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Implications of climate change for tillage practice in Australia

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Abstract

The world is experiencing climate change that in no way can be considered normal, and the challenge that this brings to agriculture is twofold. The first challenge relates to the continuing need to reduce greenhouse gas emissions that generate the changes to climate. Australia's National Greenhouse Gas Inventory estimates that agriculture produces about one-quarter of Australia's total greenhouse gas emissions (including land clearing). The main gases emitted are carbon dioxide, methane, and nitrous oxide. These gases are derived from high-value components within the agricultural production base, so reducing emissions of greenhouse gases from agriculture has the potential to provide production and financial benefits, as well as greenhouse gas reduction. Methane essentially derives from enteric fermentation in ruminants. Nitrous oxide and carbon dioxide, on the other hand, are strongly influenced, and perhaps even determined by a range of variable soil-based parameters, of which the main ones are moisture, aerobiosis, temperature, amount and form of carbon, organic and inorganic nitrogen, pH, and cation exchange capacity. Tillage has the potential to influence most of these parameters, and hence may be one of the most effective mechanisms to influence rates of emissions of greenhouse gases from Australian agriculture. There have been substantial changes in tillage practice in Australia over the past few decades – with moves away from aggressive tillage techniques to a fewer number of passes using conservative practices. The implications of these changes in tillage for reducing emissions of greenhouse gases from Australian agriculture are discussed.

The second challenge of climate change for Australian agriculture relates to the impacts of climate change on production, and the capacity of agriculture to adapt where it is most vulnerable. Already agriculture is exposed to climate change, and this exposure will be accentuated over the coming decades. The most recent projections for Australia provided by the CSIRO through the Australian Climate Change Science Programme, indicate that southern Australia can expect a trend to drying due to increased temperatures, reduced rainfalls, and increased evaporative potentials. Extremes in weather events are likely also to become more common. We anticipate that climate change will become an additional driver for continued change in tillage practice across Australia, as land managers respond to the impacts of climate change on their production base, and governments undertake a range of activities to address both emissions reduction and the impacts of climate change in agriculture and land management.

Keywords: Tillage; Climate change; Greenhouse gas emissions; Nitrous oxide; Soil carbon; Agriculture

1. Introduction

The earth's surface has warmed over the last 100 years – roughly by 0.7 °C, and this is due mainly to increases in concentrations of 'greenhouse gases' in the atmosphere – carbon dioxide, methane, and nitrous oxide. These gases have increased by 30%, 150%, and 20%, respectively over this timeframe (Pittock, 2003). As with all other industries and sectors, agricultural activity has played a part in contributing to these increases.

Carbon dioxide results from the degradation of plant biomass, fossil fuel use, and changes in soil organic

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matter; methane is a by-product of enteric fermentation in ruminants; and nitrous oxide derives from nitrogen cycling in soils. All of these gases are derived from high-value components in the agricultural production base, and so reducing the emissions of greenhouse gases provides the opportunity for production, financial, and environmental benefits at the same time. However, understanding the processes involved in the regulation of these emissions, and their modelling and measurement remain a challenge.

The build-up of greenhouse gases in the atmosphere has a flow-on effect to all aspects of climate, and hence may have a direct impact on the capacity of agriculture to continue to generate the desired incomes for some regional communities. The impact of climate change on agriculture, and the capacity of agriculture and regional communities to adapt to climate change, comprise a second major challenge.

Tillage is one of the management variables that may enhance or retard emissions of greenhouse gases from agriculture, and may help maintain or improve the productive base under the conditions of climate change. This paper draws on tillage trends within Australia to investigate the extent to which tillage may be a tool to assist with the management of greenhouse gas emissions from agriculture, and secondly, it explores the extent to which aspects of climate change may provide additional drivers for continued change in tillage practice.

2. Trends in tillage practice in Australia

Tillage and land management practices clearly influence a whole host of interactions between soil structure and biota, and this in turn influences the stability of carbon and nitrogen within the soil matrix. Throughout this paper we define the different tillage practices as follows: cultivation – multiple tillage using a wide range of disc and tined scarifiers and cultivators; minimum tillage – one or two tillage passes before sowing giving full surface disturbance; and no-till – one pass at seeding with narrow tine openers or disc openers which leave a proportion of the surface undisturbed.

A comprehensive agricultural census is conducted every 5 years by the Australian Bureau of Statistics (ABS), and this includes information on tillage. Categories in the 2000/2001 Agriculture Census for tillage in the preceding 12 months were no cultivation (apart from the actual sowing operation); one or two cultivations only (immediately prior to sowing); and other cultivation. In the 1995/1996 census, categories were no cultivation (apart from actual sowing); one or two passes only prior to sowing; and more than two passes using disc or tined ploughs. A few simple analyses are presented below.

