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Does the adoption of zero tillage reduce greenhouse gas emissions? An assessment for the grains industry in Australia

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ABSTRACT

The Australian Government has recommended that farmers move from cultivation-based dryland farming to reduced or zero tillage systems. The private benefits could include improvements in yields and a decrease in costs while the public benefits could include a reduction in greenhouse gas (GHG) emissions due to a diminution in the use of heavy machinery. The aim of this study is to estimate and compare total on-farm GHG emissions from conventional and zero tillage systems based on selected grain crop rotations in the Darling Downs region of Queensland, Australia. The value chain was identified, including all inputs, and emissions. In addition, studies of soil carbon sequestration and nitrous oxide emissions under the different cropping systems were reviewed.

The value chain analysis revealed that the net effect on GHG emissions by switching to zero tillage is positive but relatively small. In addition though, the review of the sequestration studies suggests that there might be soil-based emissions that result from zero tillage that are being under-estimated. Therefore, zero tillage may not necessarily reduce overall GHG emissions. This could have major implication on current carbon credits offered from volunteer carbon markets for converting conventional tillage to reduced tillage system.

1. Introduction

From 1997 to 2004, agricultural productivity in Australia grew by an average of 2.8%/yr, which was at a higher rate than for the economy as a whole. This was the result of the intensification, mechanisation and the modernisation of agricultural systems (AGO, 2006). Under conventional cropping systems, it might be expected that this would result in a net increase in greenhouse gas (GHG) emissions per hectare. More intensive land use might involve more fuel, farm machinery and agrochemicals and the production, packaging, transportation and application of these requires significant energy resources leading to an increase in GHG emissions (Stout, 1990; Hülsbergen et al., 2001; Vlek et al., 2003; Chauhan et al., 2005; Graham and Williams, 2005; Maraseni et al., 2007, 2009, 2010a,b). Of the total energy used in agriculture globally, 51% is expended in farm machinery manufacturing and 45% in the production of chemical fertiliser (Helsel, 1992). In addition, increased fertiliser use also contributes to more emissions. Between 1987 and 2000, Nitrogen (N) fertiliser use in Australia increased by 325% (Dalal et al., 2003), with, more than 50% of the applied N either lost through leaching into the soil or released into the atmosphere as nitrous oxide (N_2O) (Verge et al., 2007), which has 298 times more global warming potential than CO_2 (IPCC, 2007). Nonetheless, GHG emissions due to production, packaging, storage, transportation and use of many farm inputs have been largely ignored in comparing the overall benefits of new farming practices.

In relation to soils, it can also be hypothesised that continuing cultivation results in a loss of soil carbon. Approximately 75% of agricultural lands in Australia have less than 1% soil organic carbon (SOC), whereas natural scrubs and some forest areas have 4.6% and 9.6% SOC, respectively (Maraseni et al., 2008). The loss of carbon also adversely affects soil fertility and the soil water holding capacity and plant-available water capacity (Pattanayak et al., 2005). Therefore, state agriculture departments, regional natural resources management organisations and local landholder groups have generally recommended that farmers move from traditional dryland farming systems to reduced tillage systems and where appropriate towards a zero tillage system (AGO, 2006). Currently, there is significant progress in this direction (Chan et al., 2009), with 35% farmers in New South Wales and 90% in Western Australia adopting such systems (Flower et al., 2008). The Darling Down region where this research was conducted is expected to have a zero till adoption level of at least 80% by 2013 (Llewellyn and D'emden, 2010).

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It might therefore be expected that that zero till could help restore soil carbon levels, through the retention and incorporation of crop residues and the reduction in high-disturbance cultivation and furthermore that there would be an overall reduction in GHG emissions through a reduction in farm machinery operations. Some recent research brings these assumptions into question. Zero tillage and the associated stubble retention seem to be effective in reducing SOC losses but not in increasing the total carbon stock, mainly due to warmer winters which are likely to increase the rate of SOC mineralisation (Chan et al., 2003, 2009). The same system tends to increase N_2O emissions rates due to availability of more plant materials, which are sources of carbon and energy for heterotrophic denitrifying organisms (Dorland and Beauchamp, 1991; Iqbal, 1992; Dalal et al., 2003). Furthermore, zero tillage and stubble retention can promote weed growth and controlling them requires higher amounts of herbicides, which have high global warming potential compared to other agrochemicals (Lal, 2004; Maraseni et al., 2007). These findings raise a serious research question as to whether or not zero tillage is an effective option for reducing overall GHG emissions.

