CTF and Climate Change

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INTRODUCTION

"Plants grow best in soft soil, wheels work best on roads" neatly encapsulates the major conflict at the centre of most mechanised agriculture, and the rationale for controlled traffic farming. Three important things happen when we drive heavy equipment wheels over soft soil:

- We use a lot more energy (i.e. tractor power) compacting soil under the wheels.
- More energy is required to ameliorate compacted soil to its previous condition.
- Important soil processes don't work as well until it has been fully ameliorated.

Productivity increases under CTF as natural amelioration extends through the soil profile, improving soil's capacity to store and supply water and nutrients to plant roots, and improving the volume of soil available for root exploration. Costs are reduced under CTF by avoiding the energy wasted in first compacting and then ameliorating soil.

Natural amelioration spreads downwards under the influence of plant roots and soil biota, in addition to wetting/drying effects. In shrink/swell soils it occurs very rapidly at the surface, but happens more slowly as it moves downwards through the profile. The surface 2 cm might recover in two weeks, but it might take two years to get to 20 cm. Amelioration to 100 cm may take 10 years. This is why some of the benefits of CTF are found immediately, but improvements continue for a number of years.

Without controlled traffic, we can't avoid driving over at least 50% of land area per crop. The damage is immediate, so it's not surprising that farmers often continue to till in well-watered areas where erosion is not seen as an issue. Tillage only does a partial repair job, and then only down to tillage depth, but it has been the basis of cropping systems for thousands of years. Over large areas of Australia, it has been replaced by minimum or zero tillage, random traffic systems, which are now being displaced by CTF -- controlled traffic, zero tillage.

The physical impact of CTF well known. Runoff is reduced and plant available water capacity increased, supporting better yields and/or greater cropping frequency. Less runoff, filtered through greater residue will reduce movement of soil, nutrients and agricultural chemicals, reducing erosion and improving water quality (For more detail see, for instance Tullberg et al. 2007).

This paper focuses on those effects relevant to climate change: fossil fuel energy incorporated in the fuel, herbicides and fertilisers, and on soil emissions and soil carbon. Environmental effects of CTF are compared here to the alternatives. For the purposes of this paper these are taken as:

- ***Stubble Mulch*** -- minimum tillage, random traffic systems aimed at maintaining at least 30% residue cover, assumed here to involve 3 tillage, and 1 herbicide operation per crop.
- ***Zero till*** -- random traffic, assumed here to involve 4 herbicide operations per crop, with some tillage required every third year on average (= 0.33 tillage operations per year).
- ***CTF*** -- controlled traffic, zero tillage, opportunity cropping (= increased cropping frequency, reducing herbicide operations to 3/crop).

Within the general headings noted above, there is great variability depending on geographical location and season. The outcome of any analysis obviously depends on the answers to questions such as "how many operations", "how much of what fertiliser, herbicide" etc. Many of these options have been incorporated in a simple Excel spreadsheet to allow rapid examination of different options. The assumptions used in the example presented here (Table 1) are intended to be reasonably typical of broadacre cropping in eastern Australia. It can be readily manipulated to illustrate other systems.

Table 1. Crop production operations in different systems.

System	Primary Till	Seedbed Till	Spraying	Planting	Harvesting
Stubble Mulch.	1	2	1	1	1
Zero Tillage	0.33	0	4	1	1
CTF	0	0	3	1	1

FUEL REQUIREMENTS OF FIELD OPERATIONS

Typical fuel requirements of farm machinery operations are quoted in various publications by Queensland DPI, and the values quoted in the stubble mulch column of table 1 are based on these. Fuel use in individual zero till operations operations is assumed to be similar, except for spraying, while fuel use in CTF operations is much smaller in operations such as seeding and spraying, where rolling resistance is a large component. Harvester fuel requirements are reduced by 30% for the same reason.

For all practical purposes, each litre of fuel burnt produces 2.75 kg of carbon dioxide (CO_2), so it is quite straightforward to calculate the carbon dioxide production per hectare of cropping.

Table 2. Fuel requirements of cropping operations in different systems, L/hectare

Operation	Chisel plough	Cultivator	Seeder	Sprayer	Header (4t crop)	System Fuel Use L/ha	CO_2 kg/ha
Stubble Mulch*	9.8	6.0	5.0	1.4	8.0	36.2	99.6
Zero Till	9.8	0	5.0	1.4	8.0	21.9	60.1
CTF	0	0	3.0	0.7	6.0	11.0	30.5

HERBICIDES

Reducing tillage certainly reduces on-farm fuel use. Unfortunately, the production of herbicides is an energy-intensive process, and often based on mineral oils. Accurate information is difficult to obtain, but the energy incorporated in some common herbicides has been tabulated by Zentner et al. (2004), and some of this data is set out in table 3. Glyphosate is the most commonly used herbicide, and also the most energy intensive, which might account for some of the recent price increase.

