Agricultural Machinery: Problems and Potential

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Mechanisation of agriculture is fundamental to reducing poverty and improving lifestyle and food security in the developing world. Large populations are escaping subsistence agriculture, and there is a broad consensus that conservation agriculture (CA) is the only sustainable approach to cropping. Equipment for CA could be a major focus of R&D activity by the global farm machinery industry, but this is not happening.

Land preparation, seeding and harvesting units are the machine tools of agriculture, and must fit production systems. Tillage might be unnecessary, but tractor tillage-based systems have been the basis of the farm machinery industry. Conservation agriculture still lacks seeding equipment that is effective over a broad range of conditions, and machine-width variability of soil and residues is a fundamental problem.

Precision guidance and compatibility with permanent raised-bed and controlled-traffic cropping systems should represent major opportunities, but are not attractive commercial R&D investment propositions for the farm machinery industry. While industry and farmers will enjoy significant benefits from the adoption of CA, the community will be the major single beneficiary, via the reduced environmental footprint of a crop production system which is essential for food security.

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Introduction

Release from subsistence agriculture has led to a better life for most people, and the mechanisation of agriculture has been a key element in this process. Mechanisation can involve simple devices to improve the effectiveness of muscle power, but more commonly entails the use of internal combustion engines.

The continuous power output of most human beings is less than 0.1 kW, so for tasks where output is directly proportional to power, a person's output can be increased by a factor of ~10, ~100 or ~1000 respectively, if they are controlling an animal, a small power tiller or a medium-sized tractor. Output is clearly proportional to power for tasks like tillage, so available power in kilowatts per hectare was a reasonable index of agricultural development when tillage was a critical operation.

Mechanisation has been inextricably linked to increased power levels, and this was the basis for a prosperous and expanding farm machinery industry until 25 years ago in the developed world. The same process is occurring now in the developing world, where many people see the benefits of emulating this model, where mechanisation appears to speed up traditional practices and the popular television image of Western agriculture is still a large tractor and plough.

It is useful to list the traditional functions of tillage, which effectively summarise the advantage of conventional systems from a farm machinery industry perspective. Tillage systems ensure the use of:

- a standard base unit (the tractor, designed for drawbar tillage) for most tasks
- a small number of standard attachments (ploughs, cultivators, etc.) for land preparation
- a limited number of simple and standard items of seeding equipment.

Simple seeding equipment is possible only because tillage provides a fine, level unobstructed field surface, a real advantage for organisations that want to supply a full set of reliable and efficient equipment for all aspects of crop production. Tillage-based systems still dominate the thinking of most farmers in cool humid areas of northern Europe and in horticultural production, worldwide.

Tillage is demonstrably unsustainable and unnecessary, but its damaging consequences are much more obvious in erosion-prone environments. In these areas the principles of conservation agriculture (CA) (permanent soil cover, minimum soil disturbance, rotation) have been widely accepted by the scientific and farm advisory community. Farmers in erosion-prone areas also understand the sustainability benefits of CA, but the practicalities of seeding without prior tillage present a major challenge.

Conservation agriculture reduces the need for power for tillage, so hand-operated systems (dibble seeders and knapsacks sprayers) and attachments for animal-drawn equipment might be viable in some environments. Most attention has nevertheless focused on engine-powered equipment.

Wide adoption of CA depends on the availability of appropriate equipment, and local champions play a major role in encouraging adoption. Machinery manufacturers have dealer networks with the motivation and ability to champion adoption, so are well placed to play an important role in this process (the importance of which was demonstrated in the adoption of laser levelling, by J.F. Rickman, IRRI, Maputo Mozambique, pers. comm., 2009). If major manufacturers saw CA as a significant opportunity, adoption would be much more rapid.

Commercial organisations are driven by markets, and from the manufacturer's perspective CA reduces the market for tractor power, eliminates the market for tillage, and complicates the market for seeding equipment. Machinery manufacturers recognise that their prosperity ultimately depends on farmers' prosperity, and have modified products to meet the new demands of CA, but enthusiasm is limited for a system that will damage much of their current market.

R&D investment in CA equipment is clearly needed. Development of a new, universally applicable system for CA seeding would be a major advance, but dramatic breakthroughs are not expected by those familiar with the topic. Disincentives to commercial R&D investment include the difficulty of effective IP protection on agricultural equipment, and the fact that improvements in CA seeding are unlikely to be dependent on machinery innovation alone.