The aim of this study is to estimate GHG emissions from various farm inputs for two common types of dryland tillage systems (conventional cultivation and zero till) based on a crop rotation that includes barley, chickpea, wheat and durum wheat (hereafter durum) in the Darling Downs region, one of the major grain producing regions in Queensland. Here zero till (sometimes called no-till) is defined as a farming system in which crops are grown from year to year with almost no soil disturbance, whereas, **c**onventional tillage is defined as a tillage system in which cultivation is the major means of seedbed preparation and weed control. The specific objectives of this study are to estimate GHG emissions due to: (1) the production and combustion of fossil fuels used in 4 grain farm operations; (2) agrochemical production, packaging, storage and transportation; (3) soil derived nitrous oxide (N_2O) from nitrogen (N) fertiliser usage; and (5) farm machinery production and use. There could however, be significant variation in the levels of soil carbon sequestration and nitrogen nitrous oxide emissions between the two tillage systems and in order to get complete picture of GHG emissions of both tillage systems, their amounts need to be considered. In the absence of specific experimental results/data we examine relevant research on soil carbon and nitrous oxide emissions.

The results from the modelling and review will then suggest whether or not changes in production practices could contribute to meeting national emissions reduction targets and potential changes in costs if carbon emissions are eventually priced The Australian Government is currently committed to reducing Australia's GHG emissions to 5–25% below 2000 levels by 2020, with the actual target dependent on international negotiations, and 60% by 2050 (DCC, 2010). The Australian agricultural sector accounted, in 2007, for 16.3% (or 88.1 M t CO_2e, which include 61.1 M t CO_2e from livestock sector and 27.2 M t CO_2e from cropping sector) of national GHG emissions and is the second largest source of emissions (DCC, 2009). This contribution increases to 23% when energy and transport inputs in agricultural production are included (Hatfield-Dodds et al., 2007). This figure is significantly higher than the corresponding values for agricultural sectors in central and Eastern Europe (3%), the former Soviet Union (3%) and the USA (5.5%) (Smith et al., 2008). From 1990 to 2005, Annex I countries collectively decreased their agricultural emissions by 10% (Smith et al., 2008) whilst Australia's emissions from agriculture between 1990 and 2007 increased by 1.5% (DCC, 2009). If emissions from agriculture are left unchecked, they are likely to continue to increase making it difficult for future Australian Governments to meet the current emissions reduction target for 2050.

2. Methods

This study identifies and estimates the GHG emissions arising from farm inputs from barley, chickpeas, wheat and durum cultivated under the two different tillage systems in the Darling Downs region of southern Queensland. The broad approach is to identify emissions from the production, packaging and transport of inputs and the application of those inputs to crop production. All emissions data are converted into carbon dioxide equivalent (CO_2e) given the diverse range of energy use metric in other studies of farm inputs and activities. The Kyoto Protocol covers six major GHGs, but of these only three GHGs (CO_2, N_2O and CH_4) are relevant to the grain industry and these will be addressed in this study. Following the fourth assessment report of the IPCC (2007, their Table 2.14), a conversion factor of 298 is used for N_2O (1 t N_2O = 298 t CO_2e) and 25 for CH_4 (1 t CH_4 = 25 t CO_2e). Farm input data come from the Queensland Department of Primary Industry and Fisheries. Emissions estimates, relating to the production and application of those inputs comes from a range of specific studies.

