The Potential of Conservation Agriculture for the Clean Development Mechanism

Mr. JN Tullberg[1]

ABSTRACT

While reliable food production is important to humanity, the mechanization and intensification of traditional tillage-based systems has exacerbated major environmental problems because conventional tillage is a fossil-energy intensive process, which accelerates oxidation of soil organic matter. Conventional tillage buries residues which is the surface soil's natural protection against erosion by wind and water. Tillage and traffic cause subsurface degradation, reducing soil biological activity and promoting root zone water logging, which converts crop nutrients into nitrous oxide and methane -- both damaging greenhouse gases.

Conservation agriculture (CA) was originally developed to halt the soil erosion caused by traditional tillage-based agriculture (TA). . The first conservation agriculture (CA1) systems identified soil tillage as a major problem, and replaced this with herbicide and other weed control measures. Fuel energy requirements are substantially reduced in this system, but fertilizer and herbicide energy requirements could increase. A number of studies have demonstrated a relatively small or even negative reduction in overall fossil energy requirement of zero tillage CA1 systems as currently practiced in developed countries. .

Recent researches demonstrated that field traffic resulting from using farm equipment is responsible for important aspects of soil degradation, and for major 'system' effects. Second phase "CA2" conservation agriculture practices such as permanent bed minimum tillage and controlled traffic of farm equipment usage with modular wheel track and working widths to keep all heavy wheels on compacted permanent traffic lanes, could eliminate wheel-induced soil degradation from the crop zone. Field equipment works more efficiently on hard permanent lanes, which facilitate precise and timely operation, within a growing crop. In these systems, there is no requirement for tillage to repair compaction or level field surfaces.

The CA2 systems, which are relatively new, have been adopted rapidly in some areas, reducing fuel energy requirements and soil degradation, providing new options for weed control, facilitating double cropping and rotation, and eliminating the requirement to drill most fertilizer before or at planting. These new systems also improve soil aeration and reduce water logging in the seed/fertilizer placement zone. Waterlogged, anaerobic conditions reduce fertilizer efficiency, and promote gentrification and production of nitrous oxide - a potent greenhouse gas which is 310 times global warming potential of carbon dioxide.

---

[1] University of Queensland and CTF Solutions P/L

This paper provides evidence of these developments, together with information on the productivity and acceptability of CA2 systems in low-resource areas. It attempts to evaluate the comparative greenhouse impact of traditional, CA1, and CA2 cropping systems in China, and extrapolates on their impact elsewhere. It concludes with a brief discussion of the measures necessary to reduce greenhouse gas production and other modes of environmental degradation by encouraging the adoption of CA2.

The potential improvement in greenhouse gas emissions resulting from CA in northern China is summarized as follow.

Evidence of the reductions in fossil fuel use when CA is applied to cereal production is clear. If only field operations are considered, then fossil fuel use would be reduced by 43% and 80% with the adoption of CA1 and CA2 systems, respectively. Recent data on the energy requirements of herbicide manufacture are not available, but when the best estimates of herbicide energy are included, CA could be expected to reduce fossil fuel energy requirements by 24% and 67% for CA1 and CA2 systems, respectively, when compared with TA..

Evidence in relation to use of nitrogen fertilizer is more complex. Nitrogen fertilizer can often be the largest single energy input to crop production, but denitrification is responsible for wasting 20 to 60 per cent of this input. This is severe in waterlogged soil which occurs more commonly in the compacted root zone of CA1 systems. Root zone water logging is common when rainfall occurs after planting even in semi-arid environments, but its frequency and duration are substantially reduced in CA2 systems. Split fertilizer application, which increases fertilizer efficiency and reduces pollution by closer alignment of fertilizer supply with crop demand, is easier in CA2 systems.

Looking at the traditionally single-cropped dryland and limited irrigation cropping areas of northern China, it appears that the overall potential annual greenhouse impact of CA1 systems would be less than 2Mt carbon dioxide equivalent, while this value could approach 100 Mt carbon dioxide equivalent in permanent bed CA2 systems. These values are subject to one level of uncertainty related to uptake of CA2 technology. Adoption would occur only over a considerable period, but large farmer benefits would ensure a high level was achieved. The larger level of uncertainty relates to nitrous oxide emissions from denitrification of fertilizer – an area which could be explored by agricultural scientists.

There is good evidence that CA will arrest the tillage-induced decline in the soil organic matter levels, and improvements have been observed in many cases. The extent of this improvement, and its impact on atmospheric carbon dioxide levels have been widely debated, and are not considered here.

Further investigation of each of these impacts would be useful, but there is no doubt that wider adoption of CA would be an important benefit in terms of greenhouse gas production which has broader environmental effects.

The Clean Development Mechanism could be used to provide continuing support for research on CA, and more importantly, a vigorous programme of development and demonstration, aimed at the dryland grain production systems located largely in northern Asia.

1. INTRODUCTION

The association between cultivation (tillage) of the soil and conventional, traditional agriculture is well understood that the term ‘cultivation’ is commonly used as a synonym for ‘agriculture’. Conservation agriculture (CA) is the generic name for a set of farming practices designed to enhance the sustainability of food and fiber production by conserving soil, water and energy resources. Different labels have been used for different aspects of CA, usually emphasizing a specific difference between traditional or conventional agriculture.

CA attempts to move the crop production process closer to natural vegetation by maintaining soil cover with crops or plant residues; reducing mechanical soil disturbance by tillage; restricting in-field traffic to permanent wheel tracks; and by employing crop rotations or cover crops. In most parts of the world, CA is expected to use less fossil fuel, be more productive and sustainable, than traditional agriculture.

There is ample evidence of these improvements. This paper uses evidence from experimental work in low resource environments such as China and Pakistan. More detailed information is available from research in developed countries. Considering simple physical parameters, such as the percentage reduction in energy when zero-tillage planting replaces ploughing, this is likely to be valid in most environments.

Adoption of new and improved cropping systems will occur only if these are economically attractive and appropriate to the lifestyle of farmers. This paper concludes with information on this aspect, and a discussion of the steps necessary to promote widespread adoption of CA..

