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,b,*, Paul Dargusch c, Donald Cameron d, Carl Smith c

a University of Queensland St Lucia, Brisbane, Qld 4072, Australia
b University of Southern Queensland, West St, Toowoomba, Qld 4350, Australia
c University of Queensland St Lucia, Brisbane, Qld 4072, Australia
d University of Queensland, Gatton Campus, Qld 4343, Australia

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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 tCO2e 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 amongst 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.

1. 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 (Dalal et al., 2003; Garnaut, 2011; Kupfer and Karimanzira, 1990; Lal, 2004a; Luo et al., 2010). 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 (Keogh, 2007; Lal, 2004b; Regina and Alakukku, 2010; Schwenke et al., 2011; Wang and Dalal, 2006).

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, 2013).

There has been considerable research into the quantum of emissions reductions or sequestration possible on Australian farms in general (Browne et al., 2011; Cowie et al., 2012; Harris et al., 2013; Jawson et al., 2005; Li et al., 2010; Regina and Alakukku, 2010; Schwenke et al., 2011; Thamo et al., 2013; Wang et al., 2011; White and Van Rees, 2011). 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 (Ecker et al., 2012; Llewellyn, 2011). 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 (DCCEE, 2012; Garland et al., 2011; Hobbs and Govaerts, 2010; Labreuche et al., 2011; Li et al., 2010).
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 (Allmaras and Dowdy, 1985; Hobbs, 2007; Hobbs et al., 2008; Hughes, 1980; Reicosky and Saxton, 2007; Uri, 2000). 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 (Branson, 2011; Butler, 2008; Tullberg et al., 2007). There is also a body of literature on the role of CA in mitigating climate change by reducing emissions and sequestering carbon (Chan et al., 2003; D’Haene et al., 2009; Gonzalez-Sanchez et al., 2012; Govaerts et al., 2007; Lal, 2004c; Rochecouste and Dargusch, 2011; Uri, 2000; Wang and Dalal, 2006; Young et al., 2009; Zentner et al., 2004). 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 (Rochecouste and Crabtree, 2014; Thomas et al., 2007b; Tullberg, 2009).

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 (Pannell et al., 2011; Scott and Farquharson, 2004; Thomas et al., 2007a; Upadhyay et al., 2003; Vanclay, 2004; Wylie, 2008). 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.

### 2. 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 (GRDC, 2013; Kemanian et al., 2007). 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 (Department of Primary Industry, 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 practised 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 (Department of Primary Industry,
2004). In 2012, Australia produced 2.2 million 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 (Department of Primary Industry, 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. (2013), 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 (\(\text{N}_2\text{O}\)) than non-compacted soils and that CTF reduces overall soil \(\text{N}_2\text{O}\) 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 shown in Table 2.

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

### 3. 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 (Quan Van and Nam Cao, 2013; Sterman, 2000). Understanding the mechanism of change in a visual model should support better policy development (Belue et al., 2012; Bosch et al., 2007). We can use a representative mental model to identify parts of the farming system and how they might interact, thereby providing 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. Fig. 1).

In the simple example illustrated in Fig. 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 a survey 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 practised by 93% of farmers, stubble retention by 90%, with some burning stubble only if required. Crop rotation was practised 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; Maraseni and Dargusch, 2008; Patton, 2002). 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 regard 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 4. 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 and 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. 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 (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 Fig. 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, then we need to formulate policy within the social and economic framework that is already driving industry change.

In the figure above and those to follow, the symbol ‘R’ refers to a reinforcing loop where actions positively affect the outcome and increase 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 (Fig. 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., 2007b; Wuest, 2010). This is reflected in Fig. 2 and has been suggested by other studies as a key reason for farmers to adopt reduced tillage practices (Farley, 2013; Quinton, 2010; Taschetto and England, 2009). 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 (Fig. 2, R2).

However, herbicide resistance sometimes requires farmers to resort to cultivation to control weeds and it acts as a balancing factor in the model (Fig. 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 (Fig. 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 (Fig. 2, B2) and the loss of soil moisture especially in the dry years, thereby affecting profitability (Fig. 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 Fig. 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 (GRDC, 2011; Rees and Platz, 1983; Scott et al., 2010).

The main reason the farmers interviewed retained stubble was for its benefits in soil moisture retention (Fig. 3, R1). Improved soil moisture also provides more cropping opportunities (Anderson,
Mitigating soil erosion (Fig. 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 (Fig. 3, R3) (Malinda, 1995; Thomas et al., 2007b). From our farmer interviews, we determined that these benefits to production seem to be balanced by the problems of managing stubble during planting operation (Fig. 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 (Fig. 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, then 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 (N₂) is reduced to ammonia (NH₃) 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 N₂O 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 (Evans et al., 2010; Kirkegaard et al., 2008). 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 (Edwards et al., 2012; GRDC, 2012; Herridge, 2011).

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 (Fig. 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.

Cereal yield is one of the main drivers of farm profits (Fig. 4, R1). However, cereal yields can be affected by a build-up of cereal diseases, especially when increasing stubble retention occurs in adverse weather (Fig. 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) (Fig. 4, B1). If fertiliser prices are very high, farmers may look to the nitrogen value of the legume to boost future grain yields (Fig. 4, R4). Legumes also make a useful break crop to avoid herbicide resistance, thereby insulating against future herbicide-resistant weed problems (Fig. 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 of 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 N2O 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

![Fig. 4. A causal loop diagram of the factors influencing the uptake of legumes in dryland cropping rotation in Australia.](image-url)
harvest operation and spraying. The second assumption is that the better aeration of uncompacted soils leads to less \( \text{N}_2\text{O} \) 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 \( \text{N}_2\text{O} \)-N/ha compared to CTF fields at 1.2 kg \( \text{N}_2\text{O} \)-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 (Batey, 2009; Chamen et al., 2003; Li et al., 2007).

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 Fig. 5.

The main reinforcing loops that drive adoption of the CTF system (Fig. 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 auto-steering 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 (Fig. 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 (Fig. 5, B1). A delayed reinforcing loop creates a market opportunity for commercial product development (Fig. 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

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![Fig. 5. A causal loop diagram of the factors affecting the uptake of controlled traffic farming.](image-url)
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 and 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. 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 led 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 believes 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 practised 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.

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