an extended drought period. Based on a series of farm visits over time Figure 30 demonstrate the change of condition that can rapidly occur with changes in seasonal climatic conditions from 'El Nino' to 'La Nina' patterns. This can be further exacerbated by practices such as overgrazing in drought years.

Figure 30 Comparison of on ground vegetation at the same location in the dry years 2005 (left) and following wet years (2013) (photos J. Rochecouste)

Agricultural Input resources are heavily market driven; Fertiliser for example is mostly imported into Australia and sold by a number of commercial companies on a competitive basis. The material is packaged to suit current machinery operations with companies strongly supporting nutrient management. If an intended policy is aimed at reducing the sales volume of a commercially supplied commodity, it is likely to come into conflict with commercial operators in the system. The commercial culture has developed over a long period time and has a well-established pattern within the farming system. Sales agronomists have regular contact with farmers, perhaps more than any other agency. Where policy is intended to intrude into this pattern it needs to consider the responses of the firms in both an overt way (What they say publicly) and a covert way (what their staff say in private conversation to farmers). It is not too suggest a deliberate conspiracy on the part of commercial firms, but field staffs often develop a personal relationship with their clients and may well express their personal views in general conversation with farmers. Grower groups on the other hand are independent of any commercial interest and have no conflict of interest in providing advice that reduces the consumption of commercial products such as fertilisers. There is little confirmed research in this area, but from the authors own experience of 8 years in agricultural sales it is my experience that commercial firms have strong level of contacts with farmers and that sales agronomists can develop a high degree of trust with their producer clients. Without such understanding it is possible for a policy initiative to be seriously undermined or exploited.

Policy initiatives are just as likely to develop commercial allies who can benefit in some way from the policy objective of reducing a product sale. If fertiliser use is seen as directly proportional to GHG emissions, than products that support fertiliser efficiency becomes allied to the policy objective. All input products flow through a series of commercial units on the way to the farmer and the logistics of this flow and the associated costs can impact on how policy initiatives might best be deployed.

I consider a current example with the Refundable Tax offset on conservation tillage on how a policy initiative is being interpreted by the commercial suppliers in the industry. Tillage is primarily a function of the tool that engages the soil, how it is deployed and the amount of times it is used. Discs as an example, is the least disruptive to the soil depending on the angle it is operating, the number employed and the amount of times it operates (Ashworth et al. 2010). The same tool operated differently can have significant soil impacts (Table 13).

Table 13 comparative disc used in agriculture planting operations

Least disruptive to soil	**Highly disruptive to the soil**
Narrow angle relative to travel direction	Large angle relative to travel direction
Only operates as soil opener for planting	Operates with high numbers to turn over the soil
Operated once only at planting	Operates in a series of operations

This level of technical detail is relevant to policy. For example the Conservation Tillage Refundable Tax Offset. 3.1 Schedule 2 to the Clean Energy (Consequential Amendments) Bill 2011, provides a refundable tax offset (RTO) for certain new depreciating assets used in conservation tillage farming practices up until 2014[24]. It was intended to support reduced tillage practices by creating an incentive for zero-till planters. The new law entitled the taxpayer to an RTO of 15 per cent of the cost of an eligible asset above normal depreciation. This would include "disk openers" and suitable hybrid machines such as zero-till planters. A number of commercial operators have advertised their machine as being eligible in total contradiction to the intention of the legislation, whether this was done knowingly or unwittingly is uncertain (Figure 31). But it is clear the term "disc" was interpreted as any 'disc implement'. Although we can note that the term 'conservation' is missing in the advertisement

[24] The offset was repealed following the repeal of the carbon tax legislation - http://www.daff.gov.au/climatechange/carbonfarmingfutures/rto

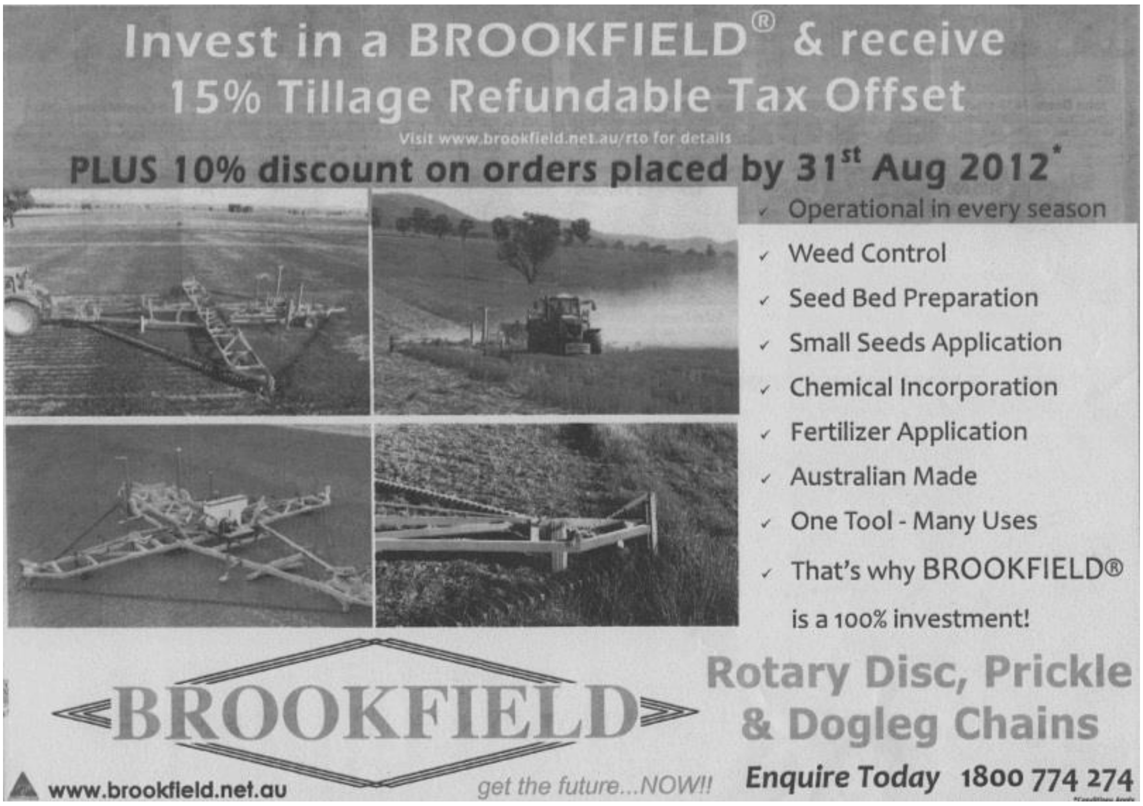


Figure 31 Advertising of a full cut cultivation equipment using discs as an eligible 'disc planter'. This type of implement is intended for full cultivation and is not in fact a no-till disc planter. (source Advertising from rural paper The Land 09August 12)

Without clear technical knowledge, the use of such a market based policy can in fact be negated in its purpose by misunderstanding or overt manipulation. The two implements are compared in Figure 32.

Figure 32 (Left) - a Brookfield disc cultivator used for full cut tillage. (Right) – A disc planter designed to plant with minimal soil disturbance and full stubble retention (photos from manufacture's website)

From the example above there is no doubt that machinery or implement purchased can be an indicator of farm practices, it does however need to be well defined and the implement itself have a specific use directly relating to the practice being sought. It also needs to be compared to its opposite factor in order to determine that one is growing at the cost of the other and not have both growing in tandem which would indicate simple market growth as oppose to change. Once the preliminary details are in place the use of market incentive such as a tax reward to report function is an excellent measurement of change as it creates a motivation to self-report on practice change.

An important consideration that is relevant to practices like reducing tillage is that they require a major shift in operational procedures, which additionally requires significant capital investment. Therefore the decision making process is expected to take more time and the process is likely to take place over many years. This means that policies such as educational activities may not deliver a response within the short term. Information is an important resource in managing farms that are isolated, not simply in a geographical sense, but also in a communication sense. Yet information can play an important role in influencing a farmer's perspective as well as providing the details to evaluate the merit of a practice change. Farmers report value in farmer field days based strongly on the opportunity to network with other farmers to share experiences (Kancans et al. 2014). Because of the perceived economic risk involved in changing whole farm operations, farmers will often take many seasons to evaluate the merit of a change and will often seek a range of other external perspective. I suggest that resources flow through the system at a pace limited by farm capacity.

6.0 DRIVERS FOR ADOPTION OF CONSERVATION AGRICULTURE PRACTICES AND IMPACT ON EMISSIONS REDUCTIONS (PAPER)

6.1 Preview

The following chapter is presented as a published paper inclusion:

Rochecouste, J., Dargusch, P., Cameron, D. & Smith, C., 2014, 'An analysis of the socio-economic factors influencing the adoption of conservation agriculture as a climate change mitigation activity in Australian dryland grain production', *Agricultural Systems, Volume 135, pages 20-30.* Article has been downloaded or viewed 1125 times since publication.

The paper is an integral part of the way this PhD research is presented to the broader research community and therefore it is included as part of the PhD submission. It is intended to be read independently of the PhD going through a separate peer review process.

The paper was designed to follow up on two aspect of the research; the first is that a review of CA practices from chapter 4 section 4.11 indicated there was a net emission reduction benefit from the adoption of CA practices in Australian dryland grain cropping (approx. 23 million hectares). Although individual practices will vary in the level of emission reduction and with some practices there is uncertainty as to the emission value due a research gap (e.g. the use of recycled organics or the inclusion of cover cropping). The assumption is that a greater level of CA practices adoption is likely to reduce agricultural emissions to a degree that stills need to be further researched. The positive level of reduction is directionally proportional with increased adoption. We looked into what drives this adoption.

The second aspect of the research is outlined in chapter 5 which looks at the agricultural system as a whole, the various emissions characteristics and the theory of adoption. The review indicates that the factors of adoption are complex and are influenced by a range of factors. Economic consideration being only one part of the equation to adoption.

The paper is seeking to evaluate the various economic and social factors that specifically drives CA adoption in the grains industry and its implication affecting carbon sequestration and emission reduction.

Due to the complex nature of socio-economic drivers we applied a systems thinking approach, using a series of systems model for each of the various CA practices. The reasoning for such an approach is outlined in the paper. This application to CA in a climate change context is a new approach and is informed by triangulating the research literature (secondary data), analysis of current industry data (mix of secondary and primary data analysis) and industry/farmer interviews and case studies (primary data). The new knowledge is designed to inform policy about the complexity that influences farmer practice change. It is intended to provide in-depth analysis as to the factors that influence farmers to adopt CA.

We conclude with comments from farmer interviews to explain the factors that influences their thinking in terms of adoption or non-adoption and what are some of their unresolved issues in terms of the CFI.

The following publication is the manuscript as sent to the publisher. The tables and figures are not listed as part of the thesis but follow the numbering pattern of the text in the publication. The paper's bibliography has been removed and incorporated into the thesis bibliography. As the paper is required to stand alone as a unit the reader will note that some parts of the previous chapters have been directly used in the paper to give it due context.

6.2 Published paper

An analysis of the socio-economic factors influencing the adoption of conservation agriculture as a climate change mitigation activity in Australian dryland grain production

Jean-Francois Rochecouste[a], Paul Dargusch[b], Donald Cameron[c] & Carl Smith[d]

Abstract

The cropping sector in Australia contributes 2.5% of national greenhouse gas emissions, not accounting for the historical loss of soil carbon. The Australian Government is developing policy initiatives targeted at farmers to encourage changes in management practices that aim to reduce emissions from the agricultural sector. The main policy proposal being developed is a market-based mechanism to pay farmers from an *Emissions Reduction Fund* using methodologies specified under the Australian *Carbon Farming Initiative*. The adoption of conservation agriculture practices in the dryland grain sector in Australia shows the potential to achieve emissions reductions in the order of three million tCO_2e annually. This paper presents a series of systems models that describe the process of how Australian dryland grain farmers decide to change and adopt conservation agriculture practices. Results indicate that a number of economic and social factors drive the rate of practice change, and change seems to be motivated mostly by the pursuit of productivity benefits rather than environmental benefits. We postulate that it may be more effective for climate policy to directly target the adoption of conservation agriculture practices among Australian dryland grain farmers by promoting the crop productivity benefits likely to be achieved by such practices, rather than attempting to develop a market-based mechanism for carbon payments. Under this approach, emissions reduction outcomes and carbon payments would not be the primary driver for changing farming practices, but rather a concurrent benefit.

Keywords

Emissions Reduction Fund, soil carbon, no-tillage, environmental plantings, crop rotation, Carbon Farming Initiative

1.0 Introduction

Cropping agriculture that employs conventional cropping systems in countries such as Australia results in greenhouse gas (GHG) emissions from the combustion of tractor fuels, the use of inorganic fertilisers and the mineralisation of soil carbon during land preparation (Kupfer and Karimanzira 1990; Dalal et al. 2003; Lal 2004a; Luo et al. 2010; Garnaut 2011). In most cases, these emissions are biologically based and not easily measured (McGinn 2006; Sanderman and Baldock 2010). This creates a policy dilemma for governments looking to create reportable changes in GHG emissions from agriculture (Lal 2004b; Wang and Dalal 2006; Keogh 2007; Regina and Alakukku 2010; Schwenke et al. 2011).

The Australian Government introduced the Australian Carbon Farming Initiative (CFI) in September 2011, a market-based instrument that pays farmers for reducing GHG emissions as an incentive for them to change to more sustainable farming practices (Australian-Government 2011). By participating in the CFI, farmers and land managers who reduce GHG emissions or sequester carbon will be able to generate credits for this abatement that can then be sold to a proposed *Emissions Reduction Fund* (Australian Government 2013b).

There has been considerable research into the quantum of emissions reductions or sequestration possible on Australian farms in general (Jawson et al. 2005; Li et al. 2010; Regina and Alakukku 2010; Browne et al. 2011; Schwenke et al. 2011; Wang et al. 2011; White and Van Rees 2011; Cowie et al. 2012; Harris et al. 2013; Thamo et al. 2013). However, there is relatively little research into the socio-economic factors affecting the drivers for changing farm practices by Australian dryland grain farmers under emerging and uncertain climate policy circumstances (Llewellyn 2011; Ecker et al. 2012). In this paper, we focus on the adoption of conservation agriculture (CA) by dryland grain farmers in Australia, a farming system recognised as one of the effective ways of reducing emissions in the sector (Hobbs and Govaerts 2010; Li et al. 2010; Garland et al. 2011; Labreuche et al. 2011; DCCEE 2012).

CA is a set of farming principles that over time aims to reduce resource inputs and maximise agricultural productivity by increasing soil carbon in crop production, but within an economically acceptable framework (Hughes 1980; Allmaras and Dowdy 1985; Uri 2000; Hobbs 2007; Reicosky and Saxton 2007; Hobbs et al. 2008). Its principles of minimal soil disturbance, permanent soil cover and crop rotations are supported by the United Nation's Food Agriculture Organization (Friedrich and Kienzle 2007; Kassam et al. 2009). In Australia, CA farmer organisations have promoted a range of additional technologies to reduce energy, improve soil health and conserve soil moisture. These include controlled traffic farming (CTF), precision agriculture, cover cropping and recycled organics (Tullberg et al. 2007; Butler 2008; Branson 2011). There is also a body of literature on the role of CA in mitigating climate change by reducing emissions and sequestering carbon (Uri 2000; Chan et al. 2003; Lal 2004c; Zentner et al. 2004; Wang and Dalal 2006; Govaerts et al. 2007; D'Haene et al. 2009; Young et al. 2009b; Rochecouste and Dargusch 2011; Gonzalez-Sanchez et al. 2012). CA provides a range of co-benefits for dryland grain farmers in Australia in that CA practices can improve cropping productivity, help to mitigate climate change and support adaptation to climate change (Thomas et al. 2007c; Tullberg 2009; Rochecouste and Crabtree 2014).