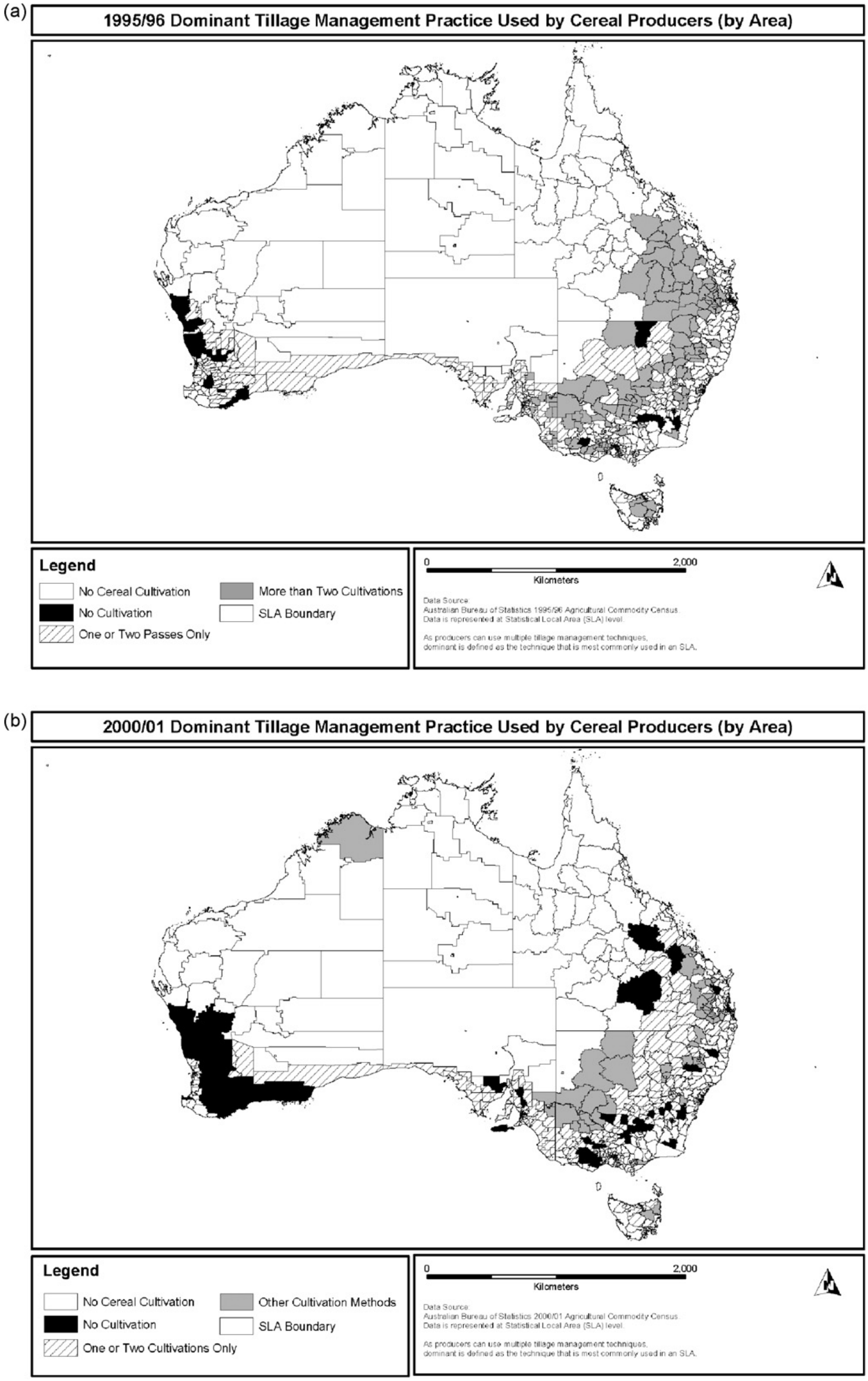
Some form of aggressive tillage appeared to be usual practice across nearly all of Australia's cereal farming systems and regions in 1995, consisting of one, two or multiple passes (Fig. 1a). There were only isolated pockets of no or minimum till (in Western Australia, Victoria, and NSW). In general, tillage was more aggressive in the heavier soils of the eastern states than in the lighter sandy soils of Western Australia.

It appears that by 2000, there were substantial shifts in land management practice, to more conservative tillage practices and with large tracts of land being farmed with no or minimum till (Fig. 1b). The shift was particularly noticeable in Western Australia where by 2005 more than 85% of the total cropped land was subject to no-till farming practice. While this data represents only two snap-shots in time, the change shown is consistent with commonly held views in industry.

Additional surveys and analysis by the Australian Grains Council indicate the same trend (Fig. 2; A. Umbers, pers. commun.). Clearly over the past decade, there have been substantial reductions in conventional tillage, and even a reduction in minimum tillage, with corresponding increases in no tillage between harvest and the sowing of the next crop.

Understandably, there also appeared trends in the way that cereal producers managed their stubble – that somewhat paralleled the trends in tillage – and this may have important implications for management of organic carbon. The areas where stubble was routinely ploughed into the soil decreased greatly in the 5 years between 1995 and 2000 (Fig. 3a and b). The changes appear more prominent in the eastern states. In many parts of New South Wales, the practice of ploughing the stubble into the soil was in fact replaced by burning, whereas in Queensland there was an increased tendency to leave the stubble intact. The belt of stubble being burnt thus expanded widely, forming an apparently continuous belt from south-eastern South Australia, through Victoria, and into central New South Wales.

It is uncertain whether this increase in stubble burning in south-eastern Australia was maintained in subsequent years. The general view from industry is that the observed increases in burning were brought about by a number of factors that may no longer apply. Reductions in the market value of pulses (e.g. lupins) and other legumes used as break crops, and increases in pests and diseases as a consequence of heavy stubble retained with no-till farming led to a resurgence in



Data Source:
Australian Bureau of Statistics 1995/96 Agricultural Commodity Census.
Data is represented at Statistical Local Area (SLA) level.

As producers can use multiple tillage management techniques,
dominant is defined as the technique that is most commonly used in an SLA.

Data Source:
Australian Bureau of Statistics 2000/01 Agricultural Commodity Census.
Data is represented at Statistical Local Area (SLA) level.

As producers can use multiple tillage management techniques,
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Fig. 1. Dominant tillage management practice used by cereal producers in Australia (by area) in (a) 1995 and (b) 2000. (Data courtesy Australian Bureau of Statistics; Bureau of Rural Sciences.)

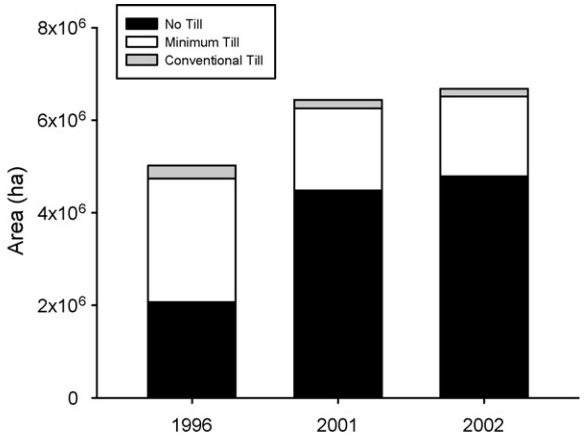


Fig. 2. Dominant tillage management practice determined by survey of cereal growers in Australia in years 1996, 2001, and 2002 (Australian Grains Council, A. Umbers, pers. commun.).

burning practice. At the same time, there were large increases in canola as a cash crop which did not provide the same ‘break’ characteristics as legumes. Indeed canola trash, in itself, is also much more difficult to handle than stubble or trash from softer-strawed crops. In some cases, the increase in biomass brought about by increased yields of cereals made sowing operations more difficult with existing machinery. In general though, over time improvements were made to the design of sowing implements so to allow sowing through the thicker (and tougher) stubble and trash with decreased reliance on burning. Some improvements in sowing equipment were narrower points and boots, raised seed boxes, increased use of discs in sowing equipment (both conventional and scalloped), use of improved press wheels, increased row spacing and increased spacing between rows of tines in the direction of machine travel.