In CA, the machine × system interaction is paramount, so effective machinery R&D must work in tandem with agricultural system R&D. Discussion of current issues is the starting point for speculation about R&D opportunities for CA equipment. Consideration of the beneficiaries of such development suggests the appropriate funding sources for such work.

CA machinery — current issues

Weed control is different in the absence of tillage, but most problems can be solved by a combination of agronomic and herbicide measures. Weed management generally becomes easier with less soil disturbance to stimulate germination, so the major mechanisation issue of CA is generally acknowledged to be seeding.

Without prior tillage, CA seeders must prepare a suitable environment for the seed, then place, cover and firm it in the soil in a single pass. Major challenges include effective control of placement depth beneath uneven surfaces with varying levels of soil compaction, and handling (avoiding, moving or cutting through) surface residue. Fertiliser placement at seeding further complicates the issue.

Researchers and development projects often provide the lead, but most commercial development has been carried out by individuals or small groups on small budgets, observing field operations with several generations of prototype, modifying, improving and retesting. Perhaps this is why most commercial CA no-till seeding units have been developed by small–medium-sized companies, and their success has occurred within limited geographical areas.

The defining characteristic of CA seeding is the complex set of interactions between seeding machine components (residue handling, seed and fertiliser placement control, covering, firming), and elements of the operating environment (soil and residues — both highly variable and highly moisture-dependent). Specifying uniform terminology for the components and describing some general characteristics of this interaction is itself a substantial task (Murray *et al.* 2006).

Seeding involves the placement of seed and fertiliser (perhaps 10 and 20 g m^{-2} respectively), effectively spaced at uniform depth (perhaps 5 cm), and no-till seeders based on tines, disks and dibblers have all shown promise in some conditions. The seed placement unit or 'opener' is the critical component. As a broad generalisation, tines cause excessive soil disturbance, disks need excessive weight for penetration and dibblers are too complex. No one opener type has proved successful under all conditions.

When soils have been managed in CA for some time they are usually softer after harvest (except for those areas wheeled by the harvester). In principle at least, the power required for no-till seeding in soft soil is small, so CA is particularly appropriate for the developing world. There are many examples of relatively small, light-weight CA seeders, usually based on tine-type openers. Individual opener depth control is unnecessary in units of small width, but residue chopping is sometimes necessary to reduce residue length and prevent blockages. Light surface tillage is sometimes used for the same purpose.

Australian CA equipment is generally built for extensive agriculture, so machine widths are large. In contrast to the light units of the developing world, most successful no-till seeders in Australia are very heavy (Ashworth *et al.* 2010). This is partly a reflection of the trend to use disk openers to minimise soil and residue disturbance, but something appears to be wrong when equipment for no-till CA is stronger and heavier than the chisel ploughs it replaced.

The underlying problem is one of variability in soil conditions within one machine width. No-till seeders units must be able to work successfully in soil which is soft and friable, but they must work equally well in that 20% of machine width where the soil is hard, having been wheeled by a >20-t harvester, in the 5% of width wheeled by sprayers and handling equipment, or in the 20–30% wheeled by the tractor and seed handling and distribution system.

Hard soil can occur at any point across the width of the machine, so every opener unit must carry adequate weight to penetrate the hardest soil. Where the weight is not needed for penetration (across 40–60% of machine width) it must be carried by opener depth control wheels. These small wheels can require a draft force of 20–30% of weight to roll over soft soil, demanding great frame strength and tractive power.

Residue handling is the other major issue for no-till seeders. In very heavy residues (maize or rice) there might sometimes be no alternative to the use of power to chop, distribute or otherwise encourage residue to pass the openers without obstruction (Blackwell 2002). In many cereal crops, serious problems occur only when the harvester concentrates residue. If residue passing through the harvester is distributed evenly, the remaining residue, anchored and standing in rows, rarely presents any obstruction to an opener passing between the rows. The exception is where residue has been flattened during harvesting.

Machine-width soil variability is the product of wheel impacts. Residue issues are a consequence of concentration or re-orientation during harvest, at least for an opener seeding in the interrow. The fundamental point is that most of the problems of no-till seeding are not inherent in the situation: they are artefacts of management — specifically they are the product of imprecise machinery operations.