In order to gain the benefits of reduced agricultural emissions from CA we need to better understand what drives CA adoption for Australia dryland grain farmers. Past studies have suggested that adoption from a farmer's perspective is based predominantly on its profitability, despite not always being simple to implement on-farm (Upadhyay et al. 2003; Scott and Farquharson 2004; Vanclay 2004; Thomas et al. 2007b; Wylie 2008; Pannell et al. 2011). Factors that drive the adoption of changes in practice are on-farm benefits as opposed to policy drivers which are usually designed to produce off-farm benefits as outlined in Table 1.

Table 1- The distribution of costs and benefits associated with conservation agriculture across different spatial scales (adapted after Knowler and Bradshaw 2007).

Practice benefit	**On-farm**	**Off-farm**
Benefits		
Reduction in on-farm costs in time, labour and machinery	✓	
Increase in soil fertility resulting in higher yields and food security	✓	✓
Reduced impact of erosion downstream		✓
Reduction of pollutants in run-off		✓
Reduced air pollution (dust and diesel fumes)		✓
Reduced carbon dioxide in the atmosphere		✓
Conservation for terrestrial biodiversity		✓
Costs		
Purchase of new machinery	✓	
Short-term pest problems (e.g. disease carryover)	✓	
Time and effort in acquiring new skills	✓	
Application of additional herbicides	✓	
Formation and operation of local farmers group	✓	✓
High risk due to technological uncertainty	✓	✓
Development of technical packages and training programs	✓	✓

2.0 Conservation agriculture practices and greenhouse gas emissions

The Carbon Farming Initiative Handbook produced by the Australian Government highlights a number of CA practices as being potentially effective opportunities for soil carbon-based climate change mitigation (DCCEE 2012). The handbook points to a number of activities that broadacre farmers may consider including reducing tillage, reducing fertiliser use, applying CTF, increasing stubble retention after harvest, green manuring with legume crops and applying ameliorants such as biochar, compost or manure (DCCEE 2012).

2.1 Reducing tillage

So called, 'No-till' practices involving less than 25% soil disturbance using narrow tines and disc planters are used on about 13.8 million hectares of Australian grain production area (Edwards et al. 2012). This equates to about 60% of the Australian dryland grain area. On the remaining 40% (approximately 9.2 million ha) a range of full-cut tillage system is used (Edwards et al. 2012). According to Lam et al. (2013) in a review of Australian studies on agricultural emissions using meta-analytic techniques to determine the feasibility of increasing soil carbon, approximately 0.139 tonne of carbon (C) per hectare per year can be saved from reducing tillage in Australia (Lam et al. 2013). Assuming that no-till practices are introduced on this remaining 40% of dryland grain that is currently using tillage, it would potentially avoid the loss of a further 1.2 million tonnes of C/year.

2.2 Retaining crop stubble

Cereal crop stubble after harvest represents a significant carbon pool. Using the estimate of a general harvest index of 0.4 for the major grain crops grown in Australia (wheat, barley, oats and triticale), the 2012 Australian grain crop harvest returned 33 866 000 tonnes of cereal grain and left a potential 50 799 000 tonnes of stubble after harvest prior to burning or grazing (Kemanian et al. 2007; GRDC 2013). If we assume that the retained stubble is 40% carbon, this equates to a potential 20 319 600 tonnes of carbon or 0.86 tonnes of C ha^{-1} for 2012. If the crop stubble is fully retained in the field, only a small fraction of this carbon potentially stabilises to a humus fraction after breaking down (excluding biota) (Stagnari et al. 2009). According to the New South Wales Department of Primary Industry, retaining stubble rather than burning it can avoid the loss of 70 to 90 kg of soil C ha^{-1}/year (DPI 2004). The more recent meta-analysis by Lam et al. (2013) suggests a carbon accumulation figure of 62 kg C ha^{-1}/year. Full stubble retention, from harvest to the next planting period, is practiced by about 60.5% of dryland grain cropping farmers, representing approximately 13.9 million hectares (Edwards et al. 2012). For the balance of 39.5% of farmers (occupying approximately 9 million hectares) that otherwise graze, remove or burn their stubble, this would equate to a loss of 558 000 tonnes C ha^{-1}/year that could potentially be returned to the soil. The details on the fate of removed stubble by either grazing, baling for hay or burning varies by season, but a 2011 industry survey showed that at least 3.8 million hectares was burnt to facilitate planting (Edwards et al. 2012).

2.3 Legumes

Including a legume in Australian cropping rotation has been estimated to add approximately 110 kg of nitrogen per hectare as a natural fertiliser depending on the type and growing conditions (typically a farmer might plant legumes in a 1:4 year rotation with cereals) (Herridge 2011). Across the industry's 23 million hectares of dryland grain production, legume crops could replace about 644 000 tonnes of manufactured urea per year. The exact abatement potential that can be gained by Australian farmers planting legumes is uncertain because the choice of legume as part of crop rotation is limited by market demand for the grain, with only a 12% increase in production as a response to demand in the 10 years from 2002 to 2012 (GRDC 2013). The New South Wales Department of Primary Industry soil research unit also suggests that legumes can sequester up to 150 kg C ha^{-1}/year (DPI 2004). In 2012, Australia produced 2201 tonnes of legumes over 1.77 million hectares or 7.5% in terms of production area, which we estimate would add 265 200 tonnes of soil carbon per year (DPI 2004; GRDC 2013). Legumes are not routinely grown in all grain cropping areas due to a lack of suitable varieties for some local climate conditions (Edwards et al. 2012). However, based on the estimate of 150 kg C ha^{-1}/year as indicated by Lam et al. (2012), every 1% increase in the area grown to legumes annually represents approximately 35 000 tonnes of additional soil carbon.

2.4 Controlled traffic farming

According to Tullberg (2010), there is an indication that compacted soils emit higher rates of nitrous oxide (N_2O) than non-compacted soils and that CTF reduces overall soil N_2O emissions by limiting compaction to a small section of the field (Tullberg 2010). It is based on limited experimental data in one region; therefore the quantity of soil emissions involved cannot yet be calculated at a national level across the various soil types. CTF also reduces fossil fuel consumption per hectare by about 50% of conventional non-CTF systems (Tullberg 2009).

2.5 Fertiliser efficiency

Fertiliser efficiency can be significantly improved by using a variable rate application system that adjusts fertiliser rate across the field based on predetermined needs (Chen et al. 2008). The process requires precise global positioning system capacity which is already used by the 66.7% of Australian dryland grain farmers with auto-steer tractors; however, the use of variable rate application with fertilisers is still quite low; in the order of 14% of dryland farmers (Robertson et al. 2012). Although the technology for increasing fertiliser efficiency is available in Australia, the amount of GHG emissions reduction that this represents is still uncertain under Australian dryland conditions. Fertiliser efficiency is included as a carbon abatement methodology for creating carbon offsets in some carbon markets, although it is not yet approved by the Australian Clean Energy Regulator for use under the Australian Carbon Farming Initiative (DCCEE 2012; De Wit et al. 2013; Millar et al. 2013).

The rate of adoption of CA practices in 2011 in Australia and the emissions reduction potential possible from full adoption of different CA practices in cropping systems in Australia is displayed in Table 2.

'Table 2 Percentage adoption of conservation agriculture farming system practices by dryland grain farmers in 2011 (Edwards et al. 2012) and the potential abatement value of changing farming practices.

Farming system practices as part of conservation agriculture in Australia	Estimated adoption by grain farmers in 2011 (% of total cropped in Australia)	Potential abatement value based on full industry adoption
No-till (<25% soil disturbance)	60% (13.8 million ha)	1.2 million tonnes of carbon loss avoided
Full stubble retention	60.5% (13.9 million ha)	558 000 tonnes of carbon added
Legume rotation	6.8%	35 000 tonnes of carbon sequestered for every 1% increase in the area of adoption
Controlled traffic farming	21.1% (4.85 million ha)	Unknown
Precision agriculture use of variable rate technology to fertilising operations	8.1% (1.9 million ha)	Unknown

Table 2 shows that Australian cropping farmers have already been adopting CA practices of their own accord for productivity reasons. In policy terms, there is still potential for further improvement in reducing emissions if we could better understand the drivers of CA adoption and consider policies that support those drivers. In the following analysis, we look at the factors influencing adoption amongst Australian cropping farmers to better understand what might motivate farmers to make changes in practices that also reduce emissions. The Australian grains industry represents a unique opportunity to study an industrial agricultural system operating in a semi-arid zone context and may provide experience to other arid-zone farming systems adopting industrial technology.

3.0 Methodology

The socio-economic drivers that create farming system change interact in complex ways, so we developed a series of systems models to visually describe the main factors that drive the adoption of CA practices in Australia. Applying 'systems thinking' to an issue helps us understand the interactions that drive adoption of changes in behaviour and those that balance the drivers in the opposite direction in complex situations (Sterman 2000; Quan Van and Nam Cao 2013). Understanding the mechanism of change in a visual model should support better policy development (Bosch et al. 2007; BeLue et al. 2012). We can use a representative mental model to identify parts of the farming system and how they might interact, thereby provide a framework to manage change by understanding dynamic feedback (Sherwood 2002). To develop this framework we use causal loop diagrams (CLDs) consisting of identified variables and arrows that represent causal relationships between variables as either (+) or (–) (Ventana-Systems 2013). A positive polarity indicates that a cause and effect are reinforcing, that is, increasing the cause increases the effect. A negative polarity indicates that a cause is inversely influencing the effect, thereby balancing the effect in the opposite direction (e.g. Figure 1).

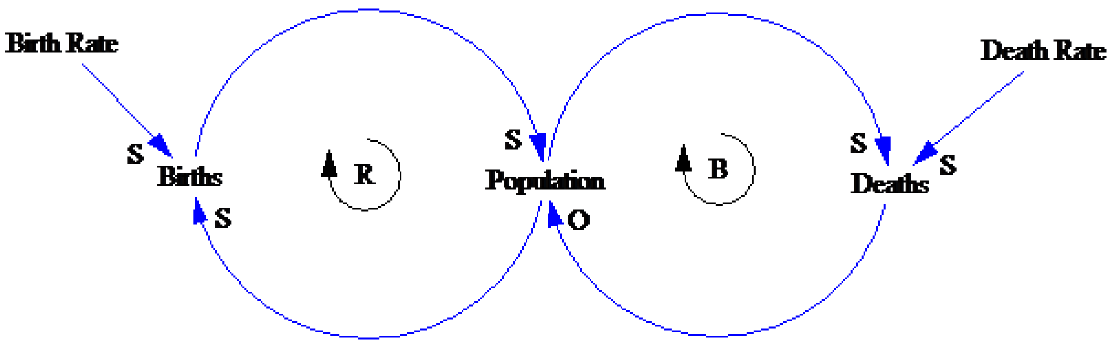


Figure 1 - A reinforcing and balancing causal loop diagram about the impact of births and deaths on a population.

In the simple example illustrated in Figure 1, a number of factors might influence deaths or births thereby impacting on the rate of deaths to births and subsequently influencing the population levels. Such mental models can help better understand cause and effect in a dynamic way (Checkland 1999). In real-world situations, there are additional interactive variables creating a more complex framework (Sherwood 2002).

For the models presented in this paper, important information about farm practices adoption has been synthesised from published literature to inform the early stages of model development. The literature provides an important framework for analysis, but not all of the factors for change are covered in the literature, nor are they contextualised to current Australian conditions. We therefore also used a qualitative survey instrument approach (semi-structured interviews with CA farmers) to determine what influenced their decisions for practice change. From across Australia's diverse farming regions, we interviewed 31 farmers attending field days or on farms, this was organised by local advisors asking if they were willing to take part in an on changes in farming practices in their area. There was only one female interviewed, two were couples and the balance males. The research approach we applied is known as phenomenography (Marton 1981). According to D'emden et. al. (2008) a significant percentage of grain farmers in Australia had adopted some form of CA in order to remain competitive. In our sample no-till was practiced by 93% of farmers, stubble retention by 90% with some burning stubble only if required. Crop rotation was practiced by most farmers at 74%, precision guidance was used by 71%, control traffic system was applied by 48% of our sample and only 19% had included some form of cover cropping. We visited the farmers on site at field days or on their farm and conducted face-to-face interviews, so our sample numbers were limited by cost and our ability to cover the large geographical spread of the Australian grain belt. We believe that it was important to go beyond telephone surveys and have a more in-depth discussion with farmers to gain a better sense of the underlying motives for the adoption or non-adoption of the various farming practices. The interviews lasting up to 45 minutes depending on the farmer's openness to conversation were conducted across all of Australia's dryland cropping regions: Western Australia (7), South Australia (11), Victoria (4), New South Wales (3) and Queensland (6). Due to the sheer size of the continent and the spread of grain growing not all agro-ecological zones could be covered but most states recorded a spread across several hundred kilometres. A previous survey on current farming systems adoption by Edwards et al. (2012) does not include underlying motivation. Other studies such as Vanclay (2004); Llewellyn (2011); Pannell et al. (2011); Ecker et al. (2012) and Schirmer and Bull (2014) have looked at drivers of practice change regarding land use but not specifically at emissions reduction to do with CA. The interviewees were representing a family farm, typically cropping 2500 to 5000 hectares. All were previously part of farming families and some had been on the same farm for many generations. For the districts involved, the precipitation varied from 250 to 600 mm annual rainfall and the crops grown were wheat, oats, barley, sorghum, corn, mung beans, canola, faba beans, lentils, chickpeas and lupins.

A similar qualitative approach has been used in other studies to gain an understanding of various phenomena (Barnard et al. 1999). Using a qualitative research approach is useful for studying rural change issues as it allows a broad series of views and perceptions to be captured (Kvale 1996; Patton 2002; Maraseni and Dargusch 2008). The interview structure used was based on an 'Interview Guide' approach as per Patton (2002). The interview questions are open-ended and based on a guided format to ensure the same basic lines of enquiry are pursued for each farmer. Farmers were asked about their location details in regards to soils, climate and crops grown. They were also asked to elaborate on the CA practices they had or had not adopted based on the list in Table 2. We sought to get a further understanding of their prior practices and the basis of their reasoning for making or not making the changes. To confirm the value of the drivers to making changes we also covered the benefits they had gained in making the changes and if they had abandoned any of the practices. This provides some structural similarity but allows for individual perspectives and experiences to emerge (Kvale 1996; Patton 2002). We asked farmers which CA practices they had adopted and why they had adopted them. If farmers wanted to expand their views into a broader range of comments, we allowed them to do so. The responses are grouped by themes of responses such as 'moisture retention'. The grouped responses formed the basis for constructing the 'drivers' in the model. We also considered why farmers had not adopted or had delayed the uptake of some practices and what might cause them to abandon a practice. These formed the positive and negative causal relationships of the model.

4.0 Results and discussion

All farmers interviewed highlighted that the main reason for changing practices was that they thought the change would make their farming operations more profitable -

> "It's the only thing that's going to keep you here is profit."
>
> *Western Australian farmer*

> "If you're still back conventionally farming your country and planting late, and you're just not making the money. So, we probably find that we've got to skew towards the early adopters and innovators in farming"
>
> *Queensland farmer*

They clearly weighed the cost involved against the potential benefit that could be observed from early adopting peers. This was also supported in the literature where farming systems groups and advisers have primarily focused on issues of profitability and economic sustainability (Gourley and Ridley, 2005; Thomas et al. 2007b; Wylie, 2008). Positive drivers were those that improved profitability. Negative drivers were those that tended to lead to conditions that may reduce profit or create financial loss. Farmers indicated that adopting a practice was also related to other factors, such as investment cost or the knowledge and skills required to implement the change of practice. Farmers were in agreement on the value of reduced tillage and stubble retention; those that had not adopted had very specific reasons for not doing so or were new to the industry and intended to adopt it in the near future. This is not surprising given the volume of published evidence in industry media supporting such benefits since the 1980s. The adoption of a legume rotation was simply a matter of economics in competition with other rotations such as canola. Controlled Traffic was more contentious with a number of farmers not convinced of the value of the investment.