This paper covers:

1. Conservation agriculture (CA), its rationale and development
2. Technology and climate impacts on CA operation and effectiveness
3. Fossil fuel use in traditional and CA
4. Other greenhouse-gas implications of CA
5. Adoption of CA
6. CA effects on greenhouse gas emissions from North-Western China with estimates
7. CA - a major opportunity for the clean development mechanism
8. References, notes and appendices

2. CONSERVATION AGRICULTURE, ITS RATIONALE AND DEVELOPMENT

Crop establishment requires seed zone conditions facilitating seed uptake of moisture and air, and root zone conditions facilitating rapid growth as well as favorable soil surface conditions. However, good soil conditions for shoot emergence, minimizing competition and permitting effective planter operation are usually not present after a crop harvest, when weeds are often growing vigorously, crop residues are concentrated, and soil surfaces are rutted and compacted.

In traditional systems, a primary tillage operation (ploughing) is used to bury crop residues, level the surface, de-compact the upper root zone and control weeds. Shallower secondary tillage operations attempt to produce a fine tilth in the seed zone, while continuing to level the surface and control weeds. The planter's task is then to cut a seed trench of the right depth, meter seed into it, and ensure the return of covering soil. This is easily achieved given a soft, level soil surface, unhampered by crop residues.

Although the TA systems have large energy requirements, they remain productive in environments such as those in northern Europe, where soil erosion is uncommon, and yields are not normally moisture-limited. Tillage can also mix and incorporate fertilizers and animal manure, and provide a short-term yield benefit by promoting oxidation of organic matter. In drier, more erosion-prone environments, however, inversion of soil by tillage promotes unnecessary moisture loss, while burying the crop residues that should protect soil from erosion by wind or water and slow soil moisture loss after rain.

Residue retention is a priority of CA.

Practical CA started with the replacement of inverted (plough) tillage systems with non-inverting tillage. These "stubble mulch" systems were effective because surface residue volumes declined over time allowing planting to proceed with relatively conventional equipment. These also allowed farmers to gain experience with herbicides, and move toward "zero tillage" farming systems, reducing and sometimes eliminating regular tillage.

If tillage is to be eliminated while heavy wheel traffic uncontrolled, planting equipment must also be able to operate effectively in heavy residue on compacted, rutted and uneven surfaces. Each row unit must be able to cut through and/or displace residues from the planting row. It must provide an adequate soil condition in the seed zone, and ensure good seed/soil contact. Individual-row depth control is usually required, and the planter must have ample under-frame clearance so residues can pass through the machine.

Zero tillage planting equipment therefore tends to be larger, heavier and more expensive while harvester modifications are needed to provide more uniform distribution of residues. With inadequate equipment and systems, zero tillage has often been achieved only when the system is compromised by burning residues prior to planting. More commonly, one tillage operation is used when required for surface leveling and residue management.

In some areas, subsoiling is required regularly or occasionally to undo some of the effects of wheel compaction. These reduced or zero tillage cropping systems might be seen as the first phase of CA1.

Permanent bed controlled traffic minimum tillage systems might be seen as a second phase of CA2, overcoming the direct costs, subsurface degradation and system impacts of wheel ruts from random wheel traffic[2]. This system, known as 'controlled traffic farming (CTF) in the drier parts of Australia, or 'permanent raised beds' (PRB) in irrigation or high-rainfall areas requires a modular system of equipment wheel track and operating widths, and accurate guidance. Track widths of commonly available equipment dictate bed width, and these vary with region and technology levels. Values of 2 m-3 m are used in Australia, but bed widths of 0.6m – 1.5 m are more common in Pakistan, Mexico and China, where harvesting equipment often spans from 2 to 4 beds.[2]

Permanent raised beds were originally developed for furrow-irrigated cropping, but there are now many instances of permanent beds being used in dryland conditions, where beds are sometimes raised in relation to the permanently compacted traffic lanes which provide an equipment guidance system. The beds are higher than the traffic lane where they are used for irrigation or drainage. Non-wheeled soil of permanent beds have been shown to provide better aeration, greater rainfall infiltration rates and plant available water capacity. Equipment operation from firm, permanent traffic lanes improves timeliness and efficiency, while more precise guidance has facilitated zero tillage planting with simpler equipment and reduced herbicide costs.

The system aspect of permanent beds has been an important facilitator of 'opportunity cropping' where a greater range of crops is used to maximize soil moisture use via productive crops rather than via weeds or soil evaporation from fallow. The underlying theme is that it is better to plant crops when soil moisture is adequate for emergence and short term growth, because the cost of seed and planting is usually not significantly greater than that of physical or herbicide control of the weeds that would otherwise use that moisture. If useful rainfall subsequently occurs, fertilizers can be applied. In moisture deficient zones, opportunity cropping is a more economic variant of the cover cropping approach used in high rainfall zones, particularly South America.

Permanent wheel lanes are an essential component of CA2 conservation agriculture systems. In addition to reducing fuel energy requirements of all operations, they allow access to crops during the early growth stages, and provide a more precise relationship between the crop (or its standing residue), for planting, fertilizing or weed control devices. This enables valuable cropping system options such as inter row planting of the next crop, physical weed control and split fertilizer application. Each of these facilitates significant indirect pathways to reducing agricultural GHG emissions, in addition to other environmental and productivity benefits.

In developed countries, the cost of high-precision GPS guidance of farm equipment has reduced rapidly in recent years. This option is increasingly common, but wheels or skids can also be used to follow furrows or the edges of beds. This simpler technology can easily be applied to the small-scale equipment used in developing countries, and provide an equivalent level of guidance.

Objections to permanent traffic lanes systems are often based on the idea that a percentage (often about 20%) of field area is lost from production in non-planted permanent traffic lanes which often double as channels for irrigation or drainage. This ignores the fact that crop production is essentially related to sunlight, moisture and nutrients -- and these parameters are largely unaffected by permanent wheel lanes. In mechanized systems, permanent lane systems have usually demonstrated increased yield.

3. TECHNOLOGY AND CLIMATE IMPACTS ON CA OPERATION AND EFFECTIVENESS

In traditional animal powered rain-fed cropping, tillage was relatively shallow and residue burial often incomplete. Various forms of zone and strip tillage systems reflected the need to minimize

---

[2] For a general information/explanation of permanent raised bed cropping systems, see Roth et al. *Evaluation and performance of permanent raised bed in systems in Asia, Australia and Mexico*. For controlled traffic farming systems, see Tullberg et al. *On Track for Sustainable Cropping in Australia.* Although these systems are not generally well known or understood, they are successfully practised over large areas in Mexico and Australia respectively.

physical effort, ensuring that problems of soil erosion and degradation were not overwhelming. The demand for increased food production has subsequently led to intensification, and pushed cropping into more marginal areas. Development programs have encouraged mechanization usually providing small-scale, low-technology versions of European/North American tillage-based systems using mould board ploughs and rotary hoes. Soil degradation issues have often followed, and hence the concern with CA.