2.1. GHG emissions due to the production and combustion of fossil fuels

There are a number of studies that document GHG emissions resulting from the production and combustion of fossil fuels. In the Australian context, AGO (2001), Beer et al. (2002) and Department of Climate Change (DCC) (2008) are noteworthy. Beer et al. (2002) found that each litre of diesel produces 0.45 kg CO_2e during its production, while the AGO (2001) estimated this value at 0.46 kg CO_2e and so an average value of 0.455 kg CO_2e is used in this study. Similarly, according to the DCC (2008; their Table 4), each kL of diesel produces 38.6 GJ of energy when combustion is for transport energy purposes, and the emission factor for each GJ of energy is 69.9 kg CO_2e (this includes 69.2 kg CO_2e from CO_2, 0.2 kg CO_2e from CH_4 and 0.5 kg CO_2e from N_2O). This means that each litre of diesel produces 2.698 kg CO_2e during its combustion and thus the total GHG emissions during the production and combustion of one litre of diesel is 3.15 kg CO_2e. GHG emissions also occur during the transportation of fuels, but in this study they are not considered, as they are negligible (Maraseni et al., 2007). Total diesel consumption for each type and frequency of grain farming operation is taken from work by the Department of Primary Industry and Fisheries (2009) and is used to calculate the total quantities of GHG emissions from farm diesel usage.

2.2. GHG emissions from production, packaging, storage, and transportation of agrochemicals

Agrochemicals include fertilisers and chemicals (herbicides, insecticides, fungicides and plant growth regulator), with their production, packaging, storage and transportation requiring energy and thus they contribute to GHG emissions. Two types of fertilizers (Urea and Supreme Z) are commonly used for winter crops in the Darling Downs. The proportions of major fertiliser-elements (such as N, P, K, S and Zn) were estimated using their chemical formula and their molecular and atomic weights. For example, 100 kg of Urea contains 46% nitrogen whereas 100 kg of Supreme Z contains 11 kg N, 21.8 kg P, 4 kg S and 1 kg Zn. Similarly, as suggested by Rab et al. (2008), each chemical is multiplied by a conversion factor (0.5 for herbicides and 0.25 for insecticides and plant growth regulator) to obtain the approximate active ingredients in the mix. CO_2e emission factors for the production, packaging, storage and transportation of each kg of fertiliser-element (in fertiliser) and active ingredient (in herbicide, insecticide and plant regulators) is adapted from Lal (2004; Table 1). As Lal (2004) presented emission

Table 1
CO_2e (kg CO_2 kg^{-1} fertiliser-element (fe) or kg CO_2 kg^{-1} active ingredient chemicals (ai)) for production, packaging, storage and transportation of agrichemicals: adapted from Lal (2004).

Fertilisers	kg CO_2 kg^{-1} fe	Chemicals	kg CO_2 kg^{-1} ai
N	4.77	Insecticides	18.7
P	0.73	Herbicides	23.1
K	0.55	Fungicides	14.3
S	0.37		

Note: Emissions factor for Zn is not available so emissions factor for S is used.

factors in C equivalent, they are converted into CO_2e by multiplying by 3.67 (molecular wt of CO_2/atomic wt of $C = 44/12$). (see Table 1).

2.3. Emissions of N_2O from soils due to N-fertiliser application

N_2O is responsible for 6% of observed global warming (Dalal et al., 2003). It currently contributes 6.3% of Australia's GHG emissions, however, this has rapidly increased from 4.3% in 1990 (Mitchell and Skjemstad, 2004). Around 80% of N_2O is produced by the agricultural sector of which 73% is emitted from agricultural soils (Dalal et al., 2003). Most of the N_2O emissions come from N-fertiliser usage and soil disturbances. Lack of oxygen or limited oxygen supply in the soil or high oxygen demand due to more carbon food in the soil causes micro-organisms to utilise nitrate (NO_3^-) and nitrite (NO_2^-) instead of oxygen. As a result of this de-nitrification process, the applied N-fertiliser is released as N_2O into the atmosphere (Dalal et al., 2003).