We developed models for four CA practices: reducing tillage, retaining crop stubble, introducing legume in rotations and adopting CTF. A model was not created for fertiliser application because most of the farmers interviewed had not yet made changes to their fertiliser application system.

4.1 Model 1 – Reducing tillage

All farmers interviewed highlighted that their decision to implement reduce tillage practices was heavily influenced by the examples provided by peer farmers which demonstrated the production and profitability benefits possible through reducing tillage. Farmers indicated that they valued the real-life context in which the peer farmer presented results. Locality was also important to the decision on whether to reduce tillage; the level of moisture retention leading to better productivity from this practice was more evident in the low-rainfall areas especially during drought years. They indicated that the economics of reducing tillage provided them with more cropping opportunities and reduced overall cost of inputs by replacing diesel with increased herbicide use. The comparative economics of 'tillage' to control weeds versus the 'herbicides' was in favour of herbicides as glyphosate prices decreased through competition. Another important driver was the impact of wind or rain erosion in removing valuable topsoil. This did not directly affect short-term income, however it did raise concerns about the long-term viability of land affected by reduced fertility and steered farmers towards measures that reduce erosion.

The CLD in Figure 2 represents a mental map of the factors that influence the profitability of reduced tillage practices. The model is premised by the finding that farmers will change practices if the change results in better profitability. It follows that if we want to further reduce tillage by farmers for environmental purposes, than we need to formulate policy within the social and economic framework that is already driving industry change.

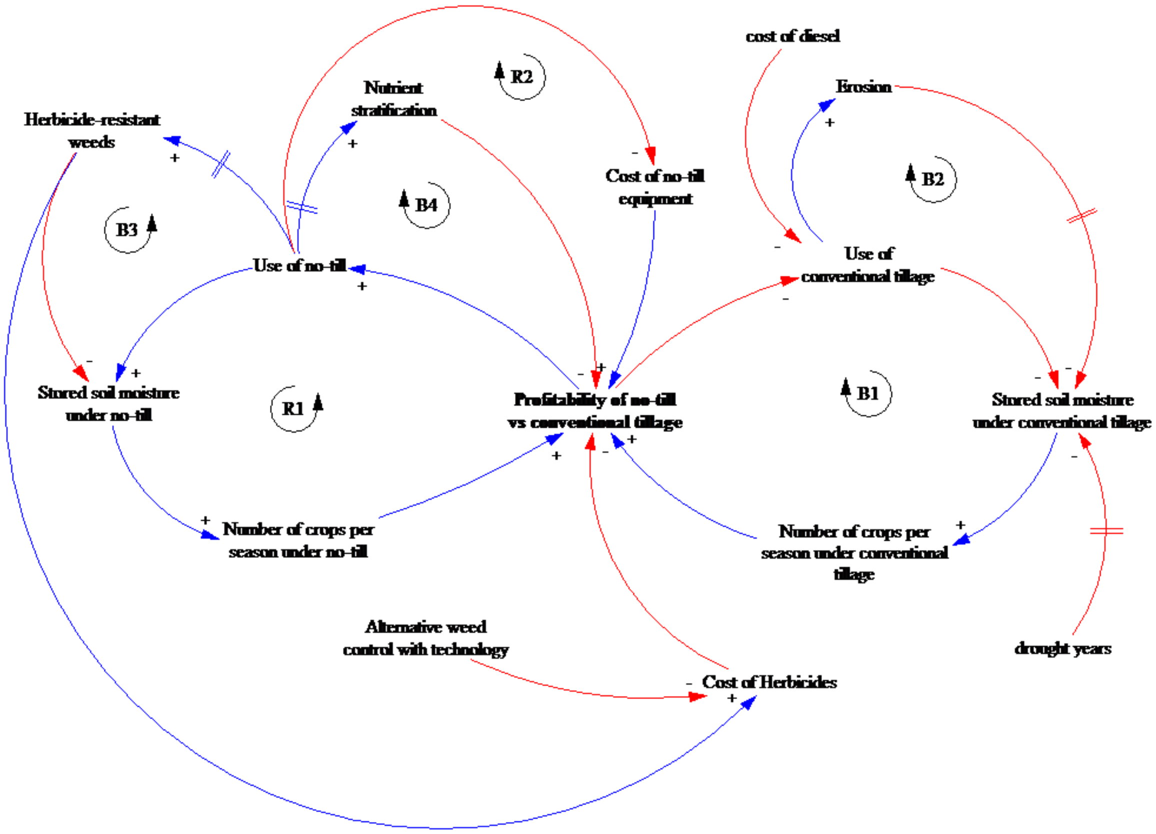


Figure 2 - A causal loop diagram of factors influencing the profitability of moving from conventional tillage to a no-till system

In the figure above and those to follow, the symbol ‘R’ refers to a reinforcing loop where actions positively affects the outcome and increases the drive creating a positive feedback loop. The symbol ‘B’ refers to a balancing loop in which the action has negative consequences that drives against continuing the action. The double slash refers to a delay in effect (Sherwood 2002). Reducing tillage to a no-till system (Figure 2, R1) can significantly improve the retention of soil moisture leading to greater yield (approximately 20 kg/ha/mm of stored soil moisture) (French and Schultz 1984) and more cropping opportunities per range of seasons, thus increasing the level of income (Silburn et al. 2007; Thomas et al. 2007c; Wuest 2010). This is reflected in Figure 2 and has been suggested by other studies as a key reason for farmers to adopt reduced tillage practices (Taschetto and England 2009; Quinton 2010; Farley 2013). Another reason for uptake seems to be the favourable commercial availability of no-till equipment which some farmers indicated as important as they no longer had to re-engineer the machine themselves (Figure 2, R2).

However, herbicide resistance sometimes requires farmers to resort to cultivation to control weeds and it acts as balancing factor in the model (Figure 2, B3). Another balancing factor is nutrient stratification where soil organic carbon and the major immobile nutrients of phosphorus and potassium can be locked into the drier surface horizon of cropping soils (Figure 2, B4) (Bauer et al. 2002; D'Haene et al. 2009; Hernanz et al. 2009). If farmers were to revert to cultivation to manage weed control or to invert soil layers to redistribute nutrients, they would once again face high diesel costs, erosion (Figure 2, B2) and the loss of soil moisture especially in the dry years, thereby affecting profitability (Figure 2, B1).

The process of reducing tillage in cropping systems in Australia is already a well-established practice. The implication for soil carbon is that further tillage reduction is coming under pressure from the looming problems of herbicide resistance and nutrient stratification, a source of concern for farmers (Argent 2012).

4.2 Model 2 – Crop stubble

A model of the factors influencing the cycling of surface carbon as a result of stubble retention is presented in Figure 3. All farmers interviewed perceived stubble retention as a component of no-till practices and considered it a beneficial practice for soil moisture retention. Stubble offers flexible options for farmers; it can be retained, grazed or sold as animal feed depending on the prevailing economic conditions. Farmers also indicated that stubble creates problems for machinery at planting and is a source of carry-over for pests and diseases. Carry-over pests themselves, including snails (*Theba pisana*) and rodents (*Mus domesticus*), weed seeds and diseases such as yellow leaf spot (*Pyrenophora tritici-repentis*), crown rot (*Fusarium pseudograminearum*) and take-all (*Gaeumannomyces graminis* var. *tritici*), can be a significant incentive for stubble removal (Rees and Platz 1983; Scott et al. 2010; GRDC 2011a).

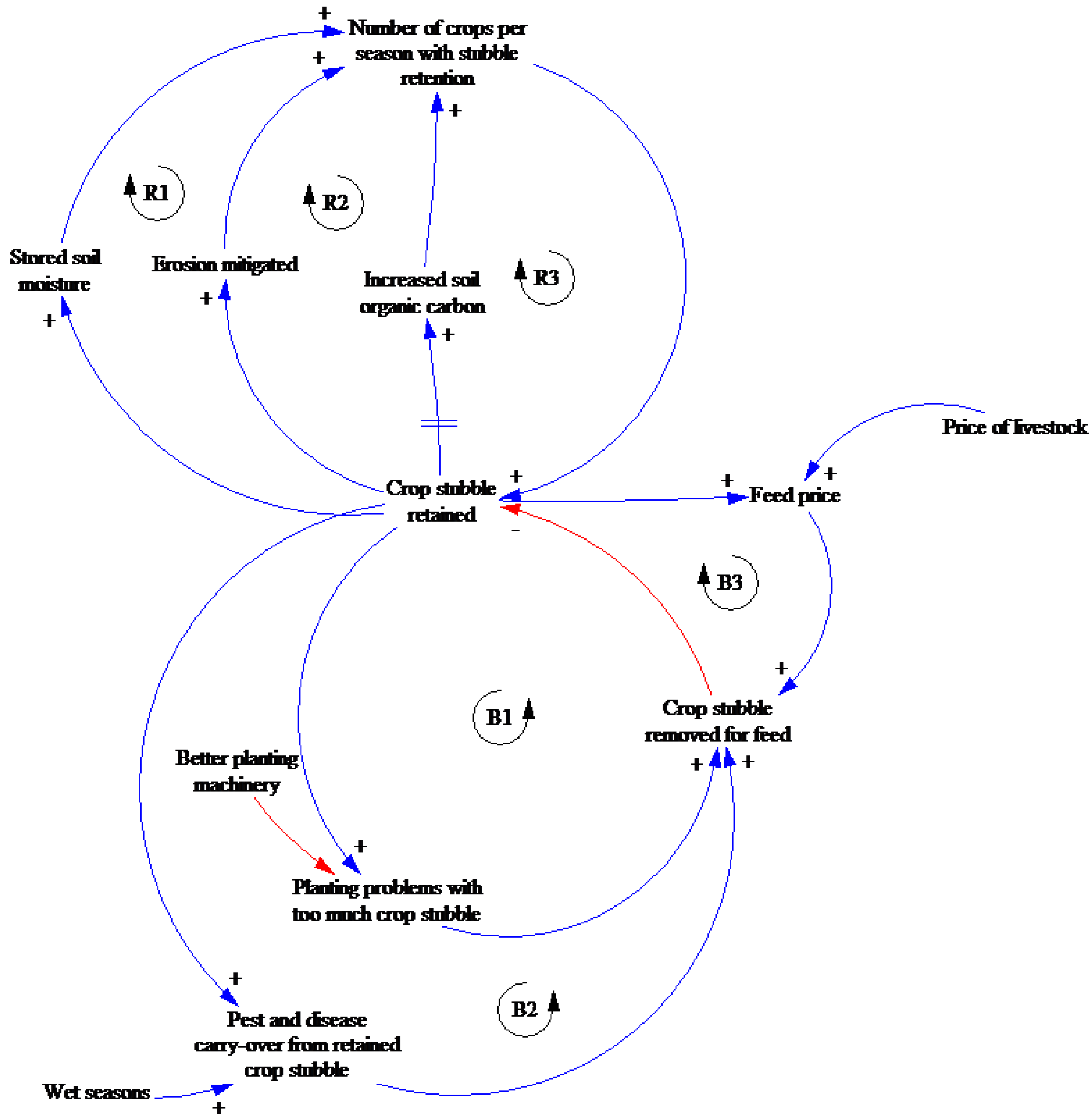


Figure 3 - A causal loop diagram of the factors that influence the retention of crop stubble after crop harvest

The main reason the farmers interviewed retained stubble was for its benefits in soil moisture retention (Figure 3, R1). Improved soil moisture also provides more cropping opportunities (Oleary and Connor 1997; Anderson 2009; Scott et al. 2010). Mitigating soil erosion (Figure 3, R2) has also been reported as a significant benefit (by retaining valuable topsoil). Retained stubble also cycles carbon back into the system, thereby buffering nutrient demand from fertiliser (Figure 3, R3) (Malinda 1995; Thomas et al. 2007c). From our farmer interviews, we determined that these benefits to production seem to be balanced by the problems of managing stubble during planting operation (Figure 3, R1). That is, problems from 'clogging' of the tines and 'pinning' which occur on soft soils when the disc does not cut the stubble straw, instead pushing it into the seed furrow and disturbing the soil–seed contact. We know that this problem can be severe enough for some farmers that they opt to burn prior to planting (Scott et. al. 2010). The other balancing factors are pest and disease carry-over (Figure 3, R2), for which the most efficacious risk option is to burn the stubble, and the basic opportunity cost of the stubble as animal feed, for which there is a ready market. To a large extent the final decision depends on how much farmers value the option of stored moisture for a future yield return compared to the immediate cash return from animal feed. The demand for crop stubble as animal feed and the need for stubble retention to reserve soil moisture both coincide with drought conditions. There is a need to better understand the issues around stubble management and its impact on crop establishment. If farmers have to make a choice about whether they are going to remove or retain crop stubble, than they need solutions to some of the problems of stubble management.

4.4 Model 3 – Legume rotations

Introducing a legume crop into a cropping rotation cycle can reduce demand for synthetic fertiliser by the next crop and thus GHG emissions can be reduced (Dalal and Wang 2010; Lupwayi et al. 2011; Schwenke et al. 2012). In legume crops atmospheric nitrogen (N_2) is reduced to ammonia (NH_3) via the nitrogenase enzymes in their root nodules which are inhabited by the soil bacteria *Rhizobia* spp. The ammonia produced is converted by the plant into amino acids and other compounds used by the plant for growth (Herridge 2011). Legumes also provide nitrogen residues after decomposition of the soft plant tissue making it available for the following crop to the value of about 100 to 120 kg per hectare of nitrogen fertiliser (Peoples and Griffiths 2009). The process also emits N_2O as a scope 1 emission, but does not have the additional scope 3 emission from the high energy inputs required by the manufacture of fertiliser using the Haber-Bosch process (Addiscott 2004).

Although legumes can be a significant contributor to soil nutrition, they are not always as favoured as cereals or oilseeds. The main reason given by the farmers in our interviews is that the relative profitability of legumes is not as good as for other crops in certain seasons. In dry years, cereals are more productive and offer better returns (Seymour et al. 2012).

Based on current adoption trends, legume crops are unlikely to be a significant alternative to purchasing synthetic fertiliser to supply the needs of cereal crops (Whitbread et al. 2000). The major driver is the need for legume as a break crop where it is cost effective (Kirkegaard et al. 2008; Evans et al. 2010). The market price for legumes is the second main driver for farmers choosing to plant legumes compared to an oil crop such as canola. It is also apparent that not all agro-ecological zones can support the high-value legume crops, and in some instances the available crop options in the southern and western regions of Australia are limited by soil type and climate (Herridge 2011; Edwards et al. 2012; GRDC 2012).

Legumes have a potential role in mitigating the climate change impacts of agriculture by reducing the need for industrial fertiliser, increasing soil organic carbon and as a possible feedstock for biofuels (Jensen et al. 2012). However, a decision about whether to pay a farmer from a carbon market to grow legumes would need to consider the potential overproduction of the legume grain and the impact this would have on its market price. A more effective approach might be to grow legumes as a green manure cover crop to increase soil carbon as there is no grain market impact (Lal et al. 2009; Olson 2013). A green manure crop refers to a crop grown for the purpose of protecting the soil from erosion and turning it back into the soil to increase the level of organic matter. The farmers we interviewed indicated that they value legume rotations, but not at any price, and seasonal conditions will influence the option. Mostly they perceive legume rotations as a break crop for risk-management and are just as likely to shift to more profitable oil crops (Figure 4). Some farmers suggested that legumes can be somewhat more complex to grow and not all farmers are confident of getting a good crop in-place.

