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Session 4: Conservation Agriculture: Components of Sustainability

ORAL ABSTRACTS

The Development and Adoption of Conservation Agriculture in Canada: From the Ecological to the Cultural.

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Background

Understanding the multidimensionality of routes to the greater adoption of conservation agriculture in Canada is essential for real increases in adoption and for a more sustainable agriculture in Canada. Conservation agriculture is understood amongst agricultural scientists to be a sustainability based approach to farming and it is commonly agreed amongst agricultural scientists and agriculturalists that current standard models of industrialized agriculture in Canada are inherently not-sustainable. There has been a great deal of work done, both by researchers and by farmers to develop strategies and tactics to increase the sustainability of agriculture often from an ecological perspective. The ecological basis and imperative for sustainable agriculture is undeniable yet the adoption of sustainable or conservation agriculture approaches remains low in Canada. This is the case for a variety of reasons, many of which are practical and are related to agronomy, economics, education and culture. More broadly, Canadian society is increasingly interested in sustainable agriculture. The roots for this interest are in environmental movements but more recently is being driven by an emerging food culture. In recent decades, new and stronger connections have been created between consumers and farmers and these provide examples for ways in which conservation agriculture can be further developed and more broadly adopted in Canada.

Approach

The challenges in achieving conservation (sustainable) agriculture are not necessarily unique to any one jurisdiction in the world although there may be unique conditions that play into the challenges. On the contrary, I would argue that there are a set of common elements required in order to achieve sustainable agriculture and these are; desire, knowledge, opportunity, support, cooperation and technology. For each of these I will explain how the element is required for sustainable agriculture using examples to support my explanation and the examples (or supporting information) that I use will come from my North American (and more commonly Canadian) experience.

Results and Discussion

The first element is desire. Developing a sustainable agricultural system is not easy and it takes ongoing work and commitment and so it cannot be achieved if there is no desire to do so. We experienced the power of desire, in this regard, in a project we did in western Canada working with farmers on a new system for reducing pesticide use on farms (Nazarko et al. 2004). We found that success in the program was not due (significantly) to any farm or farmer factor other than the farmers expressed commitment to the project. Knowledge is the next element and it is fundamentally required because simple agriculture is not sustainable and sustainable agriculture is not simple. It is only possible to pursue sustainable agriculture if one understands this principle. Agriculture happens outside on a complex living landscape relying on and impacting many interacting and complex living systems. Sustaining the productivity of agriculture and the health and productivity of the environment it depends upon and lives within cannot be simple because nothing about it is simple. This principle can be well demonstrated with data from Martin Entz's long-term rotation studies in Winnipeg, Canada (Ominski et al. 1999). But although knowledge is important it must be applied. Farmers must be given opportunities to pursue sustainable practices (like diverse cropping systems for example). The reality of farming in industrialized nations is that farmers have been increasingly facing the challenges of the cost-price squeeze. How can farmers adopt diverse rotations when they are facing increasing financial risks and they increasingly are hounded by the need to maintain high cash flow in order to service rising expenses and a rising scale of operations on narrowing marginal returns (Van Acker 2008)? When I was a professor in western Canada (in Winnipeg) I taught a 3rd year weed science course, and each year I asked the students in that course (most of whom were from farms) what the practical challenges were for achieving more sustainable farming systems and their answers were very insightful highlighting the need for fiscal room to explore new systems (the challenges of cash flow), access to knowledge as well as support from their families and their public institutions. To the last point; gaining support is a challenge when there are very few of you. For farmers in Canada, their falling numbers create a political challenge. With few farmers there are few votes and so their opportunity to gain political will for policies that provide support for sustainable agriculture is limited. In addition, there has been a farmer culture in Canada (and elsewhere) of “us” versus “them” when it comes to “farmers” versus “non-farmers” and so we have seen campaigns in Canada like the “Farmers Feed Cities” campaign which did not work to build on common ground, and in the end it did not work to gain support for farmers from “city” people. The good news, for farmers, is that city people want to support them, they already like farmers and they want to help farmers to be more sustainable if they are given the opportunity. Social watchers, like Michael Pollen, have shown us what the average North American is thinking about food. The thesis of his "Omnivore's Dilemma" (Pollen 2006) was that food had more than one purpose, it was about “Good to Eat and Good to Think” - and this creates opportunities for farmers to build relationships with eaters. And this is where Genetically Modified Organisms (GMO's) (first) fit into the story. GMO’s have been rapidly adopted by farmers in North America, Brazil, Argentina and most recently, India (Brookes and Barfoot 2014). Farmers in these countries have adopted GMO's because of operational benefits, but increasingly, there has grown activism against GMO’s. And the reasons for this are not singular. Some believe they are unsafe to consume, some believe they are unsafe for the environment, some believe that they facilitate globalization and consolidation and control of the world’s seeds. No matter the reason, the opposition builds and creates a divide between consumers and farmers further eroding political will for farmers. And farmers cannot do it alone, they need support and cooperation, which can sometimes be a cultural challenge for farmers. The final required element is technology. We have a long history with technology development and adoption in agriculture, and most notably in the modern-era. Perhaps in some cases we have taken it too far and let technology be the end instead of the means. And always with technology (in relation to sustainable agriculture) we have to be aware of the fact that the history of agricultural technology is one of technologies that facilitated simplified farming systems that separate nutrient, carbon and water cycles on the landscape. So the technologies facilitate fundamentally unsustainable systems and this is a problem. For sustainability we need to be thinking about technologies that reconnect carbon, water and nutrient cycles.