3. Influence of tillage practice on greenhouse gas emissions

3.1. Emissions of greenhouse gases from Australian agriculture

Agriculture is estimated to produce about 25% of Australia’s national emissions when land clearing is taken into account (Fig. 4). This is an abnormally high proportion among developed countries (e.g. US ~ 5.5% and EU ~ 10%), reflecting the economy-wide balance between agriculture and energy-intensive industries within Australia. Globally, the figure is about 17% (World Resources Institute, 2007).

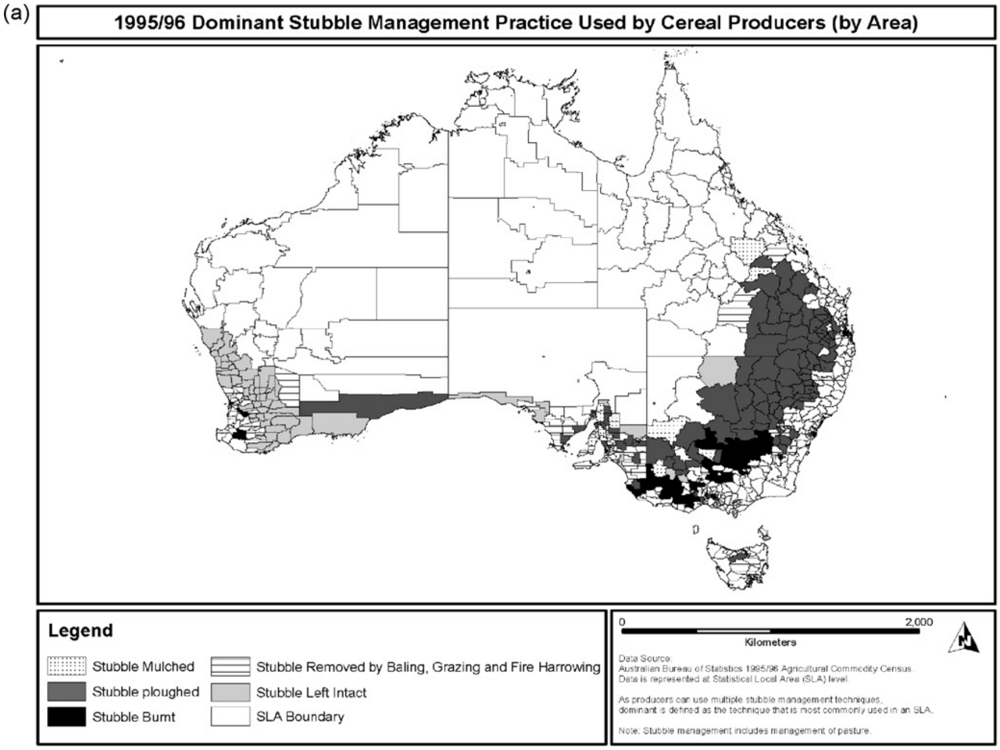
The agriculture sector appears to be Australia’s largest source of methane and nitrous oxide emissions. In 2004, agriculture was estimated to contribute about 60% of the national methane emissions and about 85% of the nitrous oxide emissions (AGO, 2006). These gases have global warming potentials 21 and 310 times that of carbon dioxide, respectively, and they dominate the greenhouse gas emissions profile from agriculture.

Enteric fermentation by livestock, mostly sheep and cattle, contribute about two-thirds of non-CO_2 emissions from agriculture (Fig. 5), or about 13% of emissions nationally (AGO, 2006). Some methane derives also from the prescribed burning of savannas, manure management, and rice cultivation. Of the nitrous oxide emissions from agriculture, nearly three-quarters derive from nitrogen cycling in soils, approximately one-quarter from prescribed burning of savannas, and small amounts from manure management and crop residue burning (Dalal et al., 2002). Nitrous oxide emissions from agriculture are estimated to have increased by a quarter from 1990 to 2004 (AGO, 2006) reflecting mainly a doubling of fertiliser use across Australian agriculture during this time (FIFA, 2007). Nitrous oxide from soils should clearly be a target in any comprehensive programme to reduce emissions from agriculture.

Emissions of carbon dioxide from Australian agricultural soils are generally considered to be small compared with methane and nitrous oxide, although this is not adequately quantified. In contrast, however, agriculture provides substantial opportunity to remove carbon dioxide from the atmosphere, and thus to act as a carbon sink. As approximately half of the Australian continent is used for agriculture, even a small increase in sequestration of carbon in vegetative stands or soils at farm level has the potential to provide substantial benefits to greenhouse accounts.

3.2. Soils as a source and store of greenhouse gases

Storage and cycling of nitrogen and carbon, and their derivatives within soil systems are driven by microbial, chemical and physical processes within the soil. Emissions or sequestration of greenhouse gases in soils are determined directly by both soil properties and external factors acting on soils. Hence, changes in soil moisture, structure, organic matter content, cation exchange capacity, and pH brought about by tillage practice, soil management or climate may affect fundamentally both emissions and sequestration of greenhouse gases.