The principles of CA, particularly the retention of crop residues for soil surface protection apply equally to high- and low-technology systems. Originally conceived to protect soil from erosion, CA now also aims to conserve water and energy. Interest in CA has been growing in areas such as northern China, India, and Pakistan, initially under the label "conservation tillage”. This progressed towards zero tillage CA1 and permanent bed CA2 systems.

Published data on CA usually started with cooperative international projects. In most cases, the first step was importation of elements of CA equipment from developed nations, and setting up research and demonstration units to evaluate and extend the technology.

Initial results of CA1 were often disappointing in low-resource areas, but some researchers and farmers saw the potential value of these systems, despite immediate problems of yield loss, weed control and planter affordability Where combinations of individuals, communities and institutional support persisted, large-scale adoption sometimes occurred[3]. Farmers and researchers adapted and modified reduced/zero tillage equipment, experimented with herbicide weed control, and sometimes adopted permanent bed systems.

In the developed world, adoption of CA has been very slow in areas such as northern Europe and the north eastern United States, where surface residue which slows soil warming in the spring presents a greater problem to farmers than soil erosion. Adoption of CA was accelerated when large-scale soil erosion resulting from traditional agriculture was obvious to the whole community. Publicly-funded extension programmes and financial incentives encouraged change, particularly from bare fallow to some form of residue retention.

In Australia, this process took place largely in the 1970-1980s. During this time, most dryland farmers were attempting to maintain some crop or residue cover during the periods of maximum erosion hazard. The first step in conservation farming was to replace full-inversion tillage (ploughing) with minimum-inversion tillage, so that residue levels were progressively reduced allowing for planting with relatively conventional equipment. Subsequent development of CA1 systems saw herbicide progressively replacing most tillage operations, and planting equipment with increasing 'zero tillage' capability.

This process was driven partly by economics, as shown by cheaper herbicides and more expensive fuel, and partly by farmer’s understanding that soil moisture was the limiting resource, which is wasted when moist soil is exposed by tillage. Critical aspects were the development of confidence in herbicide selection and application through spray application technology, and the development of seeding systems which were a combination of residue management and seeder designs.

By 2000, most large Australian farmers could use herbicides effectively, had a planter with ‘zero tillage’ capability. They would claim this was their preferred system, saying that tillage was sometimes needed to level field surfaces and deal with harvester wheel ruts, handle major weed problems or reduce residue volumes. These are issues which can be managed effectively in CA2 permanent bed/controlled traffic systems because wheel rut problems are eliminated by restricting field traffic to hard permanent lanes. Permanent lanes also reduce major weed problems by allowing more timely spraying, while greater precision reduces residue problems by allowing planting between rows of standing residue.

Controlled traffic farming research in the United States and Europe dates back from the 1960s, and continued in Australia in the 1980s. Adoption of controlled farming on a practical scale started in Australia with a small number of enthusiasts usually cultivating less than 10,000 hectares. In the mid 1990s, action learning research/extension programmes encouraged large-scale adoption of controlled farming. The adoption of this second phase of CA2 has grown rapidly since then practiced by those cultivating about 2 Mha or greater than 15 per cent of Australian dryland farming[4]. CA2 systems in Australia are predominantly zero tillage, with soil disturbed only to the minimum extent necessary during the planting operations.

Adoption of CA2 cropping systems has been facilitated in Australia with the development of precision Global Positioning System (GPS) guidance for field equipment. Guidance systems have become steadily cheaper over the past five years, and current units are readily transferable from tractor to harvester to sprayer. A precision RTK GPS "autosteer" system capable of guiding equipment within 2 cm of its proper position. The 95 per cent savings in time now adds less than 25 per cent to the price of a medium tractor. Growers are saving more than even during the first year of ownership of the equipment simply from increased field efficiency.

Appropriate technology CA2 permanent bed minimum tillage has been in place on a small-scale for several years in research and demonstration projects in India, Pakistan and China[5]. The principles behind the technology are identical to those of high-technology systems. In this case, however, guidance is provided simply by furrows or wheel ruts. This allows more precise targeting of fertilizer, herbicide or mechanical weed control, and re-planting with simple equipment rapidly after harvest by drilling seed into the interrow spaces of the previous crop. Farmers can also use this precision technology to replace selective herbicide applications with physical control of inter-row weeds. Hence, the term, permanent bed minimum tillage).

Physical weed control options are particularly valuable in the low-technology environment where farmers are still learning the practice, advantages and problems of herbicide use. Physical control is most commonly a very shallow, precise, interrow tillage operation. When soil disturbance is non-inverting, and restricted to the dry surface layer, moisture loss is avoided, residue burial and erosion hazard is minimal, and the operation requires little energy.

Interestingly, there is also an increasing awareness of the potential value of physical weed control options in developed countries, where the development and spread of herbicide tolerant weeds represent a significant threat to reduced/zero tillage farming. It is interesting to note that serious problems with resistant weeds have occurred first in areas of Australia (and other developed countries) which were the first to adopt herbicides as their principal weed control measure. There is a growing conviction that occasional use of physical weed control measures might be the best way to extend the effective life of some of the most useful and economic herbicides.

3. FOSSIL FUEL REQUIREMENTS OF TRADITIONAL AND CONSERVATION AGRICULTURE

CA is still developing rapidly, and its productivity and sustainability continue to improve as farmers, the farm machinery industry and scientists focus on the issues and adaptations necessary for different environments. Conventional, tillage-based agriculture has many variants, and the same applies to CA. For the purpose of this report, three systems are considered, representing conventional traditional agricultural practice (TA), the first phase of reduced/zero tillage (CA1) and the second phase of permanent bed minimum tillage (CA2).