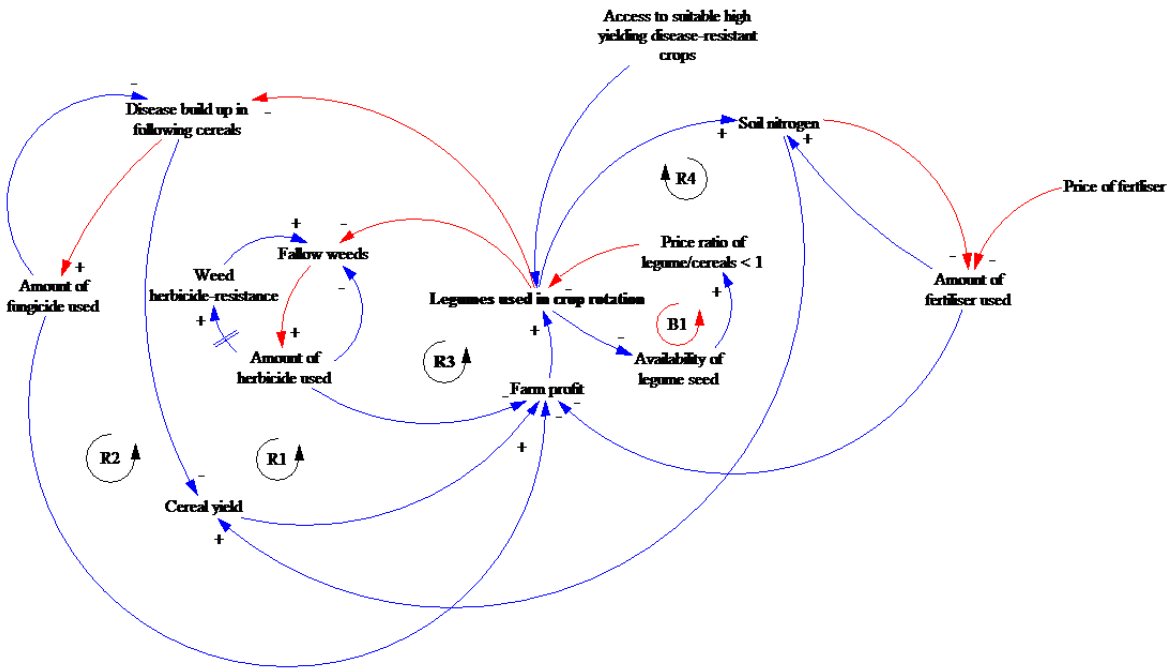


Figure 4 - A causal loop diagram of the factors influencing the uptake of legumes in dryland cropping rotation in Australia

Cereal yield is one of the main drivers of farm profits (Figure 4, R1). However, cereal yields can be affected by a build-up of cereal diseases, especially when increasing stubble retention occurs in adverse weather (Figure 4, R2). This rotation reduces the need for cereal fungicide, thus improving profits from future cereal crops. However, the choice of crop ultimately depends on farm profitability (Seymour et al. 2012) (Figure 4, B1). If fertiliser prices are very high, farmers may look to the nitrogen value of the legume to boost future grain yields (Figure 4, R4). Legumes also make a useful break crop to avoid herbicide resistance, thereby insulating against future herbicide-resistant weed problems (Figure 4, R3). The availability of suitable legumes can also limit options. A number of the farmers interviewed indicated that they recognise the value of legumes in rotation, but are required to make pragmatic economic decisions on crop choices. Hence consideration is given to what crop is available, the price return for legumes, fertiliser prices and the presence of diseases in last season's crop.

Given that there are no consistent productivity benefits from including legumes, prospects for introducing legumes as part of an emission reduction strategy appear limited. This is because farmers will introduce a legume crop into rotations for a number or reasons not directly related to carbon. Most of the emission benefits from a legume crop come from reducing the demand for manufactured fertiliser in their supply chain (Huth et al. 2010; Schwenke et al. 2011). Actual on-farm emissions from the introduction of legumes would be very difficult to measure under current conventions. There is research underway into using legume crop rotations as a means of reducing N_2O emissions by making fewer applications of fertiliser, but it is unclear at this point how that might fit into a carbon offset project methodology (Huth et al. 2010; Schwenke et al. 2012).

4.5 Model 4 – Controlled traffic farming

The value of CTF in reducing the emission profile of Australian cropping farm operations is based on two assumptions. The first is that limiting machinery traffic to set lanes means machinery operates on a compacted hard surface and this uses less energy than on soft soils. According to Tullberg (2009), fuel use is reduced by as much as 50% for tillage and planting operations and 35% for harvest operation and spraying. The second assumption is that the better aeration of uncompacted soils leads to less N_2O emissions than for compacted soils (Tullberg 2010). Early trials indicate emissions from cultivated fields and no-till paddocks that have some level of soil compaction are around 2–2.5 kg N_2O-N/ha compared to CTF fields at 1.2 kg N_2O-N/ha. Softer, less-compacted soils also increase populations of soil organisms, such as earthworms, which can help organic recycling (McKenzie et al. 2009). The agronomic benefit of CTF in providing improved yields from better managing soil compaction should be a sufficient driver for farmers to adopt it (Chamen et al. 2003; Li et al. 2007; Batey 2009).

However, advocating yield increases to farmers is not sufficient to gain adoption of new practices. At least two participants did not believe compaction was an issue, one indicated that the topography was not felt to be suitable and four saw investment in changing farming system as an important consideration—the cost of entry and how easy it is to make the change. There is an indication from our interviews that at least 20 % of the farmers were non-committal on soil compaction as an issue. Those that had become aware of the issue from past presentations by agronomists indicated they had to consider the capital cost requirements and the changes required across the farm, such as reorganising fencing or changing the direction of the planting row. Permanent wheel lanes can also cause other issues such as deep ruts in clay soils that have to be renovated (Neale 2013). The factors relating to the uptake of CTF are presented in Figure 5.

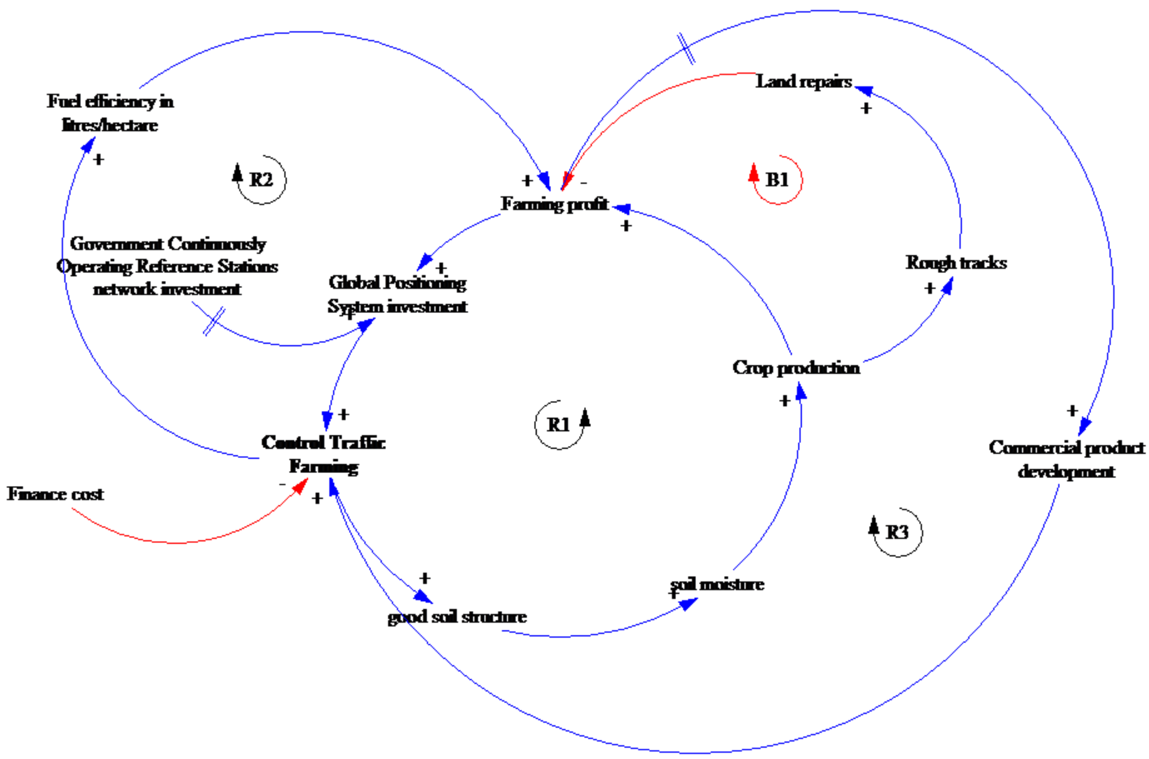


Figure 5 - A causal loop diagram of the factors affecting the uptake of controlled traffic farming

The main reinforcing loops that drive adoption of the CTF system (Figure 5, R1) relate to crop production improvement and greater profit (Blackwell et al. 2013). The Global Positioning System (GPS) investment required to operate CTF is in place on most farms that use autosteering tractors and the use of publicly accessible regionally continuous operating reference stations (CORS) is expanding (Janssen et al. 2011). These GPS reference stations are multi-compatible with various suppliers and allow farmers and other rural industries to access precision GPS positioning of their equipment without having to buy a reference station. Perhaps the simplest and most obvious benefit of CTF is in the fuel savings from running machinery on compacted tracks instead of soft soils (Figure 5, R2). Factors balancing the adoption process are cost and the problems associated with the system, such as the deep ruts from the weight of machinery operating on the same track (Figure 5, B1). A delayed reinforcing loop creates a market opportunity for commercial product development (Figure 5, R3). The relatively low level of adoption of CTF provides the opportunity to significantly increase adoption and thereby reduce future emissions. An important issue that seems to be constraining rapid adoption by Australian farmers concerns machinery configuration. Usually the front axle has to be widened to match the back wheels and this can be a problem for a farmer who has just purchased a new machine. The uptake of CTF is therefore currently limited to those farmers willing to have their machinery significantly modified.

The Australian Department of Environment recognises the climate change mitigation value of CA, but there are no carbon market methodologies for CA under the CFI (DCCEE 2012). At a macro level, Australian agricultural emissions could be reduced through greater adoption of a range of CA practices. However, based on the models presented in this paper, it is unlikely that a market-based approach will be a commercially viable solution.

Under the Australian CFI legislation, the process for producing a carbon offset unit is quite complex for farmers. Australian carbon credit units (ACCUs) are gained via an abatement project registered by the farmer or 'body corporate' acting on behalf of the farmer. For sequestration projects, the proponent must have the legal sequestration rights to register the project. This is created under a separate State law and all proponents are required to have the sequestration rights registered on the land titled to be in force for the duration of the 'permanence obligation' which is set at 100 years (Section 43 of CFI Act 2011). Further, anyone having an eligible interest in the land such as a bank or family partnership will need to give their consent to the 100-year obligation being placed on the land (section 44 CFI Act 2011). Should the carbon stored not be maintained, the proponents may be required to pay back the ACCUs received for the project (section 89, 90 & 91 CFI Act 2011). In the event of insolvency, the regulator may apply for the farmer's land to be subject to a carbon maintenance obligation, and the bank as the likely mortgagee in possession becomes the responsible entity (De Wit et al. 2013). There are also various reporting requirements to be undertaken for projects. The process requirements for what is a relatively small gain, especially when compared with the likely gains from agricultural production, suggest that farmers may be reluctant to change farming practices based on a carbon project alone.

5.0 Conclusion

Cropping agriculture in Australia is a significant source of GHG emissions. In recognition of the need to reduce emissions and return carbon to the soil environment, one of the current imperatives of the Australian Government has been to introduce a ‘market-based instrument’ to encourage farmers to change farming practices in ways that conserve and enhance soil carbon, and thereby produce carbon offsets for sale. Cropping practices globally and in Australia have been slowly changing in response to land degradation by using CA farming practices, thereby reducing emissions and increasing soil carbon.

Our interviews with Australian farmers indicate that CA has a number of productivity benefits that have lead farmers to gradually invest in making changes in practices (such as reducing tillage and retaining their crop stubble after harvest). Although such practice change can take decades to be adopted across the community, we suggest that the pace of adoption for new CA practices could be increased by education and extension policies where the benefits have been clearly demonstrated by early adopters such as control traffic farming and the use of variable rate fertiliser application using digital technology. It becomes essentially an investment option for farmers, unless government believe there is a need to introduce a policy involving incentives such as added tax benefits. Where there still exist unresolved issues such as potential cover cropping options or new rotational legume crops, a targeted research program is required to determine the opportunities.

We have noted that those drivers of practice change will vary based on the practice being targeted and that the pace of change is constrained by the farmer’s awareness of the internal benefits. Implicitly important in the extension process is a demonstrated cost-benefit analysis of these emerging practices, for example, ‘Is there a realistic economic benefit after investment cost?’, ‘Have the financial implications for the farm been made clear?’, ‘What size of investment is required by the farmer?’ and ‘What is the degree of complexity involved?’. We suggest that CA provides sufficient production benefit to drive change in practices that reduce emissions. If policy is looking to drive faster change it needs to, as a minimum, demonstrate a clear economic benefit to the farm enterprise and outline the level of investment required and return on investment that is gained. It seems the larger the investment required, the slower the adoption process and we have noted that changes that take years to show a response as opposed to seasonal responses are less likely to be adopted. In addition, the more complex the process, the less likely it is to be adopted as it requires expenditure for professional support. New unfamiliar practices not widely practiced or endorsed by trusted peers, regardless of benefit, will result in slow adoption. We suggest the need to consider an 'extension' policy that includes the use of champion farmers that demonstrate how they have overcome the barriers and allow them to tell their story of how they perceive the inherent benefits.

6.3 Concluding notes

The above paper concludes that CA does have an emission reduction and carbon sequestration benefit, and that adoption would reduce overall agricultural emissions from the cropping sector. However it also suggests that adoption of CA is driven by both economic and social factors mainly production benefit and the ability of farmers to overcome the barriers to adoption. A carbon market incentive at the current price and considering transaction cost seems unlikely to support market offset production on a per farm basis. It suggests investment in extension as a more direct means of intervention to reduce emissions.

7.0 OPPORTUNITES FOR PRODUCING MARKET OFFSETS IN DRYLAND CROPPING (PAPER)

The following chapter is presented as a paper manuscript with the intention for it to be submitted to the journal *Australian Journal of Environmental Management*.

The tables are not listed as part of the thesis but follow the numbering pattern of the text in the publication. The bibliography has been removed and incorporated into the thesis bibliography. There may be slight differences in presentation format from this thesis based on publication editorial policy.

Farmer perceptions of the opportunities and constraints to producing carbon offsets from Australian dryland grain cropping farms

Jean-Francois Rochecouste[a], Paul Dargusch[b] and Christine King[c]

Abstract

The Australian Government is attempting to use a market-based mechanism to involve agriculture in activities that reduce emissions and sequester carbon. The initiative, known as the Carbon Farming Initiative, represents a significant investment as part of the government's climate change and land-use policies. To examine the potential opportunities and constraints faced by Australia's 23 million hectares of dryland grain cropping farms to engage in these carbon farming activities, we interviewed 31 grain farmers and 6 industry professionals. Our analysis suggests that agriculture presents opportunities for reducing national emissions, but that lack of project methodology development and the current project approval processes pose significant constraints to engagement. A particular concern for farmers is the extent of the 'permanence' obligation and the 'additionality' requirement regarding the 'common practice' test required for project approval. Given the requirements of the processes and the associated transaction costs, producing offsets from dryland grain cropping operations in Australia is currently not a profitable endeavour for farmers and therefore fails to act as an incentive to participation. We propose the policy needs reviewing in order to engage farmers and

alternatives for further consideration might include a national pooling framework to account for carbon offsets produced from individual Australian farms.