The IPCC set a default emission factor of 1.25% NO_2–N emissions kg^{-1} of applied N. However, research has shown large variations from the IPCC default emission factor. In Australia, the CRC for Greenhouse Accounting has established a set of emission factors suitable for Australian agricultural systems (DCC, 2005 cited in Rab et al., 2008). For dryland and zero till grains, 0.3% (0.003 kgN_2O–N 100 kg N^{-1}) is used (DCC, 2005 cited in Rab et al., 2008). We admit that there could be significant differences in N_2O emissions factors between two systems, but we used the same value since specific values for given crops in a given research areas are not available in the literature, something that is further considered late in the discussion. After calculating the total amount of N_2O–N, it is converted into N_2O (by multiplying 1.57; molecular wt of N_2O $mole^{-1}$ wt of N_2) and then into CO_2e.

2.4. Emissions due to the production and use of farm machinery in the grains industry

Several studies have estimated GHG emissions resulting from the production of a kilogram of farm machinery (Maraseni et al., 2007, 2009, 2010a,b). Maraseni et al. (2007) investigated peanut-maize cropping in southeast Queensland, Australia and calculated GHG emissions due to the production of each kg of farm machinery and their accessories. We could not find any published information (number, types, sizes, power etc.) about tractors and other accessories specifically used in Australian winter crops. We therefore used the information given in Maraseni et al. (2007), derived from observation of farming systems and agricultural agency recommendations. Maraseni et al. (2007) concluded that GHG emissions due to use of machinery on farms are directly related to fossil fuel use. A higher amount of farm machinery use means a larger amount of fossil fuel related emissions. They reported that farm machinery related GHG emissions are 14.4% of the fossil fuels related emissions. These values are also adopted in some other studies such as Maraseni et al. (2010a,b).

3. Results

3.1. GHG emissions due to the production and combustion of fossil fuels used in farming operations for four types of winter crops under two types of tillage systems

Table 2 presents a breakdown of GHG emissions from fossil fuel usage for a range of farming activities for four types of winter crops under the two tillage systems. GHG emissions due to the use of fossil fuel for the four winter crops in zero tillage systems are similar and less than 100 kg CO_2e/ha. In a zero tillage system, barley, chickpeas, wheat and durum, on aggregate, account for 83.9, 96.4, 94.9 and 94.8 kg CO_2e/ha of GHG emissions, respectively. On the other hand, emissions of GHG emissions due to the use of fossil fuel in the production of winter crops under a conventional tillage system are almost double that of those for the zero tillage system. Barley, chickpeas, wheat and durum under conventional tillage, on aggregate result in 162.5 kg, 205 kg, 191.9 and 191.7 kg CO_2e/ha of GHG emissions, respectively. Within the group, in both tillage systems, emissions of GHG from chickpeas were found to result in the highest emissions while barley had the lowest. Conventional tillage requires a higher number of primary and secondary tillage operations but fewer boom spray operations than the zero tillage. However, less fuel is used for boom sprayings than for primary and secondary tillage so the conventional tillage system in total emits more GHG emissions than the zero tillage system.

3.2. GHG emissions due to the production, packaging, storage and transportation of agrochemicals

For these emissions, the situation is, as might be expected, somewhat reversed. In total, agrochemicals related GHG emissions (due to the production, packing, storage and transportation) in zero tillage barley, chickpeas, wheat and durum cropping are 126, 98.2 , 367.1 and 395.3 kg CO_2e/ha emissions, respectively (Table 3). Corresponding values for conventional tillage barley, chickpeas, wheat and durum cropping are 61.3 kg CO_2e/ha, 45.1 kg CO_2e/ha, 287.4 kg CO_2e/ha and 330.4 kg CO_2e/ha, respectively. As expected, crop production under conventional tillage results in a lower level of emissions than under zero tillage. The amount of fertilisers used for each crops under each tillage system was the same. However, the amount of herbicides used in the zero tillage system was much higher than that used for the same crops in a conventional tillage system. In each group, Durum wheat production released the highest amount of GHG emissions followed by wheat, barley and chickpeas.