Fertilizers, particularly nitrogen, often represents the largest single energy input to crop production, exceeding that of machinery and herbicides by a factor of 2-3. The energy impact of increased nitrogen fertilizer requirements in zero tillage systems have been cited in a number of studies as the reason for the little impact of CA1 conservation agriculture on the overall energy requirements of food production and/or greenhouse gas emissions. Most reports confirm that more nitrogenous fertilizer is required, at least during the TA-CA1 changeover phase. A reduction in nitrogen requirement might be expected with increased nitrogen efficiency in CA2 systems.

Literature provides few valid comparisons between the fuel energy requirements of different units within one system, because research funding rarely allows direct measurement of implement energy input, and tractor fuel use measurements are suspected to be given the normal variation in fuel efficiency with engine loading. The approach taken here is to use the mean unit draft values set out in the American Society of Agricultural and Biological Engineers “Agricultural Machinery Management Data” as an unbiased estimate of implement energy input[6], together with reasonable assumptions regarding typical levels of tractive, transmission, engine and field efficiency.

The validity of this analysis clearly depends on these assumptions, so these are specified to provide transparency. The notes explain the rationale for some of these. Details of representative systems, assumptions, and calculations of their fossil fuel requirements are presented as an Excel spreadsheet in Appendix 1.

Field operations required by each system are summarized in Table 1, together with the outcome of calculations on fuel energy requirement. This fuel energy requirement includes an appropriate allowance for the "overhead" energy[7] used in equipment manufacture and maintenance.

This exercise aims to provide a reasonable assessment of comparative energy use. It would not be difficult to find examples of greater or smaller energy use than those set out here, but these values are based on published data, and correspond with the author’s experience working in China and Australia. The data used here are applicable to modern high-technology tractors and equipment. The small tractors used in low-technology agricultural systems are considerably less fuel efficient, so fuel use might be greater (and the advantage of CA systems correspondingly larger) than indicated here. Examples of the fuel/energy use values used by other authors are included in the appendix, for comparison.

Reduced/zero tillage agriculture usually substitutes herbicide application for fallow tillage operations. The energy requirement of herbicide application is small (1-1 l/ha) compared with tillage operations, but the energy value of the herbicide's constituents, and that required by the manufacturing/distribution process must also be accounted for. In some cases, this is highly significant (Table 1).

Table 1. Machinery Operations and Energy Requirements for Three Tillage Systems.

Operations	Residue Mgt	Tillage Frequency, Operations/crop			Herbicide Spraying	Planting	Σ Fuel Energy MJ/ha
Representative systems		Primary	Secondary	Seedbed			
TA Conventional tillage, no herbicide.		1	2	2	0	1	1941
CA1 Reduced/zero, < 1 tillage./crop	1	0.6	0	0	4	1	1116
CA2 Permanent bed minimum till.		0.25	0	0	3	1	397
(Tillage frequencies < 1 represent operations that do not occur every year)							

The statements of herbicide manufacturing energy set out in Table 2 for herbicides commonly in fallow situations are based on data from Zentner et. *al.* (2004)[7] and Green (1987) . The energy requirements of CA1 zero tillage seeding are greater, because the machine must does element of seedbed preparation in stronger soil.

Table 2. Energy Requirements of Herbicide Manufacture.

Commercial Product	Herbicide/s	Manufacturing Energy MJ/kg	Application rate kg/ha (label)	Manufacturing Energy MJ/l/ha
2,4-D Amine	2,4-D	98	0.500	49
Atrazine	Atrazine	190	0.500	95
SpraySeed 250	Diquat	400	0.115	108.1
	Paraquat	460	0.135	
Roundup CT	Glyphosate	511	0.450	229.95

In CA2, permanent bed minimum tillage field efficiency and tractive efficiency are greater because wheels operate on permanent compacted traffic lanes, and draft is significantly reduced by the absence of wheeling on permanent beds[9]. This also reduces timeliness constraints. More importantly, aeration, infiltration rate and the plant's available water capacity of non-wheeled soil is greater by a factor of almost 2.

Total fossil energy requirements must include energy inputs to the materials, production and distribution of the herbicide (manufacturing energy). A major difficulty here is that of deciding which herbicides would be used. Glyphosate is an attractive broad-spectrum herbicide, in view of its comparative effectiveness and safety, but it is also the most energy-intensive to manufacture. A breakthrough in manufacturing technology in 2002 was claimed to have reduced energy requirements (presumably to a value less than that quoted in Table 2). However, no quantitative information is available. 2, 4 D is effective only against broadleaf weeds. Atrazine is a selective, but persistent, soil-applied herbicide with high pollution potential, so it is unlikely to be recommended to inexperienced farmers. Paraquat and related products are very effective knockdown herbicides, but are unpleasant and potentially dangerous to operators.

CA1 has been shown to reduce the germination opportunities for weed seeds, and to reduce the weed seedbank. Some reduction in both fallow and in-crop herbicide requirements might be expected in the longer term, but this study assumes no net change in cropping phase herbicide inputs. Improved timeliness of spraying, planting, and harvesting operations in CA2 permanent bed systems has been found to reduce the opportunities for weed growth, and herbicide application requirements. In this study, one less spray application is assumed for CA2 systems.

Herbicide selection and application rate will clearly have a very large effect on the total energy requirement of minimum and permanent bed zero tillage systems of CA. When CA was first introduced, effectiveness and safety considerations might well ensure that glyphosate is the major herbicide used for fallow weed control. Farmers and their advisers will subsequently learn to use a larger range of herbicides and new system management techniques, to provide effective weed control with reduced herbicide costs (and energy inputs).

It appears that the energy requirement of herbicide manufacture will decline with improved production technique. Improved application efficiency will further reduce the net energy input per hectare. For the purposes of this analysis, a conservative mean value of 80 MJ/ha for herbicide weed control has been assumed. This is an arbitrary estimate, but appears to be a reasonable medium-term prospect, given improvements in herbicide manufacturing efficiency and on-farm application techniques. It is the value assumed in the summary of total fossil energy requirements set out in Table3.

Table 3. Machinery, Herbicide and Total Energy Requirements for Three Tillage Systems.