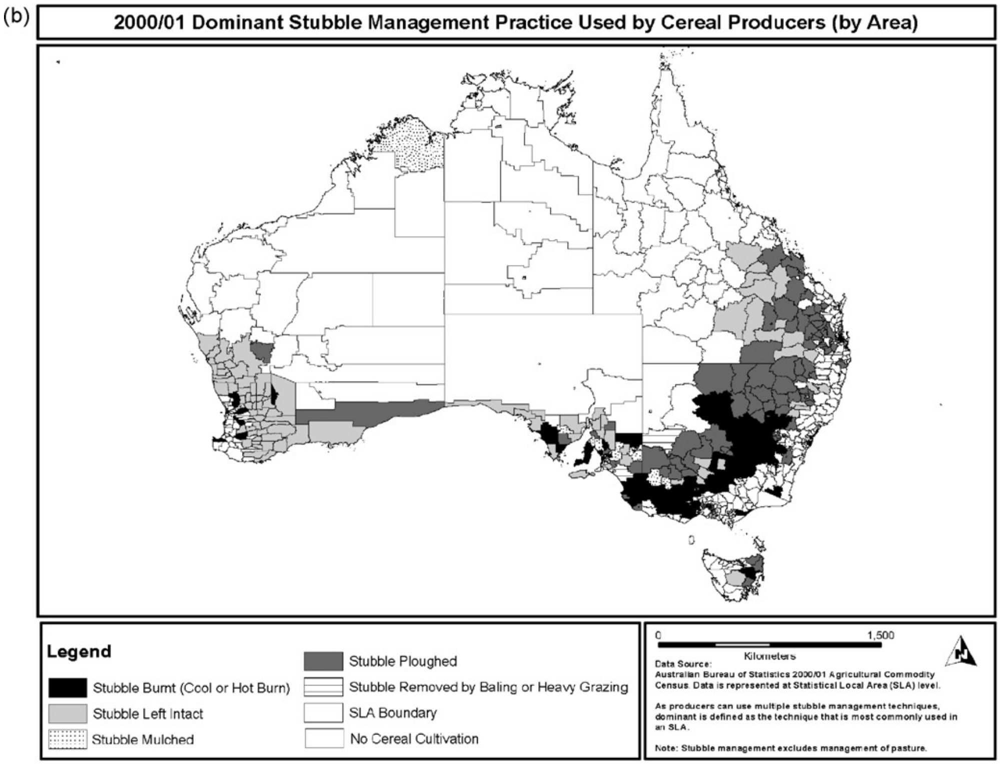


1995/96 Dominant Stubble Management Practice Used by Cereal Producers (by Area)

Data Source:
Australian Bureau of Statistics 1995/96 Agricultural Commodity Census.
Data is represented at Statistical Local Area (SLA) level.

As producers can use multiple stubble management techniques,
dominant is defined as the technique that is most commonly used in an SLA.

Note: Stubble management includes management of pasture.



2000/01 Dominant Stubble Management Practice Used by Cereal Producers (by Area)

Data Source:
Australian Bureau of Statistics 2000/01 Agricultural Commodity Census. Data is represented at Statistical Local Area (SLA) level.

As producers can use multiple stubble management techniques, dominant is defined as the technique that is most commonly used in an SLA.

Note: Stubble management excludes management of pasture.

Fig. 3. Dominant stubble management practice used by cereal producers in Australia (by area) in (a) 1995 and (b) 2000. (Data courtesy Australian Bureau of Statistics; Bureau of Rural Sciences.)

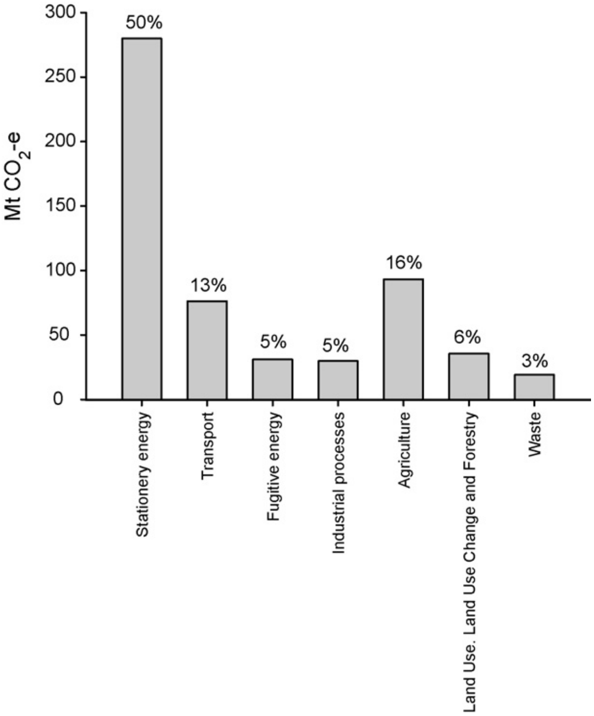


Fig. 4. Estimates of greenhouse gas emissions by sector in 2004. All values are represented as carbon dioxide equivalents (AGO, 2006).

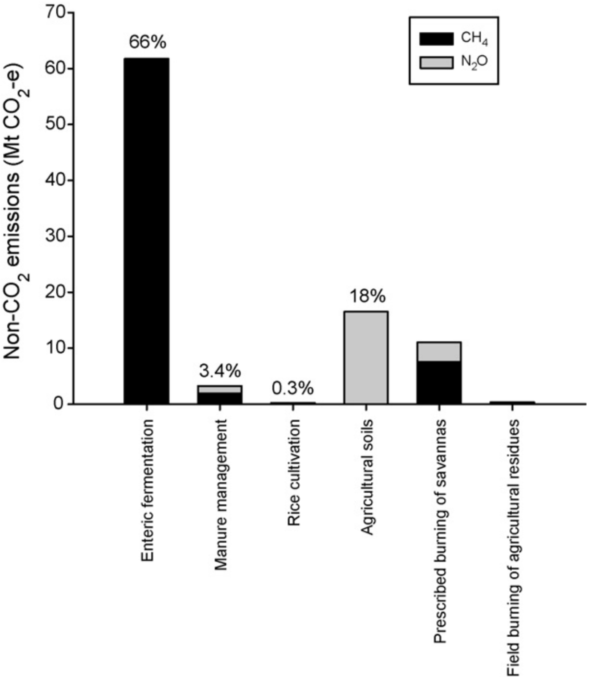


Fig. 5. Sources of emissions of methane and nitrous oxide from Australian agriculture in 2004 (AGO, 2006).

Formation and stability of soil aggregation is influenced directly by tillage, leading to affects on a whole host of soil parameters, including those affecting water holding capacity and gaseous exchange. It has been estimated that aggressive tillage may be primarily responsible for a 30–50% decrease in soil carbon worldwide since soils were brought into cultivation over a 100 years ago (Schlesinger, 1986). Tillage affects the soil carbon content directly by soil fracturing, which facilitates movement of carbon dioxide out of the soil immediately after cultivation (Reicosky, 1999); and indirectly by altering soil aggregation leading to reduced carbon adherence to clay surfaces and increased organic matter oxidation, and by accelerating carbon loss through water and wind erosion (Follett, 1998; Bradford and Peterson, 2000).