3.3. Emissions of N_2O from soils due to N-fertilizer application

As mentioned, fertiliser usage varied between the types of crop but not between the two systems. Therefore, there is no difference in N_2O emissions due to use of nitrogen fertiliser for each crop cultivated under the two different tillage systems. In both systems, barley, wheat and durum in total emit 4.6, 70.7 and 83.7 kg CO_2e GHG per hectare, respectively into the atmosphere simply from de-nitrification of applied N fertilizer (Table 4). The level of emissions is directly related to N-fertilizer amounts: the higher the N fertilizer use, the greater the emissions of N_2O and thus the higher the CO_2e. As Supreme Z contains only 11% N, its relative contribution to total emissions compared to Urea, which contain 46% N, is quite low. No fertiliser was applied to the leguminous chickpeas. Similarly, the lower amount of emissions from barley is attributed to no use of urea and a lower amount of Supreme Z.

Table 2

Emissions of GHG (kg CO_2e/ha) due to the production and combustion of fossil fuels used in farming operations for four types of winter crops under two types of farming systems in the Darling Downs region of southern Queensland, Australia.

Farming operation	Diesel (L per ha per operation)	Dry land (zero tillage)								Dry land (conventional tillage)							
		Barley		Chickpeas		Wheat		Durum		Barley		Chickpeas		Wheat		Durum	
		No	Emissions	No	Emissions	No	Emissions	No	Emissions	No	Emissions	No	Emissions	No	Emissions	No	Emissions
Primary tillage	18		0.0		0.0		0.0		0.0	1	56.7	1	56.7	1	56.7	1	56.7
Secondary tillage	8		0.0		0.0		0.0		0.0	2	50.4	2	50.4	3	75.6	3	75.6
Fertiliser application	5		0.0		0.0	1	15.8	1	15.8		0.0	1	15.8	1	15.8	1	15.8
Boom spraying	2.25	6	42.5	8	56.7	6	42.5	6	42.5	2	14.2	6	42.5	1	7.1	1	7.1
Planting	5	1	15.8	1	15.8	1	15.8	1	15.8	1	15.8	1	15.8	1	15.8	1	15.8
Aerial spray	0.035	1	0.1		0.0	1	0.1		0.0		0.0		0.0	1	0.1		0.0
Harvesting*		1	25.5	1	23.9	1	20.8	1	20.8	1	25.5	1	23.9	1	20.8	1	20.8
Total emissions			83.9		96.4		94.9		94.8		162.5		205.0		191.9		191.7

Note: Amount of fuel used for harvesting for Barley 8.1 L/ha; Chickpeas 7.6 L/ha; wheat 6.6 L/ha and Durum 6.6 L/ha.

Table 3

Emissions of GHG (kg CO_2e/ha) due to the use of agrochemicals for four winter crops in the Darling Downs region of southern Queensland, Australia.

Agrochemicals	Dry land (Zero tillage)								Dry land (conventional tillage)							
	Barley		Chickpeas		Wheat		Durum		Barley		Chickpeas		Wheat		Durum	
	Amount	Emissions	Amount	Emissions	Amount	Emissions	Amount	Emissions	Amount	Emissions	Amount	Emissions	Amount	Emissions	Amount	Emissions
Supreme Z® (kg)	30	21.1	0	0.0	40	28.1	40	28.1	30	21.1	0	0.0	40	28.1	40	28.1
Urea (kg)	0	0.0	0	0.0	100	219.4	120	263.3	0	0.0	0	0.0	100	219.4	120	263.3
Herbicides (L) for fellow spray	8.00	92.4	4.60	53.1	8.00	92.4	8.00	92.4	2.40	27.7	1.20	13.9	2.40	27.7	2.40	27.7
Herbicides (L) during cropping	1.01	11.6	1.20	13.9	1.01	11.6	1.00	11.6	1.01	11.6	0.00	0.0	1.01	11.6	1.00	11.6
Herbicides (L) before harvest	0.00	0.0	1.50	17.3	1.30	15.0	0.00	0.0	0.00	0.0	1.50	17.3	0.00	0.0	0.00	0.0
Insecticide (L)	0.00	0.0	0.68	3.2	0.00	0.0	0.00	0.0	0.00	0.0	0.68	3.2	0.00	0.0	0.00	0.0
Fungicide (L)	0.25	0.9	3.00	10.7	0.15	0.5	0.00	0.0	0.25	0.9	3.00	10.7	0.15	0.5	0.00	0.0
Total emissions		126.0		98.2		367.1		395.3		61.3		45.1		287.4		330.7

Table 4
Emissions of N_2O (kg CO_2e/ha) from N-fertilizer application in soils under the four winter crops under two farming systems in the Darling Downs region of southern Queensland, Australia.