Operations / Representative Systems	Residue Mgmt	Tillage Frequency Primary	Secondary	Seedbed	Spraying	Planting	ΣHerbicide Energy MJ/ha	Σ Fuel Energy MJ/ha	Total Energy MJ/ha	Energy saving, % TA
TA Conventional till, no herbicide.		1	2	2	0	1	0	1941	1941	/
CA1 Reduced/zero, < 1 tillage./crop	1	0.6*	0	0	4	1	320	1116	1436	26
CA2 Permanent bed minimum till		0.25*	0	0	3	1	240	397	637	67

*Tillage frequencies < 1 represent operations occurring less than once each crop year, e.g., surface leveling, bedforming or subsoiling

This data demonstrates that CA can reduce the sum of field operations and herbicide energy by 26 per cent and 67 per cent for CA1 and CA2 systems, respectively, when compared with TA traditional, tillage-based farming systems. Due to the production of a given amount of food or fibre with permanent bed minimum tillage, CA entails the use of less equipment, and that equipment is used for fewer hours per hectare. A reduction of at least the same magnitude might be expected in the energy requirements of equipment manufacture.

The net energy value of most petroleum fuels is in the range 40 – 45 MJ/L, which allows for the calculation of a liquid fuel use equivalent to the total energy values shown Table 3. This assumes that values can also be applied to herbicide manufacture. The equivalent liquid fuel values can in turn be converted to a greenhouse impact statement because carbon dioxide and other greenhouse gas emissions resulting from the combustion of petroleum fuels is approximately 2.75 kg CO_2 per liter of fuel. [10].

The mean fossil impact of these systems can thus be estimated as:

TA Conventional tillage	total fossil fuel use – 48.5 L/ha	GHG emissions –133 kg CO_2 E per crop
CA1 Reduced/zero tillage	total fossil fuel use – 35.9 L/ha	GHG emissions – 98.7 kg CO_2 E per crop
CA2 Permanent bed minimum tillage use	total fossil fuel use -- 15.9 L/ha	GHG emissions – 43.8 kg CO_2 E per crop

Clearly, different assumptions could be used to produce substantially different answers. Assumptions and methodology behind this data are set out in the Excel spreadsheet together with this paper to facilitate the examination of other system options.

5. OTHER GREENHOUSE GAS IMPACTS OF CONSERVATION AGRICULTURE*

In addition to changing the fossil fuel requirements of cropping, changes in the crop production system might also be expected to impact soil emissions of nitrous oxide, methane, and carbon dioxide. These are important, because nitrous oxide has the greatest global warming potential among the naturally occurring greenhouse gases, specifically 310 times greater than CO_2. Methane is a product of anaerobic decomposition of soil organic matter. Carbon dioxide is produced directly by the oxidation of soil organic matter, and there is good evidence that its production is accelerated by tillage.

There is equally good evidence that reduced and zero tillage cropping systems will reduce or reverse the long-established decline in the organic matter content of cropping soils, which must involve an increase in net CO_2 absorption when compared with conventional tillage. This evidence is shown in the case of sub-tropical soils in which organic matter levels have been monitored from the date they were first converted from forestry or pasture to cropping.

Independent monitoring of soil organic matter demonstrated a statistically significant improvement of 0.3 per cent soil organic matter between TA tilled and CA2 plots after six years of permanent bed zero tillage[11]. The same work showed that population of earthworms, and soil biological activity in general increased by a factor of between two and four when CA2 permanent bed zero tillage cropping replaced traditional practice.

The more significant changes in greenhouse gas emissions is likely to occur as a result of improvements in nitrogen fertilizer efficiency, and reductions in nitrous oxide emissions brought about by two mechanisms:

a) Improved soil structure and greater porosity and permeability of seed zones and root zones in CA2 permanent bed minimum tillage CA will reduce the extent of waterlogging of the zone where seed and fertilizer reside, and thus reduce denitrification and nitrous oxide production.
b) The ability to access growing crops without damaging them, and precisely drill fertilizer in the interrows of narrow-spaced crops will greatly improve the alignment of fertilizer supply with crop demand. Split fertilizer application will reduce the current inefficient and greenhouse-unfriendly requirement to apply most fertilizer at or pre-planting, or post-planting surface broadcasting.

There is an extensive literature on nitrogen fertilizer dynamics and efficiency, the interpretation of which is better left to experts in this field. Some of the important ideas have been reported by Dalal et al. [12] and summarized by Eckard and Armstrong[13]. Nitrogen efficiency and denitrification are closely related to soil moisture status, and the residence time of some nitrogen fertilizers in the soil.

(a) Denitrification occurs rapidly when air-filled porosity of the soil is in particular ranges, and commonly those exceeding field capacity (i.e., at or approaching waterlogging) and results in greater production of nitrous oxide gas than the normal aerobic process. It is more common in modern agriculture than in natural systems, due to the combination of nitrogen fertilizers with cultural practices promoting waterlogging. The greenhouse gas dimensions can be illustrated when nitrogenous fertilizers are applied at a rate which optimize yield, where application rates are usually greater than 100 kg N/ha. Conversion of fertilizer N to plant available nitrate can occur via a number of complex bacterial pathways, which always involve some denitrification loss of N[14].

Denitrification commonly involves a loss of 20 to 60 per cent of applied nitrogen and this loss is significantly greater in compacted soils[15]. It is particularly severe in waterlogged soils, where a substantial proportion of N loss is emitted from soil as nitrous oxide (N_2O), and a potent greenhouse gas. Data on this topic is very limited, but it is reasonable to assume that 50 per cent of N lost is converted to nitrous oxide. With an application rate of 100 kg N/hectare and 40 per cent denitrification, this could account for 40 kg N/ha. Half of this (20 kg) might be converted to nitrous oxide.

Greater soil porosity reduces the frequency and duration of waterlogging, so CA1 permanent bed conservation agriculture might reduce denitrification by 50 per cent or by 10 kg N/ha. The atomic weight of nitrogen is 14, and oxygen 16, so when 10 kg of fertilizer nitrogen (N) is converted to N_2O, the N_2O emitted is 15.7 kg. The global warming potential of N_2O is 310 times more than that of the major greenhouse gas, carbon dioxide (CO_2), so 10 kg of N lost is equivalent to 4870 kg CO_2E.

Given these assumptions, permanent bed CA will reduce greenhouse gas emissions due to denitrification by almost 5000 kg/ha CO2E/crop. A brief survey of the literature on this topic suggested a unanimous view that nitrogen use efficiency was smaller, and denitrification greater in more compact, zero tilled soil. Unfortunately, there is little quantitative information, but even if the calculation here overestimates denitrification by a factor of 10, the greenhouse gas impact of the change in nitrous oxide emissions is still large compared with that of fossil fuel.