It is not surprising that there is no straight forward answer as to the effect of tillage on the emissions and storage of greenhouse gases from agricultural soils, but there are a range of aspects that can be considered in formulating better farming practice to improve the management of greenhouse gases from the agricultural sector.

The high variability of production systems in Australia will continue to make projections of the greenhouse emissions equation as a function of tillage difficult. Nonetheless, from a greenhouse and productivity perspective the capacity to reduce emissions per unit of product output using improved tillage coupled with other management practices may deliver benefits beyond that expected when considered in isolation.

3.2.1. Nitrous oxide

Emissions of nitrous oxide from soils may result from three separate microbially mediated processes (Fig. 6). One is the oxidation of ammonia to nitrite via ammonium (a dissimilatory pathway) by a few genera of aerobic chemoautotropic bacteria. This pathway is dependent on the availability of carbon dioxide and oxygen. Nitrous oxide production results from a reductive process in which the bacteria use nitrite as an alternative electron acceptor. This is especially favoured under conditions of oxygen limitation (Poth and Focht, 1985), typically when soil water content lies between 55 and 65% water-filled pore space (Goodroad and Keeney, 1984; Bouwman, 1998). At elevated water contents, aerobic exchange is reduced, and the nitrification process is restricted. Oxidation of nitrite to nitrate is generally carried out by classes of *Nitrobacter.*

Two other processes leading to nitrous oxide emissions are dissimilatory and assimilatory nitrate

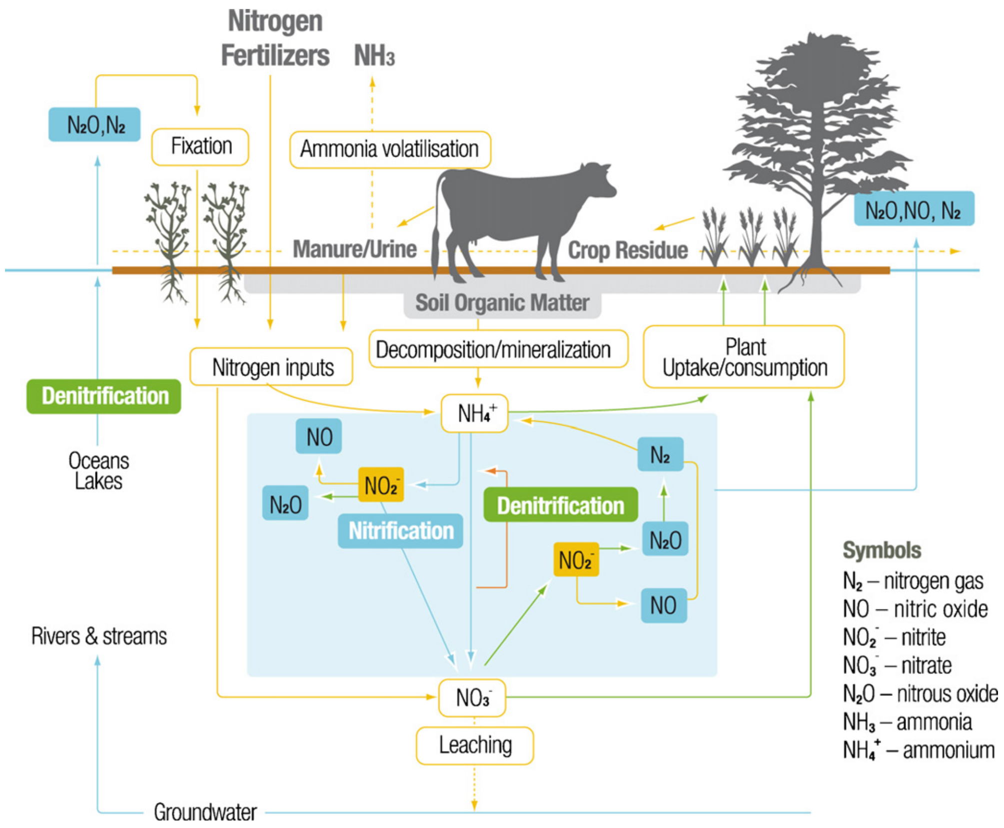


Fig. 6. Nitrogen cycling in soils (microbial processes are shaded). Nitrification and denitrification processes are dependent on the availability of nitrogen substrate, soil organic matter and oxygen, and the proportion of nitrous oxide produced depends on the extent of oxygen limitation (see text). Non-bacterial nitrogen losses occur via leaching, ammonia volatilisation, and surface run-off.

reduction. These processes are carried out by several bacterial groups that reduce nitrite or nitrate to gaseous dinitrogen (N_2) or ammonium (NH_4^+), with nitric oxide (NO) and nitrous oxide (N_2O) as intermediates (Fig. 6). Enzymic activity for reduction begins immediately following wetting of soil and formation of anaerobic conditions, and can persist for many months even as the soil dries (Smith and Parson, 1985). Denitrifying bacteria are so widely distributed that a restriction of this process would not result from a lack of enzyme, but would rather depend on the availability of organic carbon, nitrogen oxides (NO_3^-, NO_2^- and NO) as a substrate, and most importantly on restricted oxygen (Firestone and Davidson, 1989). Nitrous oxide production from this process is highest at around 60–75% water-filled pore space. Anaerobiosis, as when water-filled pore space exceeds about 75%, drives denitrification directly to dinitrogen gas (Granli and Bockman, 1994).

Dissimilatory nitrate reduction is probably the largest source of nitrous oxide from soils (Tiedje, 1994), although in some cases the nitrification pathway appears equally common (Granli and Bockman, 1994). The relative prevalence of the two pathways is determined directly by soil properties and external conditions. Nitrogen substrate which may ultimately limit nitrogen gas release is derived from both organic and inorganic sources, including fertiliser inputs and nitrogen fixing plants; and generally increased soil nitrogen creates conditions conducive to increased nitrous oxide emissions (e.g. Goossens et al., 2001).