Keywords
soil carbon, emissions reduction, agricultural policy, Carbon Farming Initiative, additionality, permanence, market-based instrument

1.0 Introduction

A range of policy instruments is available for governments to help change farming practices that create environmental externalities such as greenhouse gas (GHG) emissions. These include cash incentives, taxes applied to inputs, education, subsidies, the creation of standards, and market-based instruments (MBI) (Horan and Shortle 2001). Using markets to manage the externalities of industry is seen as a cost-efficient way of dealing with pollution. The Australian dryland grain cropping sector covers some 23 million hectares of production with just under 29,000 farmers involved in cropping including mixed livestock (Australian Bureau of Statistics 2006).

1.1 The Australian Carbon Farming Initiative

As part of its climate change policy, the Australian Government introduced the Carbon Farming Initiative (CFI) on 8 December 2011 as an MBI in the land sector. The incoming coalition government has opted to retain the CFI and be the main buyer in the market through its Emissions Reduction Fund under its Direct Action Plan (Australian Government 2013b). The scheme was designed to help farmers and land managers earn additional income from reducing emissions and by sequestering carbon in vegetation and soils by changing land management practices. Farmers can participate by registering a project, individually or with a project developer that reduces GHG emissions or sequesters carbon which in turn generates credits for abatements that can then be sold to the carbon market. The legislation on which the CFI is based was enacted on 15 September 2011 as the *Carbon Credits (Carbon Farming Initiative) Act 2011* (CFI Act)[25] and the main provisions of the Act commenced on 8 December 2014, with the supporting Carbon Credits (Carbon Farming Initiative) Regulations 2011 (CFI Regulations) commencing on 8 December 2011[26].

[25] CFI Act 2011 - http://www.comlaw.gov.au/Details/C2012C00417
[26] CFI Regulations 2011 - http://www.comlaw.gov.au/Details/F2012C00466

In this paper, we consider the practicalities for farmers producing carbon offsets through project-based activities on dryland cropping operations in Australia for sale to a government-administered market. We consider if this is likely to be an effective tool for generating carbon offsets from a major agricultural sector. The current government's Direct Action Plan intends to use a reverse auction system as a market mechanism, wherein the 'Emissions Reduction Fund' will be established to purchase emissions reductions at the lowest price as offered by industries including agriculture (Australian Government 2013b).

The government's Clean Energy Regulator is responsible for the market process and has proposed a 'positive list' which is a register of emissions reduction activities that are deemed eligible for earning carbon offsets under the CFI (CFI Regulations 3.28). The activities have to go beyond common practice and lead to emissions reductions that would not have occurred without the CFI (Woodhams et al. 2012). If a land management activity is not on the 'positive list', it cannot progress to become a methodology until it is nominated (De Wit et al. 2013). The current 'positive list' pertaining to cropping land contains the following eligible CFI activities (De Wit et al. 2013):

1. the establishment of permanent carbon plantings since 1 July 2007
2. assisted regeneration of native vegetation, since 2007, on land that is not conservation land
3. the application of biochar to soil
4. the application of urease or nitrification inhibitors to, or with, livestock manure or fertiliser

Activities proposed for the positive list from the community or industry are open for review, but may be rejected if considered inappropriate for the CFI by failing to meet the required test under section 41 (3) of the CFI Act (2011) that deems a practice to be common to the industry or that may be held to be unsuitable by the Domestic Offset Integrity Commission in advice to the minister.

The only methodology listed that is directly applicable to dryland grain-cropping operations at present is 'environmental plantings', which requires land be set aside for tree plantings.

1.2 Carbon offset opportunities in Australian dryland cropping

We want to consider the capacity of crop farmers to supply carbon offsets from projects such as environmental plantings, but also the potential for methodologies involving soil carbon sequestration and emissions reduction. We will explore some of the opportunities for and constraints to engaging farmers in the development of carbon offsets associated within the dryland grain cropping sector in Australia.

1.21 Environmental plantings

This methodology is concerned with carbon stocks within the vegetation pool and must use Australian plant species that are native to the local area. The plantings can consist of a mix of tree and understorey species or a single species if the monoculture occurs naturally in the project area. Under the 'permanency' requirement, projects must abide by strict rules in relation to tree management, weed control and other land-use activities within the project zone for up to 100 years (De Wit et al. 2013). This creates a long-term covenant over the land beyond the current generation of landowners, and may impact on the saleability of the land in the future. The current government policy draft is considering allowing landowners to select either a 100-year or 25-year permanence option with an associated discount in earnings for the reduced period (Australian Government 2013b).

Environmental planting does have an existing methodology that can be readily taken up by farmers under the CFI. We consider if dryland grain farmers are willing to take up this opportunity to create offsets on their non-cropped land. In this context, we consider the reactions of dryland grain cropping farmers to their potential role in such a policy. We seek to understand this major farm sector's intention to participate in the carbon market, but more importantly to try and understand why they might, or might not, participate as anticipated by government.

1.22 Reducing tillage for soil carbon sequestration

Tilling the soil for planting removes valuable organic matter and Australian dryland farmers have been reducing their tillage practices since the 1970s (Loveland and Webb 2003; Thomas et al. 2007a; Kirchhof and Daniels 2009). The most significant change occurred after the 1990s, when the number of farmers that had adopted some form of reduced-tillage practice increased from approximately 20% in 1992 to over 80% in 2008 (Llewellyn et al. 2009). Australian farmers have already adopted a high level of reduced tillage, but reducing tillage under dryland conditions does not accumulate much soil organic carbon (Wang and Dalal 2006; Luo et al. 2010; Chan et al. 2011). Over time, the carbon that does accumulate is usually locked into the surface layers and can be easily mineralised by changes in farming practices (VandenBygaart et al. 2007; Powlson et al. 2014). The vulnerability of carbon in dryland grain cropping in Australia makes it somewhat risky to use as a 'deemed' methodology as applied by other crop producing states (such as Alberta, Canada), where reducing tillage can be 'deemed' to have accumulated a value of carbon based on bio-physical conditions (Dalal and Chan 2001; Alberta-Environment 2009; Chan et al. 2011). Although reducing tillage will reduce the loss of soil carbon and may accumulate small quantities of carbon; the amount of carbon sequestration per farm under Australian conditions is approximately 0.139 tonne C ha^{-1} /year (Lam et al. 2013). This should, however, be considered in terms of the large area involved. According to Edwards et al. (2012), in 2011 zero-till (<12% soil disturbance) accounted for 5.6 million hectares (24.6% of grain production areas) and no-till (12% to 30% soil disturbance) accounted for 8.1 million hectares (35.4%). This leaves a potential nine million hectares of dryland cropping land in Australia on which a change in practice to zero-till might accumulate small amounts of carbon rather than incur a loss.

We are particularly interested in the response of farmers to changing practices for a carbon market opportunity. The research objective is to assess the farmer's likely response to a carbon market policy and their likely intention to participate in an MBI. We attempt to answer this question by engaging in direct dialogue with the industry, focusing primarily on environmental plantings and reducing tillage as vehicles for carbon offsets.

2.0 Methodology

To explore farmers' perceptions of the CFI and of changing practices for a carbon market economy, we used a phenomenological method of inquiry; a qualitative inquiry method that can be applied to understanding a myriad of experiences. For example, this methodology has been used in the health sector to understand a patient's experience of various phenomena (Barnard et al. 1999). This method interpreted a 'lived experience' or fact, by listening to the different stories of the participants themselves, allowing an examination of the 'phenomenon' through the subjective eyes of the participants (Patton 2002; Starks and Trinidad 2007).

The CFI was a new and relatively complex piece of legislation and Australian farmers were still unfamiliar with MBIs in general as these instruments were not widespread and were still relatively new to land management (Whitten et al. 2004). To understand farmers' perceptions of, and responses to, an environmental service market such as the CFI, we determined that a qualitative approach was the most appropriate. Qualitative approaches are useful for gaining in-depth understanding of complex issues that are not well understood (Patton 2002; Maraseni and Dargusch 2008; Schirmer and Bull 2014). These approaches contrast quantitative approaches that have the capacity to include a large sample size but lack the capacity to elicit depth and assume the issue being explored is relatively known (King 2000; Patton 2002).

The 'lived experience' we explored in our study was the response to an economic offer, rather than specific contractual processes, as there are limited methodologies in place. We were also able to determine the constraints to 'participating in a carbon offset MBI' (Maraseni and Dargusch 2008). We took into account that farmers were unlikely to be aware of the details of the CFI methodologies being developed (e.g. biochar), but were more likely to have some awareness of established CFI methodologies from the general media. We interviewed industry professionals who had a more detailed grasp of the CFI legislation and who worked with farmers to add further insights to our enquiry from their on-ground experience.

Using a phenomenographic approach, we interviewed 31 farmers and 6 industry professionals on the CFI opportunities and how such a policy is likely to be received (Marton 1981). Starks and Trinidad (2014) explain that '*phenomenologists are interested in common features of the lived experience. Although diverse samples might provide a broader range from which to distil the essence of the phenomenon, data from only a few individuals who have experienced the phenomenon—and who can provide a detailed account of their experience—might suffice to uncover its core elements*'. They suggest that typical sample sizes for phenomenological studies range from 1 to 10 persons. Table 1 summarises the research criteria and the explanation of these criteria when using a Phenomenological Approach.

Table 1: Criteria and explanation of criteria of the Phenomenology Approach (adapted from Starks and Trinidad, 2014)

Research Criteria	Phenomenological Approach
Assumption	There exists an essential, perceived reality with common features
Goal	Describe the meaning of the lived experience of the phenomenon
Question formulation	'What is the lived experience of [the phenomenon of interest]?'
Sampling	Those who have experienced the phenomenon of interest (typically 1-10 participants)
Data collection	Observe participants in the context in which the phenomenon is experienced

Interview Strategy	Participant describes experience, interviewer probes for detail and clarity
Analysis	Identify descriptions, cluster into discrete categories, taken together these describe the commonality and structure of the experience
Audience	Clinicians, practitioners and others who need to understand the lived experience of the phenomenon of interest
Product	A thematic description of the essences and structures of the lived experience

The interview structure was based on qualitative interviewing using an 'Interview Guide' approach as per Patton (2002). The interview questions were open-ended and based on a guided format to ensure the same basic lines of enquiry were pursued for each farmer. This provided some structural similarity but allowed for individual perspectives and experiences to emerge. If farmers wanted to expand their views into a broader range of comments, we allowed them to do so (Patton 2002). We did not explain all the details of the CFI market function to the farmers as we hoped to capture their current interpretation of government policy. At present, the only carbon abatement methodology for dryland crop farmers involves environmental plantings on non-cropped land, which requires farmers to hand over the rights of their non-cropped land to the project proponent under section 27 of the CFI Act 2011.

The data collected used second-order interpretation, that is, the meanings of the responses are grouped into general responses or 'themes' for reporting on general trends (Tracy 2013). The discourses of the research were retained via transcribed recordings allowing focus on participants' understanding and interpretation of the carbon offset market and perceptions towards these types of MBIs.

Participants were chosen randomly from a number of no-till farming associations. The median age of farmers was 52 and farmers' ages ranged from early 30s to late 70s (mean 58). The farmers were predominantly, but not exclusively male, with a mix of ages. This can be compared to the median range of farmers in Australia in general, where the majority of Australian farmers are male (72%) and, although the median age is 53, almost one quarter of farmers are aged 65 or older (ABARES).

The interview process operated in different parts of the dryland cropping region: Western Australia (7), South Australia (11), Victoria (4), New South Wales (3) and Queensland (6). For the districts involved, the precipitation varied from 250 mm to 600 mm annual rainfall and the crops grown were wheat, oats, barley, sorghum, corn, mung beans, canola, faba beans, lentils, chickpeas and lupins. Some had mixed livestock enterprises, but none were exclusively livestock.

Interviewees were asked about how they perceived the value of their non-cropped land, what role such land played as part of their enterprise, and whether they would be willing to be involved in a sponsorship agreement to provide vegetation services (tree planting) for financial benefit on their non-cropped land? The need for a legal covenant requirement of approximately 100 years was included in the explanation. We further asked them to elaborate on the reasons for either participating or not wanting to participate in MBIs. We did not elaborate on the soil carbon offset area as there is no detailed methodology that could be offered as part of the discussion and farmers did not seem to have an in-depth knowledge of how the CFI functions. The recorded interviews were typically 30 minutes and we encouraged the farmers to expand their views based on the standard series of questions. The Australian Landcare vegetation program was used as a familiar concept of payment for environmental services, including the legal requirement for a covenant.

The industry professionals were from various agricultural industry positions and understood both the CFI and the farming constituency. We asked them to broadly explain how they perceived farmers would react to an offset scheme regarding tree planting, but also share their thoughts on their client's likely engagement to soil carbon projects. We asked them why they believed their farmer clients would or would not participate in a CFI carbon offset scheme, based on their knowledge of the legislation and their close link with farmers.

3.0 Results and Discussion

3.1 Farmer opinions regarding environmental plantings

At present, the only established methodology for producing carbon offsets from dryland cropping in Australia is through environmental plantings defined as the planting of native trees on either retired land or marginal spaces. Of the farmers surveyed, about 16% indicated they cropped most of their land and 84% indicated that they had non-cropped land ranging from 20 to 8000 hectares. Farmers were not able to give us a condition report on the state of non-cropped land to determine its suitability for a tree planting project, variously describing their non-cropped land as 'bush', 'scrub land' 'grassland' 'pasture, small amount of remnant coolibah trees', 'bush and creek lines that are deteriorated', 'poor quality, mainly saltbush, with weed issues' and 'virgin native bushland'. It was evident that some farmers have part of their non-cropped land available for a tree planting project. Even if only a small percentage is available for revegetation, it still represents an opportunity for such tree planting projects on dryland farms across Australia.

According to the Australian Government, 65% of agricultural businesses in Australia have native vegetation in their holdings which gives an estimated total of over 224 million hectares across Australia (Barson et al. 2012b). How much of this land is degraded and available for carbon farming projects is uncertain as there are no national condition assessments to determine suitability. Nevertheless, the scale involved points to some level of opportunity for available land to carry out tree planting projects. We consider if farmers have the means and the motivation to take up such environmental plantings projects under the CFI.

Allowing for land availability, we consider if an MBI such as the CFI can create the financial motive to participate in the current methodology. Perhaps this could act as a starting level project for landowners and over time graduate to other carbon offset projects involving soil sequestration and emissions reduction.

In considering the responses to available projects for environmental plantings; of the 31 farmers interviewed, 45% of those interviewed were not interested in considering environmental plantings on their farms or in any way associated with their dryland cropping operations. This was based on lack of available land or they were simply more focussed on their own production needs and not interested in sharing control.

> ' … I guess, philosophically, I'm a little bit wary of that because I've started off with a very small farm and I still haven't got a big one and I've had to put a lot of blood, sweat and tears into paying the bank and everybody else so I can own it. And I'm a bit wary about giving up any control of that hard earned asset.'