Impact calculations presented in Table 4 are based on arbitrary but reasonable assumptions that soil which is still compacted at planting time will produce 2000 kg/ha CO2E/crop greater emission. This is the likely outcome with both CA1 zero tillage and traditional tillage-based (TA) systems. In permanent bed CA2 systems, no fertilizer is applied to compacted soil. Thus, this can be regarded as the base line for comparison.

Table 4. Greenhouse Impact of Conservation Agriculture in Northern China.

			TA	CA1	CA2
Fossil fuel	kg/ha CO2E	Per crop	133	98.7	43.8
Emission reduction	"	"		34.3	89.2
Nitrous oxide	"	"	2000	2000	0
Emission reduction	"	"		0	2000
Total Impact/ha	"	"	0	34.3	2089.2
Single dryland crop Mha		33			
Annual emission		Mt CO2E	0.0	1.1	68.9
Potential double crop* Mha		7			
Annual emission		Mt CO2E	0.0	0.5	21.9
Total annual impact		Mt CO2E	0	1.6	90.9
*with limited irrigation		Cropping	Single	X 1.5	Double

Denitrification represents a greenhouse gas problem, while loss as a nitrate solution in runoff or deep percolation represents a pollution threat to watercourse or underground water supplies. This loss of fertilizer also represents substantial economic cost to the farmer. CA2 systems should reduce this loss through two mechanisms: reducing compaction and waterlogging of the seed zone, and facilitating spatial and temporal fertilizing to correspond more closely with crop needs (i.e., split applications, rather than all at planting time).

Methane, a product of anaerobic decomposition of soil organic matter, can also be a very significant greenhouse gas which is 21 times greater than CO_2. The increased organic matter levels in CA could promote methane production, but this should be more than balanced by the lower frequency and duration of anaerobic conditions.

(b) Split fertilizer application will provide better alignment between fertilizer inputs and crop requirements, and thus reduce the time in which excess nitrogen is available for denitrification or loss by deep percolation. It is rare at present because fertilizer application post-planting is expensive (foliar application) or extremely inefficient (surface broadcasting). In CA2 systems, precision interrow fertilizer drilling will overcome these problems.

6. ADOPTION OF CONSERVATION AGRICULTURE

The idea of conservation agriculture (CA) is simple so farmers' reluctance to change has often surprised scientists and administrators. Farmers everywhere are cautious about change, and CA requires radical change in thinking, and in most aspects of farming practice. New systems bring new challenges, often related to highly practical, but unforeseen aspects of equipment operation. When immediate solutions are not available, yield loss is likely. and this is very common in the first year of CA.

Some aspects of CA were widely adopted in the drier areas of developed nations such as Australia, and western North America from the 1950s onwards. CA1 stubble mulching occurred from the 1940s to the 80s, driven initially by the need to reduce soil erosion, and subsequently by a combination of increasing fuel costs and reducing herbicide costs. From the 1990s, CA2 permanent bed controlled traffic systems in Australia have been driven by the recognition of the system's impacts of wheel damage to the soil.

It is important to recognize the substantial grass-roots learning process that is an essential component of CA. The selection and use of herbicides can be supported by training. Other aspects are more subtle, and depend on individual observation and learning. These include a number of important practical issues – for example, residue management, and recognition of system advantages, such as the potential for opportunity cropping and changes in the weed spectrum.

Wide variations occur within and between regions and industries. In Australia, some form of CA is practiced in most extensive grain production, with herbicide progressively replacing stubble-mulch tillage. Most grain farmers now prefer to avoid tillage, except when dealing with harvester ruts, or difficult situations with weeds or residue. A growing number (>15 per cent) are using controlled traffic zero tillage permanent bed systems. This 15 per cent includes a high proportion of the large, technologically-aware leading farmers, in addition to the early adopters. Agricultural extension and consulting communities has started to understand that CA 2 systems will be a prerequisite of productive and sustainable cropping.

CA2 systems have been adopted more rapidly in Australia than the USA or northern Europe. This has occurred without significant support from government extension organizations -- perhaps because the farmer benefits are clearer in a more severe, moisture-limited environment. In the absence of production subsidies, the improved economics of CA also increase the incentive for change.

In low resource areas such as northern China, India, Pakistan and northeast Russia, interest in CA generally started only after mechanization, often with cooperative international projects. In many cases, the first step was importation of elements of CA1 conservation agriculture equipment from developed nations, and setting up research and demonstration units to evaluate and extend the technology. Initial results of this first phase were disappointing unless people persisted in learning and adapting the new system.

CA2 permanent bed minimum tillage agriculture has been in place on a small scale for some time with research and demonstration projects in India, Pakistan and China. These systems have increased productivity, while reducing soil loss and degradation, capital equipment requirements and energy input. They provide an easier approach to zero-tillage CA, by facilitating a precise, shallow minimum tillage weed control option. This is important in reducing the barrier to adoption presented by a total dependence on herbicides.

There is clearly great potential for the adoption of CE 2 systems in developing nations, and particularly in the more arid low-resource areas of North Asia. CE 2 systems will enhance productivity while meeting the growing community demand for environmental protection. North China, Mongolia, and Eastern Russia all present opportunities for this technology.

7. CONSERVATION AGRICULTURE EFFECTS ON GREENHOUSE GAS EMISSIONS FROM NORTH –WESTERN CHINA

The experience of North China was used as an example in this paper because of the availability of data on dryland single cropping (33 Mha) and single cropping with limited irrigation (7Mha). These values were provided by Prof Li Hongwen of the Conservation Farming Centre of the China Agricultural University, Beijing (E Campus).

Estimates of total gross impact are necessarily crude multiplications of available area and impact per hectare. It is assumed that most of the single crop area will be restricted by rainfall limitations, but CA does improve water use efficiency and the potential for double cropping, particularly when growers take advantage of the timeliness of the benefits of CA2 systems. It has been assumed that the area currently under single cropping with limited irrigation has the potential of 1.5 crops per year under CA1, and two crops per year under CA2.

As noted earlier, the fossil fuel outcome is based on reliable field data and published information on herbicides, and is certainly achievable, but this represents roughly 10 per cent of the mean effect presented here. On the basis of data currently available, it would be possible to argue that the nitrous oxide emission outcomes for CA should be three times greater, or three times smaller than those quoted in this paper.