Tillage has been shown in numerous papers to have a detrimental effect on the growth and activity of microbial populations (e.g. Carter and Mele, 1992; Roper and Gupta, 1995) and this change can determine the extent to which nitrification and denitrification reactions proceed. For example denitrifying bacteria are found to be more abundant in no-tilled soils than those that have been tilled (Doran, 1980). The relationship between the populations of denitrifying bacteria (in itself) and emissions of nitrous oxide is not straight forward, however. In one case with tropical soils, nitrous oxide emissions were found to be seven times higher in a tilled environment compared with the no-tilled counterpart (Baggs et al., 2002).

Cation exchange capacity influences differential adsorption of cationic and anionic nitrogen forms (NH_4^+, NO_3^- and NO_3^-) and thus affects nutrient pathways in the soil and the availability of nutrients for nitrification and denitrification processes. Balances between nitrification and denitrification, and the extent of nutrient leaching, are also affected by the influence of soil structure on moisture availability and aerobicity. For example, in course textured soils with large pores, capillary forces are weak, increasing the potential loss of moisture and soluble nitrogen and carbon by leaching. In fine-textured soils, reduced pore space allows anaerobic conditions to be more easily reached and maintained for longer periods; subsequently favouring increased denitrification activity (IFA FAO, 2001).

Soil texture is also often related to pH. Nitrification is sensitive to pH extremes and operates ideally between pH 7 and 8 (resulting in nitrous oxide production). Maximum denitrification also occurs at pH 7–8 (Bryan, 1981), however reduction of nitrate has been detected at lower pH, and nitrous oxide production from denitrification becomes dominant at pH < 5.5–6.0 (Weier and Gilliam, 1986; IFA FAO, 2001). While these factors may not always be directly influenced by soil tillage, they may explain differences in emissions under similar tillage management. It has been shown that fallow soils, tilled and left devoid of vegetative cover over a full growing season will lead to increased soil nitrate levels leading to higher rates of nitrification and nitrous oxide emissions than soil that is sown to crop (Baggs et al., 2002).

3.2.2. *Carbon and carbon dioxide*

Soil carbon provides substantial benefits to plant growth by improving soil structure, increasing cation exchange capacity and nutrient retention, providing a source of energy for microbial growth and nutrient cycling, and improving the overall water holding capacity of a soil.

A recent comprehensive analysis of the impacts of tillage on the changes in soil carbon was completed in 2005 (Valzano et al., 2005) and it concluded that factors other than tillage, such as rainfall, above-ground biomass, soil type and temperature were more likely to determine carbon levels in soil than tillage practice alone.

Rainfall, for example, determines the capacity for plant growth, and therefore the total amount of biomass available for input into the soil through roots and decaying plant residues. In high rainfall environments receiving 550 mm or more of annual average rainfall, soil carbon stocks have been shown to increase – whereas in more arid environments receiving less than 400 mm of annual average rainfall, soil carbon stocks continued to decline with increasing years in agricultural production (Valzano et al., 2005).

Temperature is also a key factor, with high temperatures associated with increased soil biological activity, thereby facilitating the breakdown of organic matter and subsequent losses of carbon through microbial respiration. Soil type also influences the capacity for carbon storage, with better structured soils such as podsolic soils, krasnozems, and podsols typically associated with higher soil carbon densities than the less fertile red-brown earths, red and yellow earths, grey, brown, and red clays (Baldock and Skjemstad, 1999).

Australian soils are geologically old and highly weathered and even under pre-agricultural conditions contained low soil carbon contents relative to those in other parts of the world. Soil carbon densities for agricultural soils in Australia typically range from 20 to 50 $\mathrm{t\ ha^{-1}\ 30\ cm^{-1}}$ (Valzano et al., 2005). Over the past century, the content of soil carbon in agricultural soils has declined by between 10 and 30 $\mathrm{t\ ha^{-1}}$ in the surface 30 cm soil profile (Valzano et al., 2005). These losses can be attributed to an increase in soil disturbance with large amounts of soil carbon lost through wind and water erosion (Roberts and Chan, 1990), carbon dioxide released during tillage operations (Reicosky, 1999), and the high removal of grain and pasture produce. Adopting management practices that reduce soil disturbance and increase the return of residues to the soil provide for a healthy soil environment. This, in turn, may improve productivity and provide the potential for increasing soil carbon stocks.

From a greenhouse perspective, the most commonly held view is that reduced tillage leads to carbon sequestration. But in Australia, this may not necessarily be the case. The concentrations of organic matter in topsoils in both tropical and temperate regions routinely increase under reduced tillage in the above 550 mm rainfall regions, due to a favourable shift in the balance of accumulation and decomposition. In Australia, numerous studies have shown that long-term cultivation of soil in rainfed cropping regions decreases soil carbon, and that no-till and direct drilling may only reduce this rate of decline (e.g. Dalal and Mayer, 1986; Chan and Mead, 1988; Dalal et al., 1991; Slattery and Surapaneni, 2002). Studies in the United States have documented carbon sequestration rates of between 200 and 520 $\mathrm{kg\ C\ ha^{-1}\ year^{-1}}$ under no-till in the mid-west cropping belt (e.g. Eve et al., 2002; West and Marland, 2002). By contrast, sequestration rates in Australia have been observed to be between -150 and 1 $\mathrm{kg\ C\ ha^{-1}\ year^{-1}}$ for no-till farming practices in low rainfall farming systems (Slattery and Surapaneni, 2002).

Obviously, however, there are limits to the capacity of any soil to continue to sequester carbon over time—even in a favoured environment, and there is still very little information on the influence of reduced till on rates of carbon turnover. In one example, organic matter continued to increase for a couple of decades (in a tropical soil) after management changed to reduced tillage (Six et al., 2002). In other cases, farming land may already be at or near steady state (Saggar, 2002).

In Australia, conservation tillage, including a range of practices (zero tillage, reduced tillage, minimum tillage with direct drilling or single pass with tined implement) has retained up to 25% more carbon than conventional tillage practices over the past century under continuous cropping, effectively by slowing the rate of carbon decline. Despite this, there is still no evidence of a no-till cropping system in Australia that has been able to significantly increase soil carbon over the longer term (Valzano et al., 2005).