CA equipment — opportunities

The farm machinery industry will find new opportunities in improved harvesting systems, from agronomic developments in rice production, and from increasing mechanisation levels in vegetable production. In most crop production systems, however, the major opportunities will be those related to some aspect of precision. This will include the mapping and response to macro-scale variability — the focus of current 'precision agriculture' — and the use of weed-sensing and similar technologies. Much greater opportunities will come from the response to machine-scale variability.

Machine-scale soil variability can be managed by using precise guidance to restrict the wheels of all cropping equipment to permanent traffic lanes. With precise guidance, most crops can be interrow seeded, avoiding most residue handling problems. With this level of precision, weed management can be improved by restricting herbicide application to the row or interrow zone where it is needed, reducing off-target application. Productivity and sustainability improve substantially when a large proportion of the field area is uncompromised by wheel compaction effects in permanent raised bed (Roth *et al.* 2005) or controlled traffic farming (Tullberg *et al.* 2007).

Some benefits of precision will be available only in sophisticated systems, but a high level of precision can be achieved with permanent raised beds, particularly if machinery is designed for this purpose. In these low-cost systems permanent beds are defined by traffic lanes—permanent wheel ruts in furrows. Limited soil movement for bed rejuvenation can provide some weed control, which can be useful in environments where herbicide knowledge is poor. With greater investment, precision GPS guidance can be used to achieve the same advantages 'on the flat' in controlled-traffic farming. Permanent raised beds and controlled traffic both restrict all heavy load-bearing wheels to narrow permanent traffic lanes, where compaction and surface hardness make transport and traction operations more efficient.

Guidance precision is already adequate in small-scale mechanised CA, where the crop, residue and machine component can be seen by the operator in permanent bed systems. These systems allow low-cost mechanisation using single-axle power tillers modified for no-till CA seeding (J. Esdaile, No-till agriculture consultant, Tamworth, pers. comm., 2009). Sophisticated GPS guidance becomes essential with large-scale CA, but 2-cm precision guidance (autosteer) is already available at a cost <15% of tractor price. With GPS technology already incorporated in some mobile phones, low-cost precision guidance can be expected in the next few years, and could be readily incorporated into small-scale equipment.

A recommendation that we should deliberately drive heavy vehicles over all our cropping areas before planting would be laughable — until we note this is a close approximation of current practice. The impact is most obvious with large tractors and harvesters, but it also occurs with small machines. The problem has arisen because compatibility between machine track, tyre and working widths has been seen as 'too difficult'— but it is simply an issue of products currently on the market.

The farm machinery industry can make a major contribution to CA systems by producing equipment that is compatible with permanent raised-bed and controlled-traffic systems. For most practical purposes this is a matter of track width adjustability, narrower tyre options and a range of working widths. Agreed sets of standard track, tyre and operating widths would be a major advantage. This substitution of precise crop management for overall tillage would represent a radical change of focus for an industry organised to produce equipment often characterised by its size and weight.

CA equipment R&D — beneficiaries

Farmers

The steady accumulation of economic and production data leaves little room for doubt that farmers will be beneficiaries of a change to CA. It is nevertheless true that adoption is not a straightforward process, and farmers have sometimes been defeated by the difficulties of seeding or weed control in a new system. One tale of economic woe is always repeated many more times than a dozen success stories, so CA adoption rates are still too low. Too few farmers see themselves as beneficiaries of CA, particularly in the developing world.

Manufacturers

Manufacturers respond to markets, and current requirements for CA equipment — largely seeders — are too imprecise and uncertain for the major manufacturers. These markets are attractive to small-scale regional manufacturers, who produce most currently available CA seeders, but the issues of precision and compatibility with permanent traffic lanes are related to tractors and harvesters — products of the major manufacturers.

The large farm machinery companies are working to ensure that their products are readily compatible with precision guidance, but for a global manufacturer, the issues of track, tyre and operating width compatibility are extremely complex and influenced by factors such as road traffic regulations. The bigger companies have considered the issue, but change has been limited to acceptance of local modifications of their products. Manufacturers will not move without a market, and farmers cannot demonstrate a market until equipment is available — the traditional chicken and egg situation.