8. CONSERVATION AGRICULTURE – A MAJOR OPPORTUNITY FOR THE CLEAN WATER DEVELOPMENT MECHANISM

Adoption of CA has been slow even in developed nations with good agricultural extension services and well-educated farmers. Significant efforts will be needed to foster the adoption of CA in low-resource areas. This has the potential to provide large, long-term positive environmental effects, but it will require long-term investments in research, development, demonstration and extension to farmers, their suppliers and information networks.

CA2 conservation agriculture will provide significant reductions in GHG emissions via reduced mechanical energy inputs. Research demonstrating the mechanisms of large GHG emission reductions as a result of improved nitrogen fertilizer efficiency is already available, but has not yet been brought together to demonstrate the integrated effect of CA2 systems. Some of the initial research requirement may usefully be carried out in developed nations, particularly in relation to CA impact on waterlogging and split fertilizer application, and the consequent effects on nitrogen use efficiency, nitrous oxide and methane emissions. Involvement of developing nation scientists in this work would be critical.

Most research activity should be carried out within the target areas, aligned with simultaneous machinery development and technology extension programme appropriate to the local scale and technology level, assisted by cooperative international research, development and demonstration projects.

One major objective of this research programme would be to provide locally-relevant information to support adoption. A second major objective should be to develop a group of broadly-trained field agronomists and mechanization specialists to be the core of an ongoing demonstration and extension programme. This could be built around the loan of small-scale equipment allowing local farmers to operate demonstration/extension sites, monitor inputs and outputs, and build their confidence in this technology.

9. REFERENCES, NOTES, AND APPENDIX

1. See for instance Wylie, P. 1994, Profitable and Sustainable Farming Systems in the North East Cereal Belt of Australia, Agricultural Science, 7:43 – 47. Also Baker, C.J. et al. No-tillage Seeding: Science and Practice, Wallingford, England: CAB International, 1996.
2. See for instance Tullberg, J. N., Yule, D. F. and McGarry, D 2003, On Track to Sustainable Cropping Systems in Australia, Proceedings ISTRO 16, University of Queensland, Brisbane. Also Sayre, K., Limon, A. and Govaerts, B., 2005, Experiences with Permanent Bed Planting Systems. ACIAR Workshop on Evaluation and Performance of Permanent Raised Bed Systems in Asia and Australia, CSIRO Land and Water, Griffith, New South Wales.
3. Vere, D. 2005. Research into Conservation Tillage for Dryland Cropping in Australia and China. Impact Assessment Areas Number 33, Australian Centre for International Agricultural Research, Canberra.
4. See Proceedings of The Second and Third Australian Controlled Traffic Farming Conferences, University of Queensland, Gatton, 1988 and 2005. Also Grains Research and Development Corporation Survey Results on Equipment Used for Precision Agriculture in 2003-04, Section 4.7. This suggests that 26 per cent of Australian farmers have GPS autosteer and matched wheel tracks. GRDC Website Research Summaries.
5. See for instance Connor,D.J. et al Bed Planting in Wheat and Rice Systems, (and several other papers) in Addressing Resource Conservation Issues in Rice-Wheat Systems of South Asia. RWC-CIMMYT, New Delhi, India.
6. Agricultural Machinery Management Data D497.4 American Society of Agricultural and Biological Engineers Standards Manual 2005, ASABE, St Joseph, Michigan.
7. Zentner,R.P. et al. 2004, Effects of Tillage Method and Crop Rotation on Non-Renewable Energy Use Efficiency in the Canadian Prairies. Soil and Tillage Research 77; 125 – 136.
8. Green,M.B. 1987, Energy in Pesticide Manufacture, Distribution and Use in Stout, B.A. Energy in Plant Nutrition and Pest Control, Elsevier, Amsterdam.
9. Tullberg, JN 2000, Wheel Traffic Effects on Tillage Draft. J Agric. Eng. Res. 75, 375 – 372
10. Guidelines for Calculating Greenhouse Gas Emissions, Australian Greenhouse Office, Canberra.
11. Pangnakorn,U. George, D.L., Tullberg, J.N. and Gupta, M.L. Effect of Tillage and Traffic on Earthworm Populations in a Vertosol in South-East Queensland. Proceedings ISTRO 16, University of Queensland, Brisbane.
12. Dalal, Ram C, Wang, W, Robertson, G Pand Parton, WJ. (2003). Nitrous Oxide Emissions from Australian Agricultural Lands and Mitigation Options: A Review. Australian Journal of Soil Research, 41, 165 – 195.
13. Eckard, R and Armstrong, R. (2005). Best Management Practice Guidelines for Minimizing Nitrous Oxide Emissions from Pasture and Cropping Systems. Department of Primary Industries, Victoria.
14. Prasertsak, P., Freney, J.R., Saffigna,P.G., Denmead, O.T. and Prove, B.G. 2001. Fate of Urea Nitrogen Applied to a Banana Crop in the Wet Tropics of Queensland. Nutrient Cycling in

Agroecosystems, 59: 65-71;l Also see_ Prasertsak,P.,Freney,J.R.,Denmead,O.T. Saffigna, P.G. and Prove, B.G. 2001. Significance of Gaseous Nitrogen Loss from a Tropical Dairy Pasture Fertilized with Urea. Australian Journal Of Experimental Agriculture, 41:625-632; and Prasertsak,P., Freney, J.R., Denmead, O.T. Saffigna P,G., Prove, B.G. and Reghenzani, J.R. 2002. Effect of Fertilizer Placement on Nitrogen Loss from Sugarcane in Tropical Queensland. Nutrient Cycling in Agroecosystems, 62:229-239.

15. Denitrification of Fertilizer and Nitrous Oxide Production: see Hilton, B.R., P.E. Fixen, and H.J. Woodward. 1994. Effects of Tillage, Nitrogen Placement, and Wheel Compaction on Denitrification Rates in the Corn Cycle of a Corn-Oats Rotation. J. Plant Nutr. 17:1341-1357. Aulakh, M.S., D.A. Rennie, and E.A. Paul. 1982. Gaseous Nitrogen Losses from Cropped and Summer Fallowed Soils. Can. J. Soil Sci. 62:187-195.

