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POTENTIAL TO INCREASE PRODUCTIVITY AND SUSTAINABILITY IN ARGENTINEAN AGRICULTURE WITH CONTROLLED TRAFFIC FARMING: A SHORT DISCUSSION

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Drivers for and potential barriers against adoption of controlled traffic farming (CTF) systems in Argentina are reviewed. Traffic compaction is one of the main factors affecting crop productivity within Argentinean agriculture, and has significant although less quantified impacts on the whole-of-farm system. This suggests that the benefits of no-tillage (NT), which represents the dominant form of cropping in Argentina, are not fully realised. Conservative estimates indicate that crop yields could be improved by at least 15% if NT is used in conjunction with CTF. Cost-benefit analyses of available options for compaction management are required. Despite this, and based on reported evidence internationally, a shift toward increased uptake of CTF within Argentinean agriculture is likely to: (1) improve productivity and farm profitability, (2) enhance environmental performance, and (3) maintain competitiveness of the agricultural sector. Appropriate technical advice and support is a key requirement to drive adoption of CTF. Therefore, the adoption process will benefit from collaboration developed with well-established research and extension organisations in Australia and the United Kingdom, and active engagement of machinery manufacturers.

Keywords: greenhouse gas emissions; no-tillage; random traffic; resource use efficiency; soil compaction; sustainable intensification

In Argentina, agriculture-related activities account for approximately 20% of the country's GDP and represent the sector with the greatest prospect for growth (Lence et al., 2010). Intensification of agriculture and increased output to support economic growth will necessitate rapid adoption of sustainable technologies, and their integration with those already in place. Estimates indicated that the area under no-tillage (NT) in Argentina is approximately 30 million ha representing 90% of the land used for grain cropping (SIIA, 2015). This area recorded a ten-fold increase between 1990 (3 million ha) and 2010 (SIIA, 2010) and is, to a large extent (≥70%), continuously cropped using permanent NT (Friedrich et al., 2012). The main driver for widespread adoption of NT in Argentina has been the acknowledgement of multiplicative agronomic, economic and environmental benefits brought about by this technology, assisted by introduction of genetically modified crops, improved nutrient management practices, and effective research and extension effort (Manuel-Navarrete et al., 2009). National averages suggest an increase in productivity (kg grain per ha) equivalent to approximately 60%, 30% and 20% for corn, wheat and soybeans between 1985–1995 and 1995–2014 (SIIA, 2015), respectively. Readers are referred to several studies dealing with global adoption of NT cropping, and associated effects on crop productivity and sustainability (e.g., Kassam et al., 2009). Despite this, concerns have been raised over the long-term sustainability of NT cropping associated with deterioration of the soil resource caused by traffic compaction. Several studies conducted in Argentina (e.g., Díaz-Zorita et al., 2002) have shown that in long-term NT systems subjected to frequent, non-organised traffic by agricultural vehicles soil compaction can be significant. This occurs despite the fact that these systems have relatively lower traffic intensities (by about 50%) compared with conventionally-managed tillage systems (Kroulík et al., 2009; Mašek et al., 2014). Development of high-capacity agricultural machines has contributed to reduced costs, increased fuel efficiency and work rates (Kutzbach, 2000) but often at the expense of increased risk of soil compaction, and particularly subsoil compaction, due to high axle loads (Spoor et al., 2003; Bennett et al., 2015). The continuous increase in axle loads has, to some extent, offset advances made by the industry in developing improved running gear, such as in tyres and tracks technology, to reduce contact pressures (Misiewicz et al., 2015). This also means that subsoil stresses have continued to increase (Keller and Arvidsson, 2004). For example, work conducted by Chamen (2015), based on models of Koolen et al. (1992) and Keller et al. (2007), suggested a five-fold increase in machinery-induced subsoil stresses (depth: 0.4 m) between 1980 and 2010 (≥30 t combine harvesters). The effects of traffic-induced compaction are often persistent (e.g., more than

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five years), particularly in the subsoil (e.g., Logsdon et al., 1992; Radford et al., 2007). In intensively managed soils (e.g., double-cropping) under NT, these effects are exacerbated by the frequency of traffic, which therefore restricts the opportunities for soil repair through natural processes.

Remediation of compaction through tillage does not appear to be a practicable option for the majority of grain growers in Argentina. The shift towards NT farming observed during the 1990's meant that traditional tillage implements are not readily available. It is also known that alleviation of deep compaction is an energy-demanding process (Tullberg, 2000) and is transient (Chamen, 2011). The impact of soil compaction on crop productivity, the environment, and on the whole-of-farm system is well documented (e.g., Soane and van Ouwerkerk, 1995; Radford et al., 2001; Li et al., 2008; Chamen et al., 2015), which has implications for countries such as Argentina, whose economy relies to a large extent on commodity exports (FAOSTAT, 2015). Therefore, development of management strategies to avoid soil compaction, or to minimise the actual damage where it is unavoidable, is required. In this respect, controlled traffic farming (CTF) systems are regarded as a practical and cost-effective technology to minimise the impact of field traffic-induced soil compaction (Tullberg, 2010; Kingwell and Fuchsbichler, 2011; Chamen et al., 2015).