Community and environment

No-till CA — particularly when combined with permanent raised bed or controlled-traffic farming — will reduce the environmental footprint of agriculture, and improve food security. In the most general terms:

- Stopping tillage reduces energy requirements, and combining this with controlled traffic reduces tractor power and cropping fuel requirements dramatically. Less energy means less atmospheric pollution.
- Stopping tillage will reduce runoff and erosion. Combining this with controlled traffic produces a much larger effect. Less water running off cropped soil means less erosion, sediment, nutrients and pesticides in watercourses and water supplies.
- Controlled traffic no-till greatly improves soil porosity and internal drainage, which should substantially reduce soil emissions of nitrous oxide (a potent greenhouse gas).
- Greater precision improves the spatial placement of fertiliser and pesticides. Working from permanent traffic lanes in controlled-traffic or raised-bed systems also enhances farmers' capacity to apply fertiliser and pesticides at the optimum time to match crop requirements. The outcome is reduced loss and environmental pollution.

The overall environmental impact of different mechanised cropping systems is illustrated in Figure 1 in terms of greenhouse gas emissions due to energy in fuel, herbicides and fertilisers, and the effect on soil emissions. The magnitude of some of these effects might be arguable, but there would be little dispute about the overall trend: as we disturb the soil less by tillage and compaction, we improve productivity and the use efficiency for all inputs, and reduce the environmental footprint.

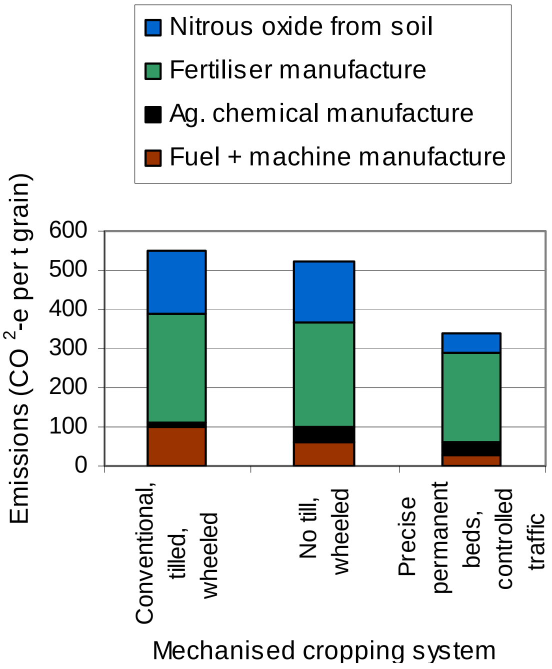

Figure 1. Carbon dioxide equivalent emissions from conventional tillage, simple no-till and precise no-till cropping systems

Emissions illustrated here are broadly representative of those from rainfed grain production, but they vary greatly with crop, soil, fertiliser regime and system. Life-cycle emissions from fuel, agricultural chemical and fertiliser use are energy related, and the comparisons are uncontroversial. System impacts on soil emissions have been inferred from research in other environments (Tullberg 2009).

Conclusion

The absence of effective CA equipment is an important factor slowing adoption of a technology of great significance to sustainable development, food security and the relief of poverty in a number of regions. Seeding residue-covered, uneven soil surfaces is the major issue.

Low-cost, locally driven development by regional manufacturers, often cooperating with research projects, has provided most CA equipment. These small organisations cannot address important tractor and harvester-related issues of compatibility with permanent traffic lanes and precise guidance.

Farmers are beneficiaries of the change to CA, but the issues of system change are real when they need to re-equip in a situation of uncertainty about equipment types and suitability.

Major farm machinery manufacturers are reluctant to invest in CA equipment R&D when they are unlikely to capture the benefits of any resultant innovation.

The community will be the major beneficiary of CA equipment research, largely as a consequence of the reduced environmental footprint of crop production activities that are necessary for food security. Government or government-mediated funding via systems such as the Clean Development Mechanism or its successors appears to be the only way forward for research and development on the basic and essential issues of mechanisation for CA.

This is not a very satisfying outcome for a conference concerned with private enterprise R&D opportunities and poverty reduction. In view of the limited farm machinery R&D resources now within the public domain in Australia, such research could well be the objective of innovative public–private partnerships.

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