The soil's capacity then to act as a sink or source of carbon will be determined largely by a range of environmental factors that may, in fact, outweigh the ability of the farmer to adopt practices that could increase carbon stocks. The research undertaken to date under Australian conditions does not support the view that there may be large increases in carbon stocks due to the adoption of no-till farming. Nonetheless no-till farming provides significant soil health benefits that lead to improved soil condition and plant growth – and this cannot be ignored. In Australia, the use of long-term pasture phases in a crop rotation using no-till and improved nitrogen fertiliser management (in contrast to continuous cropping by whatever management technique) still provides the best potential for a positive means of sequestering soil carbon and reducing greenhouse gas losses.

3.2.3. Fuel use

Early agricultural production systems in Australia (early 1900s) adopted European farming practices of that time, and this involved many tillage passes (up to 7, or even more in some cases) to control weeds and to prepare a fine textured seed bed. Over the course of the century, the number of tillage passes declined substantially – made possible through the introduction of a range of technological advances that centred on chemical weed control, improved farm machinery, and conservation tillage including no-till (Fig. 7).

Although not quantified in a comprehensive way, it can be assumed that fuel use across Australian agriculture on a per hectare basis has declined considerably over the latter stages of the last century. One piece of information in support of this is that fuel use in the grains industry has about halved from 1990 to 2004 (Fig. 8). Greenhouse gas emissions per hectare from fuel use will have decreased correspondingly, presumably driven largely by adoption of reduced tillage (Figs. 1a and b and 2), although on an industry-

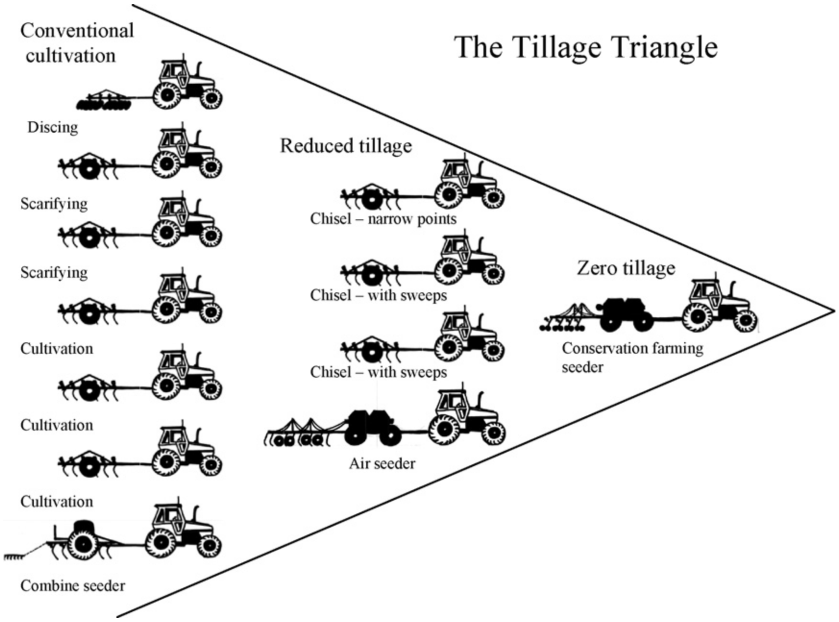


Fig. 7. Historic trends in tillage practice, showing the move away from multiple passes with cultivation equipment to a single no-till pass at sowing. (Concept adopted from a unknown farming magazine circa 1986.)

Fig. 8. Average fuel use per hectare in grain production from 1990 to 2004. (Data courtesy Australian Bureau of Agricultural and Research Economics, prepared by Grains Council of Australia as part of Grains EMS Pathways Project.)

wide basis, this will be offset somewhat by energy requirements of herbicide and fertiliser manufacture, and the increased area of cropped land.

Adoption of minimum and no-till farming practices have improved soil structure, through enhanced soil porosity and aggregation (Chan and Mead, 1988; Carter and Steed, 1992), leaving a more friable textured soil surface profile making it easier to sow a crop. Retaining plant residues, by not burning and either incorporating residues or leaving them standing, also improves soil structure by increasing microbial processes that lead to soil aggregation (Tisdall, 1991). This improved soil texture requires less shear force to move tyned implements through the soil. It has been shown in recent work sponsored by the AGO (unpublished) that stubble tillage (in this case tillage through the incorporation of plant residues) in a maize crop may lead to 30% less power required for subsequent tillage operations providing an overall reduction in greenhouse gases on-farm of about 1.9 t CO_2e ha^{-1} $year^{-1}$.

Collectively, the arguments presented in this paper lead to the conclusion that it remains possible to reduce greenhouse gas emissions through improved tillage practice by adopting a whole soil systems approach that considers both the biophysical interactions within the soil and the mechanical methods used to work the soil.

4. Tillage practice as a tool to increase resilience of farming systems to a changing climate

4.1. Trends in Australia's climate

Australia has experienced a general warming by about 0.7 °C from 1910 to 2000, and the trend is projected to continue. Using emissions scenarios of the Intergovernmental Panel on Climate Change (IPCC, 2001) and various global climate models, the CSIRO has projected further increases in average annual temperatures (relative to 1990) of 0.4–2.0 °C by 2030 and 1–6 °C by 2070. It is likely that there will be slightly less warming in some coastal areas and Tasmania, and slightly more warming in north-western Australia (CSIRO, 2001).

At the moment it is not easy to tell whether average rainfall across all of Australia has changed significantly since 1910, however clearly some regional changes have occurred. For example, there appears to have been a substantial decline in early-season rainfall in south-western Australia, and an increase in extreme daily rainfall intensity along the east coast. While some changes in rainfall patterns across Australia are likely to remain regional, the climate change projections show an overall drying trend, especially in winter and spring for most locations, except perhaps in the tropical north and in Tasmania (CSIRO, 2001).

Other climatic factors projected to change include more frequent and intense drought periods, higher risks of wild fire, increases in heavy rainfall events even in areas where average annual rainfall decreases, and an overall increase in the frequency of extreme weather events such as storms and hail.

The precision in climate change modelling is improving all the time. CSIRO has recently released its latest version of climate change modelling for regional Australia (CSIRO, 2007). But for the purposes of this paper, the precision in the climate change modelling is relatively unimportant. There is no doubt about the direction of the changes generally. The magnitude of change is in essence only a matter of timing. This paper considers the implications of only the broad direction of climate change on tillage and tillage practice.