Applications and Implications for Conservation Agriculture

The recent past in agriculture has been very much about technology, and this is not surprising because everything in the recent past has been about technology. But achieving sustainability is complicated. Agriculture happens outside on a complex living landscape relying on and impacting many, many interacting and complex living systems. Sustaining the productivity of agriculture and the health and productivity of the environment it depends upon and lives within cannot be simple because nothing about it is simple. And no single element, even powerful technology, is sufficient to achieve it and in fact the way in which we adopted and exploited technology in agriculture moved us away from sustainability. Sustainable agriculture requires the understanding and employment of many elements. I have suggested 6 elements in this presentation (there may be more) but they are all required in order for us to achieve sustainable agriculture.

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Status of Conservation Agriculture in Central Asia

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Background

The Central Asia region is comprised of five independent republics: Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan and Uzbekistan. After the collapse of former Soviet Union, the agriculture sector in Central Asia declined, mainly through a sharp reduction in the production of agricultural and horticultural crops. Growing evidence exists of the productivity, economic and environmental benefits that can be harnessed from using conservation agriculture (CA) practices in Central Asia, but several challenges need to be addressed. These challenges include the need to: mobilize policy and institutional support, facilitate the change of the tillage mind-set, develop the skills to operate CA equipment, make CA equipment available and accessible, and to develop the expertise and knowledge for residue and weed management.

Conservation agriculture rests on three major principles: minimal disturbance of the soil, the health and productivity of which is at the basis of every farming operation; permanent soil cover with plant residues or living crops in order to reduce water loss, erosion, and protect the soil from harsh climate extremes; and the diversity of crops in time (rotations) and space. Conservation agriculture also has economic benefits to the farmers who apply it. Generally, an immediate cost reduction due to decreased farming and machinery operations can be felt right after the introduction of the technology. This is important for poor farmers – for any farmer! - in times of steeply rising costs of fossil energy sources. Saving fuel also helps improving the carbon balance of land use. Whether or not the yields will increase with the introduction of conservation agriculture depends on a wide variety of factors, and generally the effect is not that immediate, as the natural soil fertility will build up only slowly. But if correctly managed, a few years of conservation agriculture will lead to similar yields as before, and often the yields will be even higher.

Applications and Implications for Conservation Agriculture

According to the Ministry of Agriculture of Kazakhstan, in 2011, no-till and conservation tillage practices were introduced on an area of 11.7 M ha, which is 70% of all the area sown to wheat in Kazakhstan (Sydyk et al. 2008). In 2011, the country harvested a record gross output of grain of 20 M t corresponding to a yield of 1.7 t ha-1 (Sydyk et al. 2008). CA might have contributed to the increased yield, although the area under no-till winter wheat in Kazakhstan is only 2.1 M ha.

Over the last 20 years, Uzbekistan has been researching various ways of introducing grain crops into existing crop rotations mainly consisting of cotton and alfalfa. Earlier, only irrigated cotton, or rainfed winter wheat, was grown. However, now with well-proven research findings, timely planting of winter wheat in standing cotton has shown promising results. As a consequence, the annual area of winter wheat sown into standing cotton has reached 600,000 ha in Uzbekistan (Qilichev and Khalilov, 2008).

Adoption of CA in other countries of Central Asia is still dormant and needs more research and extension work to start wide spread dissemination. Several grant and development projects from international donor community currently include promotion of CA and permanent raised beds system as part of the activities.