3.12 Farmer uncertainty regarding operational details

Although 55% of interviewees explained that they would consider environmental planting on their farms, all but two said they needed further information before they could respond definitively. Most of the respondents who said that they would be willing to consider environmental plantings on their farms were only interested provided it was worth their while financially and they wanted to know more about how such a scheme would operate over the long term. Many seemed initially sceptical of why anyone would want to pay them to establish and maintain native land, something they are presently doing mainly at their cost. As a preliminary finding, we perceive that farmers are interested in potential earnings outside of farm production. However, it needs to make sense financially, and for a number of them the long-term covenant over the land was a significant concern. In essence, the farmers are seeking more detailed information on how the program would operate. The major concerns for farmers as they consider their options are: 'What are to be the terms of the contract?' and 'What are the associated transaction costs?'. They operate from the business view that the validity of the arrangement is in the contractual details and the overall economics of the program. Typically farmers expressed an interest but seemed unsure of the details as indicated by the following farmer interview response that indicated interest but uncertainty in the arrangements.

> '…we cleared a lot of it (*trees*) and we shouldn't have. A few weeks ago, they (*project proponents*) come out, it was through SANTFA[27], and they were looking for land to revegetate. So I put my hand up, and they'll come out and they're going to do some figures on it. They'll come and do probably seventy or eighty hectares of country; it could even be more, it could go to two or three hundred hectares. I just looked at it as in, well, if we don't crop it may as well go back (*to native vegetation*). They started talking this carbon tax and I thought well, let's work out what I can make out of that. If I can make something out of that, well, I might do it that way. I don't know.'

This is a similar response to that reported by Maraseni and Dargusch (2008) where farmers expressed uncertainty at the details of an MBI in relation to woodland regeneration. The farmers wanted to gain a better understanding of potential return and the details of the arrangement over the long term, including intergenerational liability:

> 'But that's what's been talked about, there was one company in our shire that, I suppose, bought the carbon credits and they planted—I can't remember how many hectares or trees. It was a lot of trees - two hundred thousand. And they get the rights to the carbon for the next seventy years on that land. So what happens, in effect, is

[27] South Australian No-Till Farmers Association based in Clare, South Australia.

> that land is actually tied up for the next seventy years. Which is not attractive, because things happen and generations change.'

How farmers are going to react to their legal obligation under 'permanence' in the CFI Act is still an issue for project proponents. This type of long-term covenant is also going to require the approval of other stakeholders in the land in question, including any family partnerships or banks holding a mortgage on the land (De Wit et al. 2013).

3.2 Farmer opinions regarding increasing soil carbon

In terms of increasing the level of soil carbon, there is ample evidence that farmers are strongly focussed on improving their soil's health (Silburn et al. 2007; Kassam et al. 2009; Ashworth et al. 2010). The responses we got about changing practices to reducing tillage and retaining stubble invariably revolved around the soil.

> 'The soil is very important and the changes that we are seeing to it just keep coming back to me as the reason I'm going to stick with that (*reducing tillage*).'

The opportunity for improving soil carbon is limited by climatic conditions, but widely accepted by farmers as being relevant to their enterprise (Dalal and Chan 2001; Chan et al. 2011; Chowdhury et al. 2013). However, soil carbon sequestration is also subject to 'permanence' obligations similar to environmental plantings (De Wit et al. 2013).

3.3 Insights from industry professionals

It appears that the opportunity and the means exist for dryland farmers to produce carbon offsets, but there are concerns from some survey participants regarding the terms of the contract in relation to 'permanence' and changes to their land title. None of the farmers interviewed held a carbon offset contract or had a clear understanding of the contractual obligations under the CFI Act. We found industry professionals had a greater knowledge of the CFI and were able to provide further insights into their clients' thinking and go beyond tree planting and discuss more fully potential constraints to the market. They were able to put forward the view of their clients in terms of the other priorities farmers had to consider, priorities that farmers did not highlight in their responses.

3.31 Lack of confidence in governmental efficacy

An agricultural carbon project manager indicated that the farmers with whom his organisation dealt had expressed concern on the capacity of government to manage a market over the long term. The farmers he spoke to were concerned whether the market process could exist beyond a change of government, recognising that government can change policies retrospectively to the farmer's detriment. The company indicated that a typical forestry methodology works out around $27/tonne in transaction cost and includes the long-term liability of 'permanence' which is a big stumbling block when it is explained to a producer. The income is taxed at 30% for company rate leaving farmers with 70 cents in the dollar income, but leaves them with a contingent liability for the full amount. This in their view means an immediate loss in putting these projects together, with the returns coming over the longer term.

3.32 Time, money, and risk

A field research officer with a farming organisation dealt with a number of other issues. The adviser indicated that the reasons for participation or non-participation by farmers are associated with time, money and risk. The officer suggested that the farmers would be willing if there was money in it and it wasn't degrading the land. But time is the key issue; they would not want to take time out to learn about a whole new business practice if it's not going to pay. Their main concern is the factors that affect the crop, and anything that distracts farmers from the main game can cost them very dearly. Indicating that carbon markets were seen by farmers as 'fickle', prices are highly variable for reasons farmers don't fully understand and seem to be affected by events such as the global financial crisis. How they could play in that market is a big unknown. Options such as biochar may be better, as there are fewer risks of loss involved under drought conditions. However, the issue is that at some time in the near future the practice is likely to be deemed as common practice (*additionality rules*[28]) and credits are no longer allocated. It is seen as a waste of time and effort invested for a very short-term return. Therefore permanence and additionality are seen as the biggest agricultural carbon participation risks. When tied to an already volatile carbon market, it is likely that growers will prefer the known quantity of crop production risks.

A farm organisation executive explained his farmer's views from discussions he has had with farmers. His view was that carbon is a major part of soil health and a major focus of his farmer members. However, farmers in his view are more focussed on soil health as a driver of

[28] Additionality refers to a test that determines when a practice change is regarded as being 'common practice' and is therefore not eligible under the CFI.

productivity in the crop market, not so much in the carbon market. He thought the carbon offset market may be of some interest to farmers that are more prepared than others to take risks, but noted that most of his members are risk conservative. He indicated that the long-term liability associated with tree planting is not a serious option for cropping and emissions reduction; it is not on their agenda. They are unlikely to change their farming practices simply to suit a carbon emissions reduction requirement. Such changes are likely to be cost driven in terms of farm economics rather than as part of a CFI offer. The current pricing is not much of an incentive and he suggests that farmers are more interested in something that is going to increase their productivity (something they know) rather than diversify into making money from another system. Farmers are more profit driven than yield driven at this time and they are making the changes they can to make it as environmentally friendly as possible, but are not likely to be driven to it by the carbon market. If they are likely to get involved, it would need to be something very simple and that is easy to manage. They (*farmers*) don't want to get into the rigour that is required as part of the new methodologies; they have too much else on their plate that has a higher priority than the carbon market and that's the challenge for government to overcome when getting farmers involved.

3.3.3 The need for simplicity in carbon offset programs

We also consulted with a carbon auditor and agronomist on the Canadian experience in Alberta. Alberta operates a carbon farming program using a 'deeming' method where a practice change is deemed to have generated a certain level of carbon sequestration (Alberta-Environment 2009). He indicated that his farmer clients got involved in Alberta program primarily because it was simple—there was minimal data required which farmers already had and all it needed was someone to collate it and act as an aggregator to produce the offset. Unfortunately the data collection process was very loosely applied by the regulator. As a consequence, previously sold credits did not meet auditing standards. It needs to be simple for farmers to participate, but it needs to also be clearly verifiable and some aggregators did not do their job adequately. For his farmers in Alberta there was not a lot of money involved, they received in the range of 60 cents to $CAD1.00 per acre. The Alberta Government needed offsets and so they allowed farmers to retrospectively pool their offsets from 'reduced tillage' back to 2002 from when the market started in 2007. Although Alberta farmers did not see much value from 60 cents to $CAD1.00 per acre, he suggests they did see the value in 5+ years' worth of claims on a typical 10 000 acre farm, but that was closed after 2011. The retrospectivity it seems was a major incentive and the simplicity of the system did not place any significant barrier to participation. Up until 2011, the only methodology in practice was tillage reduction. They have since developed a fertiliser N_2O emissions reduction protocol that he says has some complex internal calculations, but is based on fertiliser nitrogen use per yield (nitrogen-use efficiency) over a three-year baseline. As of 2013, the uptake was very small compared to the tillage protocol which was much simpler to calculate. The other factor suggested as an issue is that the data is a bit more personal and involves the need to access the farmer's financial information on purchases and the farmers yield for the season. It also requires an agronomist to sign off on the crop plan, which makes the process a little more onerous for his farmers.

3.34 Concern about over-burdening farmers

What we have discerned from our sample interview is that farmers appear to lack the details at present to make clear choices and the institutional experts have been cautioning farmers about signing up to commercial carbon contracts. A leading soil scientist Jeff Baldock from CSIRO, who stated in this ABC radio interview with reporter Bel Tromp on 29 August 2012:

> ' … there are a range of challenges to be overcome before soil carbon can be sequestered in farmland to any extent and for the 100-year time line required under federal government rules. He says while measuring soil carbon is fairly easy, there's great variability across paddocks. Accurate measurement requires multiple samples in any given paddock, and the process is then very expensive. As well, a range of factors can affect the longevity of soil carbon.'

This highlights the issue of the cost associated with soil sampling in the development of a property carbon baseline. Australian dryland farms are reasonably extensive covering several thousand hectares and soil types across the farm may be quite variable. Normally sampling procedures across a paddock for agronomic purposes have to take this into account so samples are located based on different soil types. If this is required in detail, the costs will depend very much on how many samples are required to satisfy the regulator.

We have summarised the general responses in Table 2.

Table 2 Summarised findings from industry interviews about farmers' perceptions of the potential for producing carbon offsets from dryland farms

1	Farmers perceived that 'environmental plantings' are the only available methodology appropriate for crop farmers at this time.

2	84% of farmers indicated that they had non-cropped land ranging from 20 to 8000 hectares (average 438 hectares/farm).
3	Farmers perceived that there are no condition reports of non-cropped land across dryland farms requiring individual assessment.
4	45% of farmers indicated they were not interested in carbon offsets and 55% would consider carbon offsets but wanted further details of the contract terms.
5	Farmers did not have a clear idea of the Australian Carbon Farming Initiative process, the associated contractual obligations and likely returns.
6	Dryland farmers will plant trees for a host of other reasons; this is not a new process.
7	Farmers appeared comfortable with the process of mass planting trees, but believed they took a risk on their survival in the absence of available irrigation.
8	There was deep concern about a long-term covenant (permanence 100 years) on the land creating an intergenerational liability.
9	Farmers were naturally interested in the quality of their soil and saw increased organic matter as a worthwhile outcome.
10	The cost associated with deriving a soil carbon baseline across changing soil types is uncertain and may impact on returns.
11	Farmers have limited financial capacity for off-farm investment.
12	The time available for farmers to operate a carbon project is limited as they need to concentrate on their farming operations.

The concept of sequestering carbon using environmental plantings is well established and existing methodologies established under the CFI have led to various on-ground projects (Battaglia 2012; Australian Government 2013b). The value of soil carbon as a means of producing carbon offsets is still being debated as an option for agriculture. There is recognition that the level of soil carbon that can be accumulated in Australian agricultural systems is limited in scope by climatic conditions (Dalal and Chan 2001; Wang et al. 2010; Luo et al. 2011; Chowdhury et al. 2013). The proponents of soil carbon as the means of generating carbon offsets point to the extensive potential in storage capacity when its applied across the nation, and the detractors point to the associated cost per farm being unfeasible (Butler 2009; Walcott et al. 2009; Sanderman and Baldock 2010; Sanderman et al. 2010; Luo et al. 2011; Chowdhury et al. 2013; Lam et al. 2013; Murphy et al. 2013; Heath 2014). Soil carbon sequestration in an agricultural system is technically possible, but who is going to produce it is an important question.

In terms of managing a carbon offset policy involving dryland agriculture, Australia has two mitigating issues. Firstly, it has an arid climate with limited rainfall and poor soils extending over much of its agricultural area. This limits the storage capacity of carbon in plants via native vegetation and soils. Secondly, it has a highly industrialised form of agriculture that requires high input costs. A grain farmer in northern Australia reported a typical crop gross income for his area being approximately $AUD500/hectare and a profit/loss range of ±$AUD100 depending on costs and seasonal conditions (Farmer's name withheld pers. comm. 28 September 2013).

In regards to emissions reduction, a report by the Birchip Cropping Group[29] investigating typical emissions from farms in south-eastern Australia varied from 166 kg CO_2e ha^{-1} to 228 kg CO_2e ha^{-1} (White and Van Rees 2011). The average farm size in this southern region is about 2000+ hectares and cropping is just under that figure depending on livestock mix (Edwards et al. 2012). This suggests that whole-farm emissions typically range from 332 to 546 tonnes CO_2e per annum and if we assume an efficiency reduction in the range of 10% to 20%, this would be about 60 tonne CO_2e of available offset per farm per annum. Further, project establishment will have a time and cost burden; in making this investment farmers will necessarily consider the amount of abatement that can be offered by the farm versus the price the market is willing to pay. The complexity of farm operations also means that farmers are time poor and proper risk evaluation is limited (Pannell and Vanclay 2011). According to our interviews with industry professionals, most farmers will use a precautionary principle until they hear reports from other farmers that demonstrate value.

Farmers and industry professionals in our interviews also identified issues associated with additionality as a key constraint to engaging in carbon farming. The 'additionality' rule exists to avoid commercial enterprises claiming offsets for what is expected to be 'business as usual' development. It presumes that if the development is financially viable to provide a return on investment, it should be open to normal commercial investment and not be eligible for carbon finance.

[29] A farmer cooperative involved in agricultural research and extension

In the CFI under Division 3.6, offset projects need to pass an 'additionality test' (section 27(4)(d) of the CFI Act). The test criterion is set out in subsection 41(1) of the CFI Act, which provides that a project passes the additionality test if the project is of a kind specified in the regulations and the project is not required to be carried out by or under a law of the Commonwealth, a state or a territory. Under section 59 of the CFI legislation, the positive list identifies activities that are not considered to be common practice within relevant industries or environments. If a project consists of activities listed in the positive list and is not required to be carried out by law, then the project passes the additionality test. Subject to compliance with other eligibility requirements, the project would be eligible to participate in the CFI.

The main issue for farmers is that the additionality provision is applied as a 'common practice test' as operated by farmers. The Australian Bureau of Agricultural and Resource Economics and Sciences has put forward parameters to define common practice. These parameters outline that if the number of adopters of a practice falls below 2.5% of the target population (category of farmers), the practice can be deemed additional. If the number of adopters is above 20% of the target population, the practice can be deemed non-additional and will not be accepted on the positive list (Woodhams et al. 2012). Above 20%, the concept suggests that firms or farmers would view a practice as commercially beneficial and would be adopting the practice regardless of any carbon unit incentive.

According to the industry professionals that we interviewed, many farmers lack sufficient resources or cashflow to evaluate business opportunities that do not provide a significant return and hence conveniently operate only within the practices they are used to and comfortable with (Table 2, points 11 and 12). Given the level of emissions reduction likely in dryland cropping farms in Australia, industry interviews indicated that income from carbon offsets on an individual farm level is likely to be too small to significantly influence farm activity decisions.

Our interviews with industry professionals and farmers also revealed that the issues associated with 'permanence' also served as constraints to dryland cropping farmers engaging in carbon offset production (Table 2, point 8). The rule of permanence as applied to carbon sequestration was designed to ensure that the 'sequestered' carbon was not released back into the atmosphere within the short to medium term. To prevent this, land-based offset projects involving the biosphere or pedosphere usually have a legal covenant of 100 years imposed on that carbon.