Fertilisers	Dry land (Zero tillage)								Dry land (conventional tillage)							
	Barley		Chickpeas		Wheat		Durum		Barley		Chickpeas		Wheat		Durum	
	Amount	Emissions	Amount	Emissions	Amount	Emissions	Amount	Emissions	Amount	Emissions	Amount	Emissions	Amount	Emissions	Amount	Emissions
Supreme Z® (kg)	30.0	4.6	0.0	0.0	40.0	6.2	40.0	6.2	30.0	4.6	0.0	0.0	40.0	6.2	40.0	6.2
Urea (kg)	0.0	0.0	0.0	0.0	100.0	64.6	120.0	77.5	0.0	0.0	0.0	0.0	100.0	64.6	120.0	77.5
Total Emissions (kg CO_2e/ha)		4.6		0.0		70.7		83.7		4.6		0.0		70.7		83.7

Table 5
GHG emissions (kg CO_2e/ha) due to various farming inputs for the four winter crops under two farming systems in the Darling Downs region of southern Queensland, Australia.

Sources of emissions	Dry land (Zero tillage)								Dry land (conventional tillage)							
	Barley		Chickpeas		Wheat		Durum		Barley		Chickpeas		Wheat		Durum	
Fuels	83.9	37.0	96.4	46.2	94.9	17.4	94.8	16.1	162.5	64.5	205	73.3	191.9	33.2	191.7	30.3
Agrochemicals	126	55.6	98.2	47.1	367.1	67.2	395.3	67.3	61.3	24.3	45.1	16.1	287.4	49.8	330.7	52.2
Emissions from soils due to N-fertilizer use	4.6	2.0	0	0.0	70.7	12.9	83.7	14.2	4.6	1.8	0	0.0	70.7	12.2	83.7	13.2
Machinery	12.1	5.3	13.9	6.7	13.7	2.5	13.7	2.3	23.4	9.3	29.5	10.6	27.6	4.8	27.6	4.4
Total emissions (kg CO_2e/ha)	226.6	100.0	208.5	100.0	546.4	100.0	587.5	100.0	251.8	100.0	279.6	100.0	577.6	100.0	633.7	100.0

Note: left column of under each crop shows GHG emissions (kg CO_2e/ha) due to various farming inputs and right column show the percentage of total GHG emissions due to given inputs.

3.4. GHG emissions due to the production of farm machinery

As mentioned, the quantity of GHG emissions due to the use of farm machinery is directly related to fossil fuel-related emissions (Table 5). Therefore, as in the case of fuel related emissions, machinery related emissions for the four winter crops in zero tillage are almost similar to each other and are almost half of their counter parts in the conventional tillage system. For example, barley, chickpeas, wheat and durum under conventional tillage, on aggregate, account for 23.4 kg CO_2e/ha, 29.5 kg CO_2e/ha, 27.6 kg CO_2e/ha and 27.6 kg CO_2e/ha of GHG emissions, respec tively, whereas in zero tillage they respectively account for 12.1 kg CO_2e/ha, 13.9 kg CO_2e/ham, 13.7 kg CO_2e/ha and 13.7 kg CO_2e/ha of GHG emissions.

In total, for each crop, GHGs emissions from conventional tillage are higher than the emissions from the zero tillage system (Table 5) but the difference is not pronounced. For example, in total, barley, chickpeas, wheat and durum under conventional tillage are 251.8, 279.6, 577.6 and 633.7 kg CO_2e/ha, whereas under a zero tillage system production of each crop would release 226.6 (10% reduction), 208.5 (25%), 546.4 (5.4%) and 587.5 kg (7.3%) CO_2e/ha, respectively. The biggest reduction is with the legume crop (chickpeas), while the highest amount of emissions in both systems and the proportionately lowest gain from switching to zero till would be from durum followed by wheat. Across a rotation of the four crops, emissions would be reduced by approximately 11%, or for a rotation that excluded durum, there would be a 13% reduction in emissions. These results do not include the most emissions intensive crops grown in this region, with dryland cotton (Maraseni et al., 2010b) and dryland peanut-maize cultivation (Maraseni et al., 2007) both resulting in more emissions. The wheat and durum require lower amounts of agrochemicals and fewer tillage operations than do cotton and peanut-maize cropping.