Table 3. Diesel fuel equivalents of herbicides (manufacturing component)

Commercial Product	Herbicide/s	Manufacturing Energy MJ/kg	Application rate (label) kg/ha	Energy/Spray MJ//ha	L/ha Diesel Equivalent
2,4-D Amine	2,4-D	98	0.500	49	1.2
Atrazine	Atrazine	190	0.500	95	2.4
SpraySeed	Diquat/Paraquat	430	0.250	108.1	2.7
Roundup CT	Glyphosate	511	0.450	229.95	5.8

*Petroleum feedstock, 1kg Diesel = 40MJ .

Herbicide selection obviously determines the total diesel fuel equivalent of any given cropping system. For the current estimates, it is assumed for each other herbicide application, 2 glyphosate applications occur, so a reasonable assumption of average herbicide manufacture is 4.6 L diesel /ha, or 12.7 kg CO_2 /ha, per spray operation. This could be reduced slightly to the extent that natural gas has replaced petroleum oil in this manufacturing process.

FERTILISERS

People are often surprised to find that the production of nitrogen fertiliser is usually the largest single energy input to agriculture (other than the sun!). It's another significant source of carbon dioxide, a major cost, and another major inefficiency. Only around half of the nitrogen applied is taken away in crops, and the unused N is an important source of pollution and greenhouse gases.

Inefficient use of nitrogen is often associated with waterlogging, which might be part of the background for the common observation that more nitrogen is required in (random traffic) zero tillage systems. There are also a number of claims of "greater yield with less fertiliser" in CTF. This has not been the subject of specific research, but most CTF trials have demonstrated greater yields (often 10 -- 15%), without any increase in fertiliser input.

Nitrogen efficiency and nitrogen requirement could be argued about for a long time. For the purposes of this paper is assumed that zero tillage requires roughly 10% more N, and CTF requires approximately 10% less N, which is the basis of the values quoted in table 4.

Nitrogen fertiliser production requires approximately 75 MJ of energy per kg of fertiliser, but the feedstock involved is almost always gas, which produces only 0.065 kg carbon dioxide per MJ energy. For most practical purposes, we can therefore assume that about 4.9 kg carbon dioxide is produced per kilogram of N fertiliser produced.

Assumed application rates and emissions relate to nitrogen fertiliser production are included in table 4, along with emissions related to herbicide production and diesel fuel. All these inputs are similar to the extent they are all energy-related. They are all also a direct consequence of management inputs, and will change if these inputs are changed.

Table 4. Energy-related CO_2 emissions, from inputs (nitrogen fertiliser, herbicide and diesel fuel).

System	N.Application Rate kg/ha	N. Production CO_2 kg/ha	Herbicide Prod'n CO_2 kg/ha	Diesel fuel CO_2 kg/ha	Total CO_2 kg/ha
Stubble Mulch.	45	205	12.7	99.6	362.3
Zero Tillage	50	245	50.8	60.1	405.9
CTF	40	196	38.1	30.5	304.6

SOIL EMISSIONS

All the above data is related to direct energy inputs, and CO_2 produced by combustion of fossil fuels. Carbon dioxide is the most important "greenhouse" gas, and cropping has other important effects on CO_2 absorption and emission (compared with the natural ecosystem it replaced). Absorption occurs rapidly by photosynthesis of growing crops to produce organic matter -- some small proportion of which will become soil organic matter, and be out of atmospheric circulation for some years. Agriculture also reduces soil organic matter (and carbon storage) by accelerating the cycling of soil organic matter back into atmospheric CO_2 , with tillage.

Other expertise is needed to make sense of this complex subject, but there would be general agreement with the proposition that in moisture-limited environments, other things being equal, growing more biomass, removing as little as possible, and causing less soil disturbance will all increase the rate of soil organic matter accumulation, or reduce its rate of loss from the soil. CTF meet these targets.

CTF maximises water use efficiency and minimises soil disturbance. Water use efficiency and biomass production could be further increased if we can develop precision CTF systems to allow relay cropping -- planting a double crop before harvesting the previous crop -- to soak up excess water prior to harvest. Cover crops which provide weed suppression could make good economic sense in this situation.

Nitrous oxide (N_2O) and methane (CH_4) are the other significant soil emissions from cropping agriculture. In both cases the quantities are small, but because nitrous oxide and methane have approximately 310 times and 23 times the greenhouse impact of carbon dioxide, they are both important. To make the data comparable, their impact is usually expressed in terms of their carbon dioxide equivalent, CO_2 E.