Our interviews suggest that few farmers are likely to enter into 100-year-long agreements and sequestration projects will attract little interest from dryland cropping farmers, unless applied to marginal land that would have no value for cropping at any time. The permanence rule is a major barrier to participation by crop farmers in sequestration projects generally (McClinton 2008). Reducing the liability period for permanence would have some effect, but it would need to be reasonably significant to have any substantial impact given that returns may be low and the income period is capped. Basing a project on soil carbon is seen as a high-risk strategy as the carbon fractions in soils are small, highly ephemeral and prone to being lost through mineralisation from changing farm practices (Powlson et al. 2014). A loss of carbon within the permanence period would leave the project proponent with a requirement to make up for the loss.

An option for consideration is to regionally pool carbon offsets based on local practices, thereby limiting liability for individual farmers. Farmers are naturally motivated to improve soil conditions by increasing organic carbon and a scheme that incentivises natural drivers to better perform as a sector can create an increasing pool of carbon offset units. After risk adjustment, such a pool can be sold to support extension activities at farm level. Ideally national measurements using adjusted survey data can be linked to National Greenhouse Accounts to demonstrate agriculture meeting its obligation despite the difficulties in measuring climate-dependent biochemical reactions. Discounting to allow for uncertainties can be applied to support market acceptance. This scheme is essentially paid for by the market seeking offsets.

5.0 Conclusion

The results of our interviews with industry professionals and farmers suggest that the supply of carbon offsets by farmers face a number of constraints. The responses suggest project activities need to make economic sense for the farmer, and at present it seems they do not. Further any project that imposes legal constraints that may affect the viability of the farm or the earning potential of future generations is not likely to be taken up. Finally it seems farmers are looking for rules and administrative processes that are easy to follow in order to participate. The interviews with industry professionals suggest that for farmers the carbon market is a ‘sideline event’ and they perhaps cannot afford to have it distract them from the main business of grain production, which has its own financial challenges. At present it does not appear that Australian dryland cropping farmers will likely engage with the CFI to supply carbon offset units. If the dryland grain cropping industry is to participate, it will need more specific methodologies to be developed for the sector that also addresses their concerns of simplicity, additionality and permanence. It appears that the current CFI is not engaging a major part of the farming sector as the government had anticipated and as such it may need to review its policy in regards to farmer engagement or consider alternative policy instruments as outlined in the introduction.

8.0 CONCLUSION

With agriculture the second largest emitter for Australia's national inventory (16%), reducing the sector's emissions liability is a current priority of the Government as part of reducing the nation's overall emissions accounts. There is a high degree of variability within sub-sections of the agricultural sector both in terms of the types of emissions produced and the overall amount it produces. The dryland cropping sector occupying the inland cereal belt from central Queensland to Western Australia was considered for study as it represents a significant area of agricultural production. The sector's emissions contribution is primarily in the form of N_2O and CO_2 from fertiliser application, tillage, residue burning and machinery operations. It rates relatively small within the agricultural sector accounting for approximately 2.9% of national emissions in 2012. The historical transfer of SOC from cropping soils by means of mineralisation to the atmosphere is not included in the national accounts.

Climate change mitigation involves removing CO_2 from the atmosphere for sequestration within the land sector. The cropping sector has little scope for atmospheric carbon to be stored in the biosphere pool since agricultural production is highly cyclical in the management of biomass. Bio-sequestration would have to sit aside from the production part of the farm. There is also a question as to whether agriculture could act to store atmospheric carbon in the soil over the long term. This would in effect reverse the trend from pre-colonial practice of aggressive soil tillage and the loss of soil organic carbon from mineralisation.

Waste in agricultural practices is also strongly linked to emissions from the sector, thereby reducing waste, reduces emissions. Leakage contributing factors such as fertiliser and chemical imports has been used to maintain farm profitability and is directly linked to environmental externalities. Given that the atmosphere is a global common, the shifting of externalities abroad does not assist with managing climate change. It is therefore incumbent on Australian agriculture to manage its inputs as efficiently as it can while maintaining profitability. This is in line with FAO recommendations that globally agriculture needs to better manage its inputs but not at the cost of farmer's livelihoods which is important to food security (Friedrich and Kienzle 2007; Diouf 2009; Collette et al. 2011).

8.1 What is the current role of Conservation Agriculture in grain farming enterprises in Australia?

I discussed that Conservation Agriculture has evolved in Australia based on two significant consequences of the traditional tillage farming system; erosion and the loss of soil moisture. The most visible consequence of full-cut tillage was erosion from both water and wind depending on local climate patterns. In the northern cropping zones of Australia, high-intensity summer storms prior to summer cropping resulted in severe loss of topsoil and the associated loss of organic matter in the A horizon. In the southern and western cropping regions where lighter soils predominate, pre-frontal late autumn dust storms were similarly removing topsoils with severe impacts on soil fertility.

Cultivation also resulted in the loss of soil moisture and as soil moisture is integral to yield; retained soil moisture from CA saw an increase in productivity benefits for farmers.

The adoption process of early CA practices involving reduced tillage and stubble retention has extended to include control traffic farming to reduce soil compaction, crop rotations to reduce disease carry-over, the use of precision systems in agriculture to reduce input costs, the consideration for cover crops and recycled manure to improve soil health. There is some indication from surveys that CA farming practices are gradually being taken up by Australian cropping farmers to improve farm profitability by managing inputs more carefully. These adaptations are covered in more details in chapter 2 Part I which is book chapter publication and outlines the current status of CA in Australia. Significantly for this thesis the adoption of CA practices has climate change implications in terms of emissions and soil carbon sequestration.

One of the contributions this PhD research makes to agricultural knowledge is to offer the terminology that delineates the range of CA practices in Australian dryland cropping; including practices other than the FAO definition of ‘reducing tillage, stubble retention and crop rotation’ which is more often applied to developing countries. The proposed terminologies for Australian dryland cropping is justified on the basis of an analysis of the discourse of CA farmer groups around Australia that promote these new practices (e.g. control traffic farming and the use of precision agriculture tools) to all their members and the broader farming community. Members of CA farming groups voluntarily share their knowledge of these new technologies and their application to CA principles for protecting the soil. The research review of CA also indicates that some of these practices are only just emerging (≤ 20%) and as they demonstrate a reduced emissions profile as outlined in chapter 4, their greater adoption would likely further reduce emissions from the dryland cropping sector (Table 11). However our ability to quantify the emission values cannot be certain as it is complicated by the nature of a mix of energy use and biological emissions typical of agriculture and this is discussed in the rationale section 1.2.1 *Agricultural contributions to emissions in Australia* and section 1.2.3 *Production practices and emissions* indicating that agricultural emissions are generally highly variable, which is problematic for market mechanism that would prefer simple verifiable units that have low transaction costs.

The degree of emission variability would suggest that it is difficult and therefore more expensive to determine a verifiable level of emission for farming practices in typical dryland cropping, when compared to many industrial type practices. We therefore suggest that consideration be given to the rate of practice adoption as a proxy to the sectors overall emission reductions. Farming practices are routinely measured by Research Development Corporations and the Department of Agriculture. The measure of 'what practices?' is usually based on the farmer's own terminology, as they are the ones responding to the surveys.

The research also indicate that greater adoption of CA practices supports the profitability of farmers but the required investment is slowed by a complex number of barriers highlighted in the published paper include as part of chapter 6. The complex nature of those barriers is why a 'systems approach' has been included in the research to explain the factors that influence adoption. The justification for a systems approach is outlined in the paper's methodology and not repeated in the main thesis.

8.2 How does Conservation Agriculture influence greenhouse gas emissions from grain farming enterprises in Australia?

The fundamental principle of CA is based on conserving natural resources by eliminating waste within the production system. The research indicates that the uptake of Conservation Agriculture practices will reduce emissions from the dryland grain production sector. The potential value of CA adoption to the dryland grain sector in climate change terms is estimated at 2.5 million tonnes CO_2e of potential offsets per year not accounting for various Scope 3 emissions reductions. Those figures are subject to significant variation but does indicate something of the order of magnitude of emission reduction across the dryland cropping sector. In this thesis, I considered how the various Conservation Agriculture farming practices meet the farmer's requirement for future sustainability and impact on climate change mitigation and adaptation (Table 14).

Table 14 The relative merits of Conservation Agricultural Practices to farm sustainability indicators

Practice	Climate Change Adaptation	Economic benefit	Environmental Outcome
Reduced Tillage	Reduces moisture loss in dry years. More crops.	Less fuel and resource requirement	Reduces the loss of SOC
Stubble retention	Reduces moisture loss in dry years. More crops.	Balances crop yield with price of feed	Increases recycled Organic Matter towards soil sequestration
Control Traffic Farming	Reduces moisture loss, improved plant growth.	Less fuel	Reduced emissions
Precision Agriculture		Reduces waste	Waste reductions reduces externalities from resource supply
Legume crop rotations		Reduces demand for inorganic fertilisers	Reduced energy demand in producing nitrate fertilisers
Recycled organics	Increased SOC improves fertility and holds moisture	Improves fertility but depends on price of supply	Recycling reduces energy demand in producing nitrate fertilisers. Increases SOC.
Cover cropping	Increased SOC improves fertility and holds moisture		Increases SOC
Environmental Plantings			Increased biodiversity and

			improved water quality in riparian zones

Any of the practices listed - *reducing tillage, retaining stubble, reducing compaction associated with machinery and applying recycled organics* - meet at least two of the three criteria set out in the table 14. Climate change benefit is primarily based on moisture retention capacity to continue producing crops under drying climatic conditions. They do this primarily by reducing soil moisture loss or increasing soil organic carbon which has positive environmental benefits. The economic benefit is primarily based on improving efficiency on farm and maintaining crop production. The climate change environmental benefit results from emissions reductions associated with operational waste and the drive to increase soil carbon for its plant productivity benefit. CA is essentially a departure from the traditional industrial agriculture of the 1950s and 60s to a less intensive intervention in crop production. The thesis newly highlights the linkages between CA practices which covers a large proportion of our agriculture and their associated emission profile. It does not do this in exact terms as it is beyond the scope of this research, it simply highlights approximate measures based on second order data (e.g. reduced fuel consumption and stubble burning). This connection is important to the central relationship between CA expansion in dryland cropping and climate change mitigation and adaptation. More research is needed to more clearly identify the relative value of farming practice's emission if it is to play its role in reducing its climate change impacts along with other industries.

The thesis also indicates that the adoption of CA practices is incomplete for a number of socio-economic reasons; primarily to do with investment capacity and the need for farmers to be thoroughly convinced of the productivity benefits. This discussed in more detail in the next section.

8.3 What factors influence adoption of Conservation Agricultural practices in Australian grain production?

Accepting that Australian dryland agricultural practices is gradually changing and that this will in turn change the emission profile of the sector as outlined in section 4.7. The thesis is particularly concerned to analyse the factors that affect practices adoption and how that can inform climate change policy. To do this in some depth I have opted to employ qualitative methods in addition to the available data and literature. This required being thoroughly immersed as a participant in the way that CA farming groups, farm advisors and allied industry farming groups operate. These groups represent the key knowledge based of farmers' perceptive value of CA practices. Many of the CA group's farmers are actively writing and demonstrating new methods to other farmers. Being involved in those discussions provides a rich source of insight into why farmers 'choose' or 'not choose' to adopt various CA practices. This information is important to determine if farmers will actually adopt any particular practice or how they can be influence to adopt a practice. This will impact on such matters as 'Additionality' rules under the CFI that makes assumption that once a percentage of adoption in the farming population has been reached, it needs no further incentive for future adoption. However what the thesis has determined is that the factors affecting adoption relates less directly to promoted economic benefits by Government and more based of what the farmers perceive as an economic benefit from their farmer peers. This is a process of affirmation from trusted peers as to its demonstrable farm benefit and they perceive that these peers have taken all farm considerations into account and can clearly demonstrate the benefits. Without this catalyst from farmer group and advisors adoption is much reduced and market incentives does not effectively promote changes in behaviour.

Farmers need to clearly see the production benefits and how the process of a promoted practice change will occur from the required 'investment cost' to the timeline for a 'return' on investment. The closer to a 'turn-key' solution that can be presented and costed, the easier it is for farmers to understand the cost-benefit analysis for making practice change. Too many promoted benefits from government fails to outline the full cost involved (social & economic) and the likely consequences as a result of the change. This uncertainty about the true value of the promoted benefits delays the rate of adoption.

Whether the gradual uptake of CA practices across the dryland industry should be left to market forces over time or should there be some form of government intervention to speed up the process depends very much on the urgency for reducing emissions from the agricultural sector. It will also depend on the perceived efficiency gains that can be achieved by intervening in the sector and the cost of that intervention. CA practices also have two other dimensions; the first is that some of the CA practices conserves soil moisture so can support adaptation to climate change where hotter, dryer conditions are likely to increase in frequency. The second dimension is that Australian agriculture is one of the most advanced industrial agricultural systems in arid zone cropping. Most other industrial agricultural systems are located in wetter temperate zones. Australian agriculture does therefore provide an important leadership role for arid zone farming management in developing countries. As the problem of climate change is a global issue there is significant value in providing the management experience in the better use of limited resources.

If CA practices are to be encouraged it is suggested that the most gains in reducing emissions or sequestering carbon can be obtained from full crop residue retention, controlling compaction via limiting machinery traffic to set lanes, improving fertiliser efficiency through precision agriculture, increasing the opportunity for cover cropping and the use of recycled organics where available. It is recognised that tillage reductions is already at a high adoption rate, although there is still significant option for improvement. Most of these practices apart from cover cropping are practiced in some form by over 20% of farmers, but the rate of uptake based on experiences with reducing tillage would indicate that significant adoption is still some 20 years away. Once again the question of urgency would be a determining factor in terms of the need for policy intervention.

This thesis has reviewed factors of CA adoption by looking at the existing literature and delved in more depth by interviewing farmers and advisors as to what motivates farmers to change practices. This is new knowledge providing insight into motivation factors of dryland farmers and I believed it complemented the broader survey data by ABARES and sections of the in-depth farmer interviews was provided to Robert Kancans of ABARES for inclusion (with permission) in their latest reports by Eckers et al 2012 called 'Drivers of Practice Change in Land Management in Australian Agriculture: Results of a national farm survey ', *ABARES report to Department of Agriculture, Fisheries and Forestry, Canberra, December*, p. 61.

The farmer interviews and the balance of the data was used in a different way in this thesis it interpreted the data in terms of its relevance to emission reduction using a socio-economic analysis of the drivers and was published in a journal paper titled *An analysis of the socio-economic factors influencing the adoption of conservation agriculture as a climate change mitigation activity in Australian dryland grain production*. The paper is included as part of chapter 6.

Understanding these drivers is important to develop policy that is likely to increase farm practice change adoption. It was clear that the offer of a price to farmers for carbon offsets interested very few dryland growers. The major undelying reason being the high transaction costs to meet the demands of the market and the uncertainty around operating in such a market.

8.4 What climate Change policies are likely to increase adoption of CA in Australia?

Any policy must be fully costed and the benefits of change presented clearly to farmers along with any related consequences. The choice of policy tools should be cognizant of the economic and social consideration that creates practice adoption within a rural context. Such practices as CA cannot be imposed via a 'command and control' policy regime without creating social inequities as many farmers would not have the capacity for rapid adoption. The use of incentives is also limited by available funds and any excessive expenditure in terms of incentive programs may be regarded as an unjustified use of taxpayer funds.