4. Discussion

The results from this analysis suggest that switching from conventional cultivation to zero till would clearly reduce on-farm emissions. When the production of agrochemicals is taken into account, the gains are much less. Furthermore, if emissions were to be priced, which is not the case in Australia at the time of writing, the economic gains of switching to zero till, for farmers would be relatively low. For example, when the Australian Government proposed an emissions trading scheme in 2009, it was forecast that the initial price might be $20/tonne, increasing at 4% per year (Lawson et al., 2008), reaching more than $40 after 20 years. Hence, even at $40, the ‘savings’ on emissions payments would range from $2.80/ha/yr for chickpeas to $1/ha/yr for barley. This does not of course consider the savings that might come from reducing machinery, fuel and labour use. There might also be an increase in yields, some of which could come from an improvement in soil texture and water-holding capacity, as noted earlier.

A recent survey of 1172 grain growers in 19 selected grain growing regions from Western Australia, South Australia, Victoria, New South Wales and southern Queensland shows that farmers are more inclined toward no-till for three main reasons: reduced fuel and labour costs; and increased soil conservation benefits (Llewellyn and D’emden, 2010). However, two factors work against the adoption of a no-till system. First, the cost of herbicides, especially glyphosate, is increasing. For example, during 2007, price of glyphosate increased exponentially, from $3.5/L in January to $7.2/L in December (NSW Farmers Association, 2008). Second, farmers appear less likely to accept the perception that “using no-till with stubble retention will: increase the economic value of the land; increase moisture retention; increase wheat yields; increase reliability of wheat yields; result in less rain needed for reliable seeding; lower fuel costs” (Llewellyn and D’emden, 2010). The survey shows that there is no unanimous view about soil carbon sequestration.

Several studies compare soil organic carbon (SOC) in conventional and conservation tillage systems. In most of these studies, soils were sampled to a depth of 30 cm or less, and results were consistent with the general perception that zero-till increases the carbon sequestration (Baker et al., 2007). However, in cases where sampling extended deeper than 30 cm, the story is completely different, with higher concentrations of SOC near the surface in conservation tillage and higher concentrations in deeper layers under conventional tillage (Baker et al., 2007). Similarly, a review of ~100 plot studies in Canada shows that for measurements where the sampling depth was 30 cm or less, 82% of no-till plots reported more SOC than those which were conventionally tilled, with a mean annual SOC gain of 0.38–0.72 t/ha/yr, while samples from depths greater than 30 cm showed less SOC in 69% of no-till plots relative to conventional tillage, with a mean annual SOC loss of −0.23 to −0.97 t/ha/yr (VandenBygaart et al., 2003). This trend is supported to some extent by trials at Hermitage Research Station (28°12′S and 152°06′E), southern Queensland, Australia, an area close to our study area. Measurement of 33-year effects of no-till versus conventional till indicated that no-till (NT), stubble retention (SR) and nitrogen fertilisation (NF) influenced total organic carbon (TOC) only in the top 10 cm soil and only when these treatments were combined, with a TOC content being 1.1 to 3.4 t/ha higher under NT + SR + NF than under other treatments (Wang et al., 2004). No significant difference in TOC between NT and conventional till was observed in the top layer (0–10 cm depth) where no NF was applied or stubble was burned. Moreover, TOC content in the 10–20 cm depth of soil did not differ significantly between the different treatments ($p < 0.05$) (Wang et al., 2004), indicating support for the Baker et al. (2007) findings with increasing soil depth. However, without deeper soil sampling at the current research site, a concrete conclusion cannot be drawn. Therefore, at this stage, it is not possible to accurately pinpoint whether no-till in Australia would attract carbon credits under the CPRS and Kyoto Protocol.