4.2. Possible impacts of climate change on Australian agriculture and soil systems

The projected changes in climate change for Australia are likely to have substantial impacts on the agricultural sector, both directly (e.g. water and temperature), and indirectly (e.g. soil effects, hydrology, pests, weeds and markets).

There remains uncertainty over the effects of increased atmospheric carbon dioxide on the productivity of cropping, pastoral, forestry, and rangeland systems. There has been very little, if any, comprehensive experimentation on the effects of elevated carbon dioxide on plant systems in arid and semi-arid regions –

indeed in regions (and under conditions) that make up the bulk of Australia's agricultural lands. From a physiological perspective it is even possible to argue that elevated atmospheric carbon dioxide in water deficient conditions could in fact decrease productivity in a response similar to the well-documented haying-off response in cereals induced by imbalances of nitrogen and water throughout the season.

Be that as it may, clearly in most of Australia, water is the ultimate limit to productivity, and reduced rainfall (and increased evaporative potentials) will undoubtedly impose additional limits in both rainfed and irrigated systems. The horticulture and viticulture industries may need to deal with additional risks of hail damage and reduced occurrences of winter chill.

Soils are likely to be affected by changes in rainfall and temperature—depending *inter alia* on the level of soil disturbance by farming practice. Heavier rainfall events with courser sandier soils may lead to higher nitrogen and carbon losses through leaching, while in heavier soils such events may lead to reduced oxygen potentials favouring nitrification or denitrification, and nitrogen loss in volatile forms. Alternate wet and dry cycles may have a compounding effect—with nitrogen mineralised and accumulated during the dry phase serving as additional substrate for nitrous oxide production during the wet (Dalal et al., 2002; IFA FAO, 2001).

As soil temperature and moisture are major controlling factors of soil chemistry and biotic activity, the overall warming and drying projected for most regions of Australia are likely to influence the cycling of nitrogen and carbon, the emission of carbon dioxide and nitrous oxide, and overall soil fertility. Nitrification and denitrification rates tend to increase with increasing temperature to an apparent optimum between 25 and 35 °C (Haynes, 1986; Granli and Bockman, 1994). At the same time, elevated temperatures favour a higher ratio of nitrous oxide to nitrate from nitrification (Goodroad and Keeney, 1984), and thus result in increases of nitrous oxide emissions and nitrogen loss from the soil. Soils in warmer and drier climates also tend to have lower organic matter levels and a lower cation exchange capacity (Bandel et al., 2002), which generally translates to reduced soil productivity.

Australian agriculture will also need be alert to the possibility of increased erosion risk, and changes in host/parasite or pathogen relations, or indeed spread of pests and weeds outside of currently observed ranges.

There is no doubt that Australian agriculture, and indeed agriculture globally is entering a new operating environment. Clearly a comprehensive approach is needed in the design of modified management in response, and this includes consideration of tillage practice.

4.3. Tillage practice as a modifier of the impacts of climate change

Knowledge of climate change is an obvious first step to maintain or improve production and land management in the future. Within this context, changing the intensity, timing, or form of tillage may be one of the management options more readily implemented to assist with adaptation to climate change. Other more extreme measures may need to involve new or modified production systems, or even structural change to alter land use.

The decreased intensity of tillage across Australia's cropping industry over the past decades (see above) seems to be a natural basis for improved adaptation. Vegetation cover is crucial to the maintenance of a number of factors that may lessen the impacts of climate change, including reducing the direct temperature effects of sunlight on soil, preserving channels for water infiltration, reduced slaking in heavier soils, and preserving structural integrity of the topsoil to resist wind and water erosion events.

Increased rainfall intensity on a tilled system may also lead to higher nutrient loss by leaching, and thus provide further incentives for farmers to employ conservative tillage practices. It is well accepted that direct drilling and stubble retention reduces loss of organic carbon and nitrogen compared with conventional tillage and burning (e.g. Heenan et al., 1995).

Increased knowledge of changing seasonal rainfall patterns and pending drought events can also guide management practices, for instance modifying plant type, timing of sowing, form of tillage, and fertiliser application – and indeed in extreme cases whether to plant a crop at all. As such, it will become increasingly important for landholders to have access to the best and most reliable seasonal forecast information to plan management of their land.

It is probable that changes to temperature and rainfall (whether perceived or real) are already leading to changes in the planting dates for cereals in some areas (Western Australia for example), and in the future, it is likely that an increased understanding of climate change will influence a whole host of other management decisions. Decisions relating to the use of tillage will be made in the context of both the longer term strategic response to climate change, and the shorter term practical response to annual weather patterns. Timing of fertiliser application, improved application methodologies, including better delivery of nitrogen to the roots (banding), are options that may provide additional advantages under a reduced till regime to ameliorate the effects of climate change.

We would like to mention a case study that amply demonstrates this point. Growers in the Wimmera-Mallee region of southern Australia have experienced a number of dry and seasonally variable years over the past decade or so. Lessons learnt over this time have meant that direct drilling (i.e. no-till) has become the standard management technique in many parts. The year 2006 was particularly tough with much of Australia in the grip of what is commonly referred to as the worst drought on record. The small amount of rain that did fall (20 mm in April, 20 mm in July, and 20 mm in September) was separated by long periods of dry conditions. Yields were always going to be poor, but young seedlings established by early sowing in dry soil using no-till showed incredible resilience to the harsh conditions, surviving the dry periods between rainfall events.

In many cases, early decisions were made to cut the cereal for hay production. But due to the serious shortage of grain for animal feed, the prices of hay escalated, allowing farmers to make positive returns. In addition, those farmers who managed to take the crop through to maturity, obtained high returns due to the widespread impact of the drought and the national shortage of grain (for more information see Birchip Cropping Group, 2005, 2006).

In some regions, and in more extreme cases, climate change may impact on existing farm systems to such an extent that it may become increasingly difficult to maintain a profitable operation without major change. In these regions, making management adjustments early will provide the best options to maintain regional wealth. Alternatively farming businesses may benefit from the changing climate by utilising land for completely new production processes. By modifying current operations, increases in the concentration of atmospheric carbon dioxide, or changed rainfall patterns may thus be used as an advantage to drive future productivity. Regardless of the approaches taken to ameliorate adverse effects of climate change or to capitalise on opportunity, tillage and progression in tillage practice will remain a key management variable for Australian farming to maintain its capacity to produce and compete in a changing climate.

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