The Australian Controlled Traffic Farming Association Inc. (ACTFA, http://actfa.net/) defines CTF as a system in which: (1) all machinery has the same or modular working and track widths so that field traffic can be confined to the least possible area of permanent traffic lanes, (2) all machinery is capable of precise guidance along those permanent traffic lanes, and (3) the layout of the permanent traffic lanes is designed to optimise surface drainage and logistics. In well-designed systems, permanent traffic lanes occupy less than 15% of cultivated field area. By contrast, in non-CTF systems varying equipment operating and track widths result in random traffic patterns, which can cover up to 85% of the cultivated field area each time a crop is produced (Kroulík et al., 2009). CTF is not only an engineering solution to some of the unwanted effects of soil compaction but importantly it transforms a problem of random traffic-induced soil compaction into an advantage of improved trafficability and timeliness, which has additional agronomic and environmental benefits (Tullberg, 2010; Gasso et al., 2013; Antille et al., 2015).

At present, global adoption of CTF appears to be small with the exception of Australia, where it is used by approximately 25% of grain growers (Tullberg et al., 2007; Chamen, 2015). CTF remains a novel concept for most farmers in Argentina and therefore current uptake of this technology is almost non-existent. This article discusses some of the main benefits associated with adoption of CTF, particularly when coupled with NT, and the implications for crop productivity, soil health and all dimensions of sustainability within Argentinean agriculture. Drivers for and obstacles against adoption of CTF, relevant to Argentina, are also reviewed based on the experience of Australia and the United Kingdom, and reported evidence available

Table 1 Benefits of CTF likely to drive adoption in Argentinean grain cropping systems

Factor	Description	Reference
Timeliness and field efficiency	– improved field access for all field operations, particularly planting, spraying and harvesting	ACTFA[1], CTF Alberta[2], CTF Europe Ltd.[3], Bochtis et al. (2010)
Tractive efficiency	– improved energy use efficiency due to reduced rolling resistance and wheel-slip. Reduced fuel consumption and draft in minimum tillage systems under CTF	Burt et al. (1994), Tullberg (2000)
Fertiliser use efficiency	– greater fertiliser recovery in crop (both grain and biomass by up to 20%), reduced nutrient loss in runoff or gaseous evolution	Alakukku and Elonen (1995), Lipiec and Stępniewski (1995), Antille et al. (2015)
Runoff and soil erosion, internal drainage	– improved soil porosity and structural conditions, hence, hydraulic conductivity (by a factor of 2) and surface infiltration (by a factor of 4), and water (rainfall and irrigation) use efficiency	Li et al. (2001, 2007), Tullberg et al. (2001), McHugh et al. (2009)
Crop yield, reduced in-field crop variability	– improved crop yield (by 15% or greater) with potential to increase soil C sequestration through greater crop residue returned to soil	Radford et al. (2001), Botta et al. (2007), Tullberg et al. (2007), Neale (2011), Smith et al. (2014)
Greenhouse gas emissions	– reduced potential for N_2O emissions (by 20% to 50%) with enhanced absorption of CH_4	Ruser et al. (2006), Tullberg et al. (2011), Antille et al. (2015)
Profitability	– improved resource use efficiency translates into greater economic return	Chamen (2011), Kingwell and Fuchsbichler (2011), Chamen et al. (2015)
Compatibility with NT and precision agriculture technologies	– demonstrated synergism between NT (or minimum tillage) and CTF. Compatibility with variable rate technology but this should be preceded by CTF. There is a requirement for good (overall) soil husbandry to ensure that the implementation of these technologies can deliver tangible benefits	Tullberg et al. (2007), Godwin (2015), Smith et al. (2014), Antille et al. (2015)

Source: Chamen, 2006

[1]ACTFA (http://actfa.net/), [2]CTF Alberta (http://controlledtrafficfarming.org/), [3]CTF Europe Ltd. (http://www.controlledtrafficfarming.com/)

Table 2 Potential obstacles against CTF adoption in Argentinean grain cropping systems

Factor	Description	Reference
Equipment incompatibilities, reliance on contractors	– non-matching equipment between crops in the rotation (e.g., cutter-bars or planters widths). Potential incompatibilities between owned and contracted farm equipment (e.g., track gauge, operating widths or both). Lack of qualified labour to modify farm machinery	McPhee et al. (1995), Chamen (2006), Isbister et al. (2013)
Land tenure system	– influences the motivation to change the system	The authors
Cost of conversion, size of farming enterprise	– difficulties in gaining access to credit, changes in interest rates and price of commodities, and associated financial risks. Adverse effects of climate on yield, such as lack of rainfall, potentially overcome by greater cropping reliability. Loss of product warranty when equipment is made CTF-compatible. Cost of guidance systems and accuracy	Kingwell and Fuchsbichler (2011), Blacwell et al. (2013), Rataj et al. (2013)
Direction of field operations, field characteristics (topography, size, shape)	– orientation of field operations permanently restricted to parallel directions but can be overcome with changes to implement design. Potential interference of in-field infrastructure for soil erosion control (e.g., contour banks) or surface drainage. Careful design of permanent traffic lanes' layout is required	Chamen (2006) with data from Titmarsh et al. (2003); McPhee et al. (2013)

Source: Chamen, 2006

in the scientific literature. Readers are referred to reviews by Tullberg et al. (2007) and Chamen (2006, 2015) dealing specifically with these issues for Australia and Northern Europe, respectively.