Nitrous oxide is a significant component of agriculture's greenhouse impact, produced largely by denitrification of soil nitrates. In cropping agriculture, these are derived largely from fertilisers, and their loss, whether by denitrification, leaching or runoff, represents the loss of an expensive input. Each of these mechanisms occurs when soil is close to saturation. Methane is seen mostly as an issue for rice growing and animal agriculture, but cropped systems often produce small amounts of methane. Relatively dry areas of natural vegetation usually absorb and oxidise small amounts of methane.

Research into nitrous oxide production from soils has shown large, apparently random, small-scale spatial variability. Random traffic and non-uniform fertiliser distribution could be part of this. Great variability also occurs with time, but this is associated with high levels of water-filled porosity. Soil compaction and continuity of soil porosity appear to have an important influence (Ball et al.2008).

Research into CTF impacts on nitrous oxide and methane production is rare, but recent work in Holland (Vermeulen et al. 2007) has compared emissions of these gases from random traffic and "seasonal" precision CTF (with annual mouldboard ploughing) in an organic vegetable production system. This work, carried out over three crops in two seasons demonstrated a large and statistically significant reduction in nitrous oxide emissions from seasonal CTF. Methane was absorbed by seasonal CTF, while random traffic produced small methane emissions. Consistent and significant improvements occurred in total and air-filled porosity, together with yield increases in seasonal CTF.

It is obviously not possible to talk with confidence about the implications for Australian CTF when these results were obtained in organic systems with annual soil disturbance, nitrogen input largely from manures and higher rainfall. At the same time, it might reasonably be suggested that improved porosity and pore continuity would be a major factor. On this basis, random traffic zero tillage might produce the greatest nitrous oxide and methane emissions and full zero till CTF the least. Relative emission rates might be the similar in the Australian situation, but a drier climate and generally smaller rates of fertiliser application might reduce the absolute values, but this is all highly speculative.

Mean values of emissions per 30 days would have been calculated from the Dutch results (each of which was an average of measurements made over at least 33 days). These are set out in table 5, which also provides their CO_2 equivalent values. Although the methane values appear relatively insignificant, this source of emissions or absorption might be active for a much longer period than those of nitrous oxide, which will occur largely during periods when soil nitrate levels are high.

Table 5. Seasonal CTF effects on nitrous oxide and methane emissions in organic farming (Holland)

System	Emissions - kg/ha in 30 days		CO_2 Equivalent - kg/ha in 30 days		Total
	Nitrous oxide	Methane	Nitrous oxide	Methane	CO_2 E kg/ha
Random Traffic	+2.04	+0.0225	632	+0.52	633
Seasonal CTF	+1.41	-0.146	437	-3.37	434

Increasing nitrogen efficiency makes obvious economic and environmental sense, but this is another topic best left to experts. It is clear nevertheless that nitrogen efficiency can be improved by avoiding the situation where excess nitrates are available in waterlogged soil. In practical terms, waterlogging can be minimised by using CTF to avoid soil compaction and provide effective drainage. The time period over which nitrates are available can be minimised by split fertiliser application, which is also facilitated by the permanent traffic lanes of CTF. Viability would be determined by a simple balance between costs and fertiliser-saving benefits of the additional operation.

TOTAL EMISSIONS

Emissions from all sources considered above are set out in Table 6 which includes the 30 day emissions measured under grossly different conditions in Holland. This might be the case if emissions in Australia occur at a smaller rate, but over a longer period. Zero tillage has also been assumed to produce 20% more emissions than stubble mulch, on the assumption that random traffic zero tillage is more prone to waterlogging and inefficient nitrogen use. These assumptions are highly speculative

The major point of the comparison is to indicate the possible relative importance of emissions from different sources. Soil emissions largely related to use of nitrogen fertiliser, together with the manufacture of that fertiliser, are clearly the dominant effects. CTF offers some possibility of improving nitrogen efficiency and reducing those emissions. This makes good sense in economic and environmental terms.

Table 6. Cropping System Effects on Emissions

System	**Diesel fuel CO_2 kg/ha**	**Herbicide Prod'n CO_2 kg/ha**	**N. Production CO_2 kg/ha**	**Total CO_2 kg/ha**	**Soil Emissions* CO_2E kg/ha**
Stubble Mulch.	99.6	12.7	205	362.3	633
Zero Tillage	60.1	50.8	245	405.9	760
CTF	30.5	38.1	196	304.6	434

*N.B. These values are highly speculative

CONCLUSIONS

1. Emissions from on-farm fuel use in CTF systems are approximately half those of random traffic zero tillage, and one third of those from stubble mulch systems.
2. Emissions related to herbicide and fertiliser manufacture appear to be 30 -- 40% greater from random traffic zero tillage than from CTF or stubble mulch systems.
3. Available evidence on soil emissions suggests that these should be very substantially smaller from CTF systems, but further research is needed.

To the extent that CTF allows cropping systems to more closely mimic the processes of natural vegetation that contributed to the greenhouse gas levels established prior to significant human influence, this is unsurprising.

REFERENCES

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