Appendix 1. Fuel and Herbicide Requirements of Cropping Operations.

Traditional tillage

		Residue management		Tillage-primary		Tillage-secondary			Sprayin
Fine soils		Chopping	Subsoiling	Mouldboard	Chisel	Chisel	Disc	Harrow	
	Depth cm			15	12	10	8	5	
Frequency	Ops/crop			1		1	1	2	
Unit Draft	kN/m			10.0	6.0	5.0	4.0	2.5	
Drawbar energy	MJ/ha			100.0	60.0	50.0	40.0	25.0	
Tractive efficiency	%			75.0	75.0	70.0	70.0	70.0	
Axle energy	MJ/ha			133.3	80.0	71.4	57.1	35.7	
Transmission efficiency	%			85.0	85.0	86.0	87.0	88.0	
Engine output	MJ/ha			156.9	94.1	83.1	65.7	40.6	
Engine efficiency	%			30.0	30.0	31.0	32.0	33.0	
Energy input	MJ/ha			522.9	313.7	267.9	205.3	123.0	
Energy "overhead"	%			15	15	15	15	15	
Field efficiency	%			80.0	80.0	80.0	80.0	80.0	
Total energy	MJ/ha			751.6	451.0	385.1	295.1	176.8	
Fuel requirement	L/ha			18.8	11.3	9.6	7.4	4.4	

Grand totals **Energy Fuel**

Reduced/zero tillage

		Residue management		Tillage-primary		Tillage-secondary			Sprayin A
		Chopping A	Subsoiling	Mouldboard	Chisel	Chisel	Disc	Harrow	
Fuel use	l/ha	4							1.5
Tillage depth	mm		30	15	12	10	8	5	
Frequency	Ops/crop	1	0.2		0.4				3
Unit draft	kN/m		16.0	10.0	6.0	5.0	4.0	2.5	
Drawbar energy	MJ/ha		160.0	100.0	60.0	50.0	40.0	25.0	
Tractive efficiency	%		75.0	75.0	75.0	75.0	75.0	75.0	
Axle energy	MJ/ha		213.3	133.3	80.0	66.7	53.3	33.3	
Transmission efficiency	%		84.0	85.0	85.0	86.0	87.0	88.0	
Engine output	MJ/ha		254.0	156.9	94.1	77.5	61.3	37.9	
Engine	%		29.0	30.0	30.0	31.0	32.0	33.0	

efficiency									
Energy input	MJ/ha		875.8	522.9	313.7	250.1	191.6	114.8	
Energy “Overhead”	%		15	15	15	15	15	15	30
Field efficiency	%		80.0	80.0	80.0	80.0	80.0	80.0	
Total energy	MJ/ha	160	1258.9	751.6	451.0	359.5	275.4	165.0	78.0
Fuel requirement	L/ha	4.0	31.5	18.8	11.3	9.0	6.9	4.1	2.0
						Grand totals			**Energy** **Fuel**

Permanent bed minimum/zero tillage

		Residue management		Tillage-primary		Tillage-secondary			Sprayin A
		Chopping	Bedforming	Mouldboard	Chisel	Chisel	Disc	Harrow	
Fuel use	l/ha								1
Tillage depth	mm		30	15	12	10	8	5	
Frequency	Ops/crop	0	0.25	0	0	0	0	0	3
Unit draft	kN/m		7.0	10.0	6.0	5.0	4.0	2.5	
Drawbar energy	MJ/ha		70.0	100.0	60.0	50.0	40.0	25.0	
Tractive efficiency B	%		80.0	80.0	80.0	80.0	80.0	80.0	
Axle energy	MJ/ha		87.5	125.0	75.0	62.5	50.0	31.3	
Transmission efficiency	%		84.0	85.0	85.0	86.0	87.0	88.0	
Engine output	MJ/ha		104.2	147.1	88.2	72.7	57.5	35.5	
Engine efficiency	%		29.0	30.0	30.0	31.0	32.0	33.0	
Energy input	MJ/ha		359.2	490.2	294.1	234.4	179.6	107.6	
Energy “overhead”	%		15	15	15	15	15	15	30
Field efficiency B	%		85.0	85.0	85.0	85.0	85.0	85.0	
Total energy	MJ/ha		486.0	663.2	397.9	317.2	243.0	145.6	52.0
Fuel requirement	L/ha		14.3	19.6	11.7	9.4	7.2	4.3	1.0
						Grand totals			**Energy** **Fuel**

Process: Unit draft is a direct measure of mechanical energy input to the soil by draft implements, easily converted to energy/ha.

Tractive efficiency, transmission efficiency, and engine efficiency are used to calculate total engine energy requirement.

Field efficiency and energy overhead account for additional losses, and energy for equipment manufacture, respectively.

Fuel requirement per operation calculated as total energy/40 (approximate fuel net energy -- MJ/L)

Grand total energy (MJ/ha) and fuel(L/ha) take account of the frequency of that operation (number of times per crop)

Notes

A Chopping and spraying are both quoted as simple mean fuel requirement/ha from survey data

B Tractive efficiency and field efficiency improved by at least 5 per cent in permanent bed systems.

Miscellaneous data

1 L Diesel fuel = 2.75 kg CO^2 equivalent (Australian greenhouse office)

Fuel consumption, direct and overhead energy values for various tillage implements, Lobb D (1989)

Implement	**Fuel consumption**[1] (1/ha)	**Operating energy** [2](MJ/ha)	**Overhead energy**[3](MJ/ha)	**Total energy** (MJ/ha)
Mouldboard plough	12.35	557.1	66.8	624.0
Chisel plough	9.21	415.5	49.9	465.4
Disk harrow	6.51	293.7	35.2	328.9
Cultivator	4.04	182.2	21.9	204.1
Inter-row cultivator	3.59	161.9	19.4	181.3
Rotary hoe (non-powered)	2.90	130.8	18.3	149.1

Adapted from Lobb 1989, cited 17.

[1] Equivalent fuel energy expressed as fuel consumption per ha

[2] Energy value expressed as the fuel energy required to perform each operation.

Mean fuel consumption of tillage operations, Queensland Department of Primary Industries (2004)

Subsoiler 20cm	24.1 L/ha
Chisel plough	9.8
Bed former	8.6
Offset disc	9.6)
Planter (zero till or conventional).	6.1)
Sprayer	1.4