Emissions of N_2O from soils due to the use of nitrogen fertilisation are also worth considering for two main reasons: (1) as discussed above, nitrogen fertilisation is one of the preconditions for having more TOC in a no-till system; and (2) N_2O has 298 times more global warming potential than CO_2. De-nitrification of applied nitrogen fertiliser is the main source of N_2O emissions in soil (Dalal et al., 2003). Introduction of plant material such as plant litter and root exudates, which are sources of carbon and energy for heterotrophic denitrifying organisms, enhances the rate of denitrification (Dorland and Beauchamp, 1991; Iqbal, 1992). This conclusion is further supported by studies in Australia. For example, nitrate applied to a sugarcane soil at the rate of 160 kg N/ha lost 0.13% and 15.4% of N as N_2O from the cultivated and no-till soil respectively, over a 4-day period after fertiliser application and irrigation (Dalal et al., 2003). Trash retention in soil also accelerates N_2O emissions. For example, the application of sugarcane trash (10 t/ha) to a soil fertilised with potassium nitrate or urea at the rate of 160 kg/ha, followed by 50 mm of irrigation, increased emissions of N_2O from a mean value of 11.3 kg N_2O–N/ha/day without trash retention to 13.3 kg N_2O–N/ha/day for soil with trash retained (Weiler, 2002 cited in Dalal et al., 2003). Similarly, the addition of wheat residue at the rate of 10.5 t/ha to a Vertisol soil doubled the de-nitrification loss of applied urea (Dalal et al., 2003). These findings show that no-till increases soil nitrogen emissions, thus likely reducing or perhaps even offsetting the overall emissions gains from switching to this form of production.

Emission of N_2O from soils due to biologically fixed nitrogen is another discussable topic. Legumes can fix atmospheric nitrogen and also make available to the companion/next crop, thus saving additional synthetic nitrogen fertiliser use and costs and reducing GHG emissions. Among the four grain crops analysed in this paper, only the chickpeas is a legume crop. Therefore, there is no use of urea and supreme-z fertilisers in chickpeas whereas at least one of them is used for all other croppings. Part of the biologically-fixed nitrogen emits into the atmosphere in the form of N_2O. There is a debate among the scientific community about whether the biologically fixed nitrogen is equally as harmful for global warming as that of nitrogen fertiliser. Dalal et al. (2003) suggested that the N_2O emissions from legume crops exceed those from nitrogen due to frequent wetting and drying cycles over a longer period. Crews and Peoples (2004) argued that the biologically-fixed nitrogen is ultimately derived from solar energy while nitrogen fertiliser requires significant amounts of fossil fuels, thus, legumes should have a lower impact. However, this study has not considered N_2O emissions from biologically fixed nitrogen.

5. Conclusions

The aim of this study was to quantify GHG emissions from the use of different farm inputs for four winter crops under two different dryland tillage systems in the Darling Downs region of southern Queensland. On aggregate, zero-tilled winter crops release less GHGs than conventional tillage crops, however, the difference was very small. Compared to conventional tillage, zero-tillage systems have significantly reduced fuel-related emissions but agrochemical-related emissions in zero-tillage systems are significantly greater than for the conventional tillage system.

Two potential GHG benefits in zero-tillage system are believed to be increased soil organic carbon and reduced nitrous oxide (N_2O) emissions. However, N_2O from soils after the use of nitrogen fertilisers can be higher in zero tillage than conventional tillage systems. Zero tillage may increase soil carbon concentrations only on the upper surface, with increases in deeper layers more commonly found with conventional tillage. However, in Australia, this needs to be verified, as current research is limited to 20 cm soil depth.

While there are many good reasons for farmers to adopt zero tillage, this study suggests that, against previous expectations, there may only be very small reductions in greenhouse gas emissions. Further to this, if soil-based sequestration is to be included in any mitigation payment scheme, the choice of accounting mechanisms will be critical. The inclusion of production and transport emissions estimations will significantly diminish returns to farmers who are paid to switch to and maintain zero till production. On the other hand, payments based only on farm-based emissions could be wasting public money.

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