Adoption of Controlled Traffic Farming

Based on work compiled by Chamen (2006) for the United Kingdom, Tables 1 and 2 quote aspects of CTF relevant to Argentinean grain farming systems. The benefits of CTF highlighted in Table 1 are likely to be key drivers for adoption within Argentina. The reader is also referred to work reported in Isbister et al. (2013), where practical aspects of CTF implementation are addressed in detail.

The study by Botta et al. (2007) on soybeans showed that a 60% reduction in traffic intensity at harvest from about 40 tkm/ha (random traffic) to 15 tkm/ha (controlled traffic) increased grain yield by approximately 30% on average after three years. The increment in yield with controlled traffic improved profit margins by about USD 130 per ha (price of grain: USD 0.17 per kg). The change from random to controlled traffic reduced fuel consumption by about 35% (Botta et al., 2007). The controlled traffic system was achieved by maintaining chaser bins on the edge of the field. The results by Botta et al. (2007) reinforce the potential of CTF to improve the profitability of a major crop in Argentina such as soybeans. However, further work is required to validate these findings for a wider spectrum of soil conditions and cropping systems using 'true' CTF systems.

Conclusions and Future Work

A key requirement is to use the store of information available with emphasis on technology transfer and development, drawing from the well-established experience and knowledge base internationally. Applied on-farm research into CTF in Australia is of particular relevance to Argentina due to similar scales and labour unit to area ratios of farming enterprises. There are also similarities in terms of cropping, edapho-climatic conditions, and management practices, which make the CTF technology readily transferable. Likewise, there are opportunities for Argentinean technology such as NT (discs) and relay planters to be used by Australian farmers. However, work is needed to assess the practicalities, costs, drawbacks and deliverable benefits of CTF at local (national) level. Soil compaction impacts need to be quantified on the wider aspects of farm economics to aid decision-making. Well-developed decision support systems that incorporate the economics of managing soil compaction can facilitate the farm-scale analysis of available options, including conventional practice (non-CTF), conversion to CTF, use of low ground pressure vehicle systems (e.g., Smith et al., 2014) and precision tillage. The relative advantages of CTF and low ground pressure vehicle systems are discussed in Godwin (2015) and Godwin et al. (2015) based on results derived from long-term *tillage × traffic* trials established at Harper Adams University (Shropshire, United Kingdom). These results are supportive of the use of no- or minimum tillage systems in conjunction with CTF and low ground pressure vehicle systems. These latter systems may be a cost-effective option to minimise soil compaction in situations where machine-related constraints impose a restriction to adoption of CTF. Removal of drainage and soil compaction constraints is a key requirement to ensure that the benefits associated with the use of these systems are realised (Godwin, 2015).

A three-year research project established at Universidad Nacional del Litoral (Esperanza, Argentina), and funded by CONICET (Consejo Nacional de Investigaciones Científicas y Técnicas, http://www.conicet.gov.ar/), is investigating the effects of fully controlling field traffic on crop yield, soil water dynamics and greenhouse gas emissions (Imhoff, 2015). This research aims to validate the benefits associated with this technology to stimulate a shift toward uptake of CTF in Argentina. Data derived from this project may be used to develop whole-farm economics models applicable to Argentinean farming systems.

In addition to the above, the following work needs to be prioritised:

1. Increase awareness of CTF and its adoption as a means of improving farm profitability, environmental sustainability, and maintaining the agricultural sector's competitiveness.

2. Promote on-farm action-learning research activities to:
   a) determine if the expected benefits can be delivered,
   b) develop appropriate and cost-effective CTF systems that meet the requirements of broadacre farming systems in Argentina.
3. Disseminate the knowledge through farmer-oriented workshops.
4. Promote active engagement of machinery manufacturers (Tullberg, 2010).
5. Engage with policy-makers to incorporate CTF into the suite of technologies listed under current legislation promoting the adoption of soil conservation practices (e.g., Soil Conservation Act No. 22.428, SADS, 2015).

Knowledge transfer will require a group of research and extension specialists, and technical advisers who need to be trained at universities and research centres both national and international. Therefore, international collaboration needs to be developed, particularly with Australia and the United Kingdom, to engage in research and development activities, and assist the mentoring process by those with proven experience in the field. Agreements with research organisations overseas may facilitate academic exchange and development of technical expertise. At national level, mentoring may be achieved using the range of technology networks available, including independent and private organisations, government-funded research institutions and extension agencies, and farmers groups. These bodies need to be alerted to the synergism of NT and CTF, and encourage land managers to shift from a largely production-driven approach to farming to one that can also deliver long-term economic and environmental benefits.

Abbreviations

CTF (Controlled traffic farming), GDP (Gross domestic product), GHG (Greenhouse gases), NT (No-tillage)

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