8.4.1 Market based instrument

The CFI as a market based instrument is a bold piece of legislation, but unfortunately fails to provide a full cost-benefit analysis for farmers and offers an uncertain market price for a high level of compliance requirement. There has been a significant cost in establishing a market structure without consideration as to the target audience benefit. The transaction costs associated with compliance requirement to produce carbon offset would indicate a lack of potential financial benefit to the farmer based on current carbon price. This is in part due to the climate dependent bio-chemical nature of emissions and carbon sequestration, and in part to the highly variable nature of farming practices. Although practice change can act as proxies to emissions reductions and sequestration, they can only be broad estimates and would only be applicable to large areas requiring aggregation of data with some form of discounting as a buffer. It is difficult to justify the fungibility of these units to those coming from the manufacturing sector using measurable mechanical processes. Biological systems can also be reversed under adverse climatic condition such as drought, which is highly likely in a climate change scenario. The potential impact of climate change is an additional uncertainty factor. The cost of creating confidence in a biological offset unit is likely to significantly increase the transaction cost to the market.

It is clear that farmers want to engage in environmental schemes but it needs to fit their paradigm. In this instance, to engage the agricultural industry requires a shift in paradigm towards farmers in that any scheme should consider "*how abatement can operate in their system*" rather than "*how their system can fit into abatement*". The issue of price being the only determinant factor is not entirely correct, as a proportion of farmers have indicated some acceptance of discounting in return for simplicity and risk reductions. Farmers want "fair recompense" for their effort; certainly not be "out of pocket". Farmers also want to avoid future uncertainty and their paradigm emanates from having a sound knowledge of their system but limited knowledge of abatement requirements.

If farmers are reducing emissions by making changes to their systems without resorting to market incentives, than it would seem that the only value of incentives is to speed the process. Is there a need for a carbon trading scheme or can we simply support farmers to keep on doing what they are already doing, but to get there faster. Is there an option to value and trade their national offset to further support changes that drive emissions reductions and carbon sequestration.

8.4.2 Education

The use of 'education' as a policy tool to change farmer behaviour is a workable option if it is acknowledged that information on the process of practice change is only one part of the equation towards meeting the requirement for adoption. There is also a need to consider capital available to farmers and capacity of farmers to make the change, especially in those areas involving technology.

The recommendations from this research is not about pushing for more extension but moving to a different avenue for environmental extension to farmers. Education in an agricultural context is complicated by the ways farmers prefer to learn, the indication from the research is that farmers prefer a more 'hands on' approach learning on site via such activities as field days and field workshops. This leads to a more complicated andragogical framework requiring specific skills familiar with the farming environment which is limited in some areas. Farms are also geographically isolated and there is a cost to farmers and education providers in providing the services required. For farmers it is not always a question of money, sometimes it is also about having the time. The best people to understand this intricate balance are farm advisers and grower groups who are the major contact points for the farming community. The research indicates that these groups are not strongly connected to the market mechanism being offered by government. Therefore farmers have very few trusted advice sources to discuss the options of taking up options in the carbon market. The grower groups and farm advisers can play a significant role in driving government policy but it's not evident from the interviews that they have been specifically engaged and as indicated in section 5.2.3 they play an important role in influencing farmers. A new policy condition would take into account the means of delivering the message (e.g. reducing emissions) in a way that would focus how such messages are best received by the farmers and what avenues need to be pursued to deliver the message in the right context.

The context of the message is also important to gain the interest of grower groups and advisors. They need to be strongly engaged in determining the context of the message delivery. It is noticeable that where changes are simple, relatively low cost and provide evident benefit than adoption is more readily taken up. However the converse is often the case and in the context of this thesis many CA practices can be complex to put into practice, and may have consequences to other parts of the system or they require capital investment in new equipment; which results as a barrier to adoption. The risk and time investment required in learning a new system further adds to the slow pace of adoption. The use of digital technology is beyond some as they have never acquired the underpinning knowledge over time to cope with current evolutions of the technology. Those types of barriers are not easily overcome regardless of incentives and many farmers close to retirement age would prefer to simply continue as they have done leaving the changes for the new generation.

Policy consideration needs to take into account the content of the message, the social context of the recipients (e.g. age, education), the context of the message (e.g. does it align with the farm goals) and the avenue for delivery.

8.5 Contribution to knowledge

The following table summarises the contribution to knowledge made by this thesis,

Table 15 Contribution to knowledge made by the thesis

	What have I confirmed or disconfirmed in terms of previous work?	**What is my new contribution to knowledge? (in addition to confirmation and disconfirmation)**	**What data actually showed this contribution to knowledge?**	**What research method captured this data and any reflections on research method?**
How can the potential climate change mitigation and adaption benefits of Conservation Agriculture (CA) be most effectively integrated into dryland grain farming enterprises in Australia?	I have confirmed that conservation agriculture creates less emissions than traditional farming practices. I have also confirmed that there is still an opportunity for further adoption of CA practices in Australian dryland cropping.	My contribution to knowledge is that climate change market-based mechanism targeted at Australian dryland grain growers, as a subset of the farming community, would need to better understand how the target audience will perceive the risk and cost-benefit required to produce the carbon credit unit in relation to the carbon price. Without such an understanding of the farming system drivers, market mechanism will bear a significant cost burden for government and the community without creating the intended practice change at farm level. Despite the existing opportunity that dryland grain farmers can reduce emissions by changing practices, they are unlikely to take up the offer of changing for the specific purpose of supplying carbon credit units to the Carbon Farming Initiative (CFI). The evidence supports the view that the	The data supporting this contribution resides in two areas, firstly in a cost analysis of farming systems some of which is outlined in chapter 7 '*Opportunities for producing market offsets in dryland farming*'; secondly from in-depth interviews with farmers on what is their motivating drivers in considering investment in market-based mechanism. This is outlined in chapters 5 '*A review of systems and adoption factors in agricultural industries*' and 6 '*Drivers for adoption of conservation agriculture practices and impact on emissions reductions*'	A review of the scientific literature in regards to dryland farm practices in general and noted Conservation Agriculture practices in particular in regards to their comparative emissions
	I have disconfirmed that publishing the scientific benefit of farm practice change from climate research will logically result in a significant increase in adoption by farmers; thereby reducing agricultural emissions. It seems rather that research recommendations are best supported by trusted advisors and peer on-farm demonstrations. This has			I have used qualitative analysis by interviewing 31 farmers and 6 advisors using semi-structured interviews, also a review of the literature on adoption and the factors likely to act as drivers for change (e.g. social concern) or constraints (e.g. economics) in regards to the way farmers respond to information on farm practice change.

	consequences for agricultural extension policy.	current transaction costs of the CFI scheme and a farm business risk analysis by dryland grain farmers does not commercially support individual farmers supplying carbon credit units to the Emission Reduction Fund. Further that farmers will only engage in very simple schemes that require minimal effort on their part.		
1. What is the current role of Conservation Agriculture in grain farming enterprises in Australia?	That Conservation agriculture plays an important role in reducing costs of farm inputs and makes more efficient use of available rainfall	I have identified the need for a more consistent definition of Conservation Agriculture as they are practiced on grain farming enterprises in Australia before the practices can contribute to measurable emission reduction. I have offered a potential definition for emissions in a published paper included in Table 1, also in chapter 2, section 2.2 and chapter 4, section 4.11. This would allow a regulator to consider what is the CA farm practice change required and something of the order of emissions reduction that may be involved. The direct emissions would have to be measured in a different format due to variability of agro-ecological zones.	The data in determining the role of CA in dryland grain was obtained from the research literature, from current government and industry literature, from CA farming groups, farm advisors and finally from farmers themselves.	I have confirmed this from Participant observation of the Conservation Agricultural community in dryland farming and a literature review was used to collect other more specific data
2. How does Conservation Agriculture influence greenhouse gas emissions from grain farming enterprises in Australia?	The review of previous work by the thesis confirmed that Conservation Agriculture delivers a net reduction in average dryland grain farm emissions if adopted.	The thesis reviewed the dryland grain industry and clearly demonstrates the various emission reduction benefits of all the CA practices in the Australian context. The farmer and industry in-depth interviews added a social dimension that explains some of the thinking that determines what makes farmers consider changes in practices. The interviews also confirmed the lack of understanding	The data was obtained from the published research literature, from government reports on emissions this was combined with farm practices data supplied by CA grower to determine potential emissions at farm level and at regional level	The method of analysis used relied on document analysis of literature from industry and Government publications and technical reports from research institutions and journal articles. Data on emissions in the Australian context were sourced principally from government publications dealing with a broad range of farm practices not
	Previous work reviewed disconfirmed that the possible level of carbon sequestration		The conclusion from this was determined from the research literature and was included for consideration when using	

	is Australia is on par with international measurements. The main reason being intermittent and low rainfall patterns in inland Australia.	of how the Australian Carbon Farming Initiative actually operates. This lack of understanding is likely to be behind the lack of interest by farmers in the carbon market.	international calculations to determine potential carbon sequestration in Australia.	always related to CA. The various reports are collated to cover greenhouse gas emissions from those specific CA practices such as tillage or stubble management. Where available, industry data on farm practices survey such as fuel consumption, chemical and fertiliser use is also collated to support details of practices in the current Australian context. The emissions characteristic of a practice on grain farms is reviewed in the international academic literature for validation.
3. What factors influence adoption of Conservation Agricultural practices in Australian grain production?	The review of previous work Adoption of new farm practices such as Conservation Agriculture is influenced by a complex range of factors including investment capacity, inherent knowledge, personality type, existing stress condition (e.g. drought) and confidence in being able to effect change with minimal risk to income.	The review of industry data and interviews have confirmed that dryland grain farmers operate on small margins and are more influence by production incentives then potential benefits from environmental markets, especially if the price of carbon is low. Farmers adopt CA practices to better manage time, to reduce resource input and have more consistency in crop production. To make the change from traditional practices to CA farmers need the support of trusted extension services and other farmers who have made the changes.	The data for this was synthesised from the published research literature, from unpublished data obtained from grower groups and from interviews with farmers and advisors.	Once again I have relied on qualitative analysis by interviewing 31 farmers and 6 advisors using semi-structured interviews, also a review of the literature on adoption and the factors likely to act as drivers for change (e.g. social concern) or constraints (e.g. economics) in regards to the way farmers respond to information on farm practice change. I have further included the concept of a systems model as a means of interpreting the various socio-economic drivers that influence the adoption of CA. Changes in a system such as agriculture interact in complex ways, so I developed a series of systems models to visually
		I have disconfirmed that the current carbon price (2010-15) will prove a sufficient incentive for the majority of farmers to involve themselves in producing carbon credit units for a	This was determined from direct interviews from growers and advisors.	

		carbon offset scheme requiring practice change.		describe the main factors that drive the adoption of CA practices in Australia. Applying ‘systems thinking’ to an issue helps us understand the interactions that drive adoption in complex situations
4. What climate policies are likely to increase adoption of CA in Australia?	I have confirmed that the Carbon Farming Initiative is a new scheme, and that farmer reaction to such a scheme in the Australian grains industry does not have clear precedence. I have also confirmed that available methodologies are very limited for dryland grain producers so they have limited option to participate in carbon reduction scheme.	I have identified that farmers are more likely to adopt CA practices when extension and field day programs of the production benefits is delivered by trusted advisors and peers rather than an environmental market incentive. The in-depth interviews indicated that farmers were confused by the details of the requirements for the carbon market and were very concerned about the legal implications. This will impact on policy for creating practice change in agriculture when considering incentive schemes. It is more likely that an extension policy will have greater influence for change than purchasing carbon units from an environmental market.	This was determined from direct interviews from growers and advisors.	Finally, I have relied on qualitative analysis by interviewing 31 farmers and 6 advisors using semi-structured interviews, also a review of the literature on adoption and the factors likely to act as drivers for change (e.g. social concern) or constraints (e.g. economics) in regards to the way farmers respond to information on farm practice change.

8.6 Concluding comments

The stated aim of this thesis was “An analysis of conservation agriculture as a response to climate change in Australian dryland farming systems”. The conclusion is that although the adoption CA practices (new & old) can reduce emissions in dryland grain enterprises; there are a number of barriers to farmers quickly changing practices. The current use of a carbon market instrument to encourage farmers to reduce emissions by changing practices is not viable for dryland grain farmers under the current market condition and the associated compliance requirement to generate a market unit. The CFI policy did not account for such a significant market downturn in the price of carbon and the increasing compliance requirement to meet the IPCC guidelines. As such the inherent complexity of the market system and the transaction cost in relation to individual farm benefits does not favour uptake by dryland grain farmers as a sector.

Government policy in 2016 under Direct Action is supportive of soil carbon units for a carbon market and seems set to continue the failure of previous policy in not making the cost-benefit argument for the farming sector. Despite simplifying the argument for barriers such as ‘permanence’ the December 2013 Green Paper has not addressed the issue of ‘additionality’ or the transaction cost associated with verifying an offset unit.

As the average individual farm units are too small in regards to the transaction costs, any continuation of the current policy of a market based instrument should consider whether a simplified aggregation process could be used instead. Grower groups provide the means from which such a farm aggregation process might operate but this would require a more detailed analysis beyond the context of this research. A number of their member farmers may create a pool of units thereby reducing the transaction costs. This would also need further investigation to determine if the cost benefits are acceptable to the grower groups. I propose there is a need for a simplification of the process through which the means of pooling carbon units are based on independent recorded practices. Farming systems have become increasingly complex and demanding of farmer’s time. The removal of state government extension officers over time means that the dynamics of how farmers react to government policy very much involves the messages they receive from their current advisors and peers.

Policy intent on driving farm practice change can only succeed when due consideration has been given to the way farmers currently make decisions.

These type of market policy can drive changes in behaviour, but in a complex system like agriculture not all parts of the system will benefit equally. In some cases, as in this study the benefit for the dryland grain sector is minimal when compared to industries such as intensive pork production. There is a suggestion that broad policy initiative like the CFI can create unrealistic expectation in the community and governments might want to consider the development of smaller more specific initiatives related to the context of sector being targeted.

In general future climate change policy reliant on changes in farmers' behaviour would do well to start engaging with farmers and advisors more directly before the drafting of policy on the changes they want farmers to make. In some cases it may not simply be about farmers intention to participate as their inability to participate due to structural constraints such as farm size or social constraints such digital literacy. Consultation must also involve all the actors influencing farmers such as grower groups and farm advisers, because they connect more broadly with the farming community and are strong influencers of behaviour. This broader engagement process may take longer and would require more resources but it is likely to deliver a better targeted program with increased participation.

8.6.1 Limitations of the Thesis

I believe it is necessary to draw attention to the following limitations of this thesis. The first is that the broad study area of this thesis is complex and rapidly changing with a large volume of international research and changing policy framework being continuously generated. This means that emerging information is likely to impact on the findings of the thesis and there is a strong possibility that some new information will have been missed.

The second is that an analysis of policy is subjected to continual changes in legislation and changes in government intention. Partway through this thesis there was a change of Government and the previous Government's Carbon Tax legislation was repealed. The CFI legislation has been retained for the moment, and is anticipated to be funded by an Emission Reduction Fund. The details of the process are yet to be released in the Government's White

Paper. It is still expected that Climate Change policy will still involve agriculture and will necessarily require some form of change in farming practices.

The third limitation is based on the necessary assumptions that are made in a qualitative analysis. A qualitative framework most often contains limited data sets and it is therefore necessary to qualify the conclusions as being open to alternative interpretations based on new information.

8.6.2 Future research ideas

The character of farming enterprises is changing rapidly with the incoming generation and a number of farms appear to be adopting a more business orientated model. There is more to do to establish a business case at the farm level addressing the impacts of climate change in the grains industry. There is a need for more research on the financial impact of better managing farm investment and rural debt in dealing with climate risks.

A combination of social and economic research is a sound investment in the effective development of land and climate policy. Future research should consider how a research mechanism could be better used to support the development of better climate policy as far as it relates to Australian agriculture. That research mechanism should rigorously consider the costs and benefits of specific policy to farmers, the likely rates of uptake and an analysis of the likely outcomes. This suggest the greater use of multi-disciplinary approach to the research of complex systems involving human activity such as farming and the environment.

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