Experimental Approach

The overarching experimental evidence from these many different production environments demonstrate that CA-based management can have both immediate (e.g. reduced production costs, reduced erosion, stabilized crop yield, and improved water productivity) and long-term benefits (e.g. higher soil organic matter contents and improved soil structure), although the magnitude of these benefits tends to be site and year specific depending on the nature of land degradation and the level farming system development (e.g. Derpsch, 2003; Hobbs, 2007; Friedrich and Kassam, 2009; Kassam et al., 2010).

The evidence from Central Asia indicates that CA practices are suitable for the existing major cropping systems. Research results from all Central Asian countries have shown that CA is suitable for the heterogeneous local conditions; and can provide similar or higher crop yields while saving considerable production resources, including fuel, seeds, water and labour. CA also can combat land degradation in the region through application of no-till, crop residue retention and crop diversification. So, the maintenance of significant amounts of soil coverage by residues reduces wind and water erosion, increases water infiltration for storage for reduced crop water stress, improves soil quality and increases organic matter, and stores atmospheric carbon. Therefore, the benefits are obvious to the scientist, the environmentalist, and many others, but not necessarily to the farmer! CA, and especially the residue management component, must be packaged into easily adopted technology transfer schemes.

Discussion

CA is not a single, or uniform, technology that can be immediately applied anywhere in a standard manner. Rather, it represents a set of principles that encourage the formulation of locally adapted practices, approaches and methods, which need to be tested, evaluated and then adopted or implemented under various biophysical and socio-economic conditions. Further research in Central Asia and evaluated across agro-ecological zones is necessary, in order to study the effects of various CA crop rotations and mulch cover on: weed, nutrient, pest and water management; on sowing depth, dates, density; on fertilizer and irrigation rates; and on the impact to livelihoods and environmental conditions, including the potential of integrating trees, pastures and livestock into CA farming systems, particularly with small-scale farmers. To make results applicable on a wider scale, state programmes should become more active in conducting research, training and extension on CA.

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Landscape Position and Winter Cover Crops Impact Northern Great Plains Corn (*Zea mays*) Yield, Nitrogen, and Water Cycling.

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Background:
Winter cover crops can increase yields, improve soil health, reduce nutrient losses, improve nutrient recycling, and reduce plant disease risk. However, capturing these benefits in frigid semi-arid environment is complicated by a short growing season. To improve cover crop recommendation in frigid semi-arid regions, a better understanding on how interaction among available soil water, available soil nutrients, and cover crop production impacts the cash crop's yield is needed. The objective was to determine the influence of winter cover crops and landscape positions on corn (*Zea mays*) yield losses due to water and N stress, soil biology, and gene expression.

Applications and Implications for Conservation Agriculture:
Three year rotations commonly implemented in the United States Northern Great Plains are soybeans (year 1), wheat (year 2), and corn (year 3). The main challenge with respect to cover crops in this geographic region is a short growing season. In a three year rotation of soybeans – wheat – corn, the optimum time to seed a fall cover crop is following wheat. In this region, wheat is typically harvested in late July or early August. A killing frost usually occurs mid to late October. This allows for a 2-3 month window where an August seeded, cool season cover crop may thrive and provide soil health and nutrient cycling benefits.

Experimental Approach:
The research was conducted at two landscape positions (summit and footslope) at three US Northern Great Plains sites in 2011 and 2012. These sites were characterized as low, moderate, and high water stress environments. Experimental design was a split-plot randomized block. No-tillage was used at all sites. Treatments were ether (1) no cover crop or (2) fall cover crop plots that were split by 4 N rates (0, 34, 67, and 134 kg ammonium nitrate-N ha^{-1}). Wheat was harvested in July. Fall cover crops were seeded in early August. Nitrogen fertilizer was applied in May the following spring.

Results and Discussion
Soil was analyzed for bacteria/fungi ratios, soil moisture, and inorganic N. Leaf samples, collected at V12 were analyzed for gene regulation and grain samples were analyzed for yield loss due to water (YLWS) and N stress (YLNS) using the 13C stable isotopic technique. In the moderate water stress environment, the cover crops reduced ($p=0.09$) the corn yield. These results are attributed to the cover crop using water that could have been used by the crop. Findings also showed that winter cover crops contributed to a higher bacterium to fungi ratio, reduced nitrate-N in the spring soil samples, increased or did not impact water infiltration, and had a mixed impact on gene regulation. The cover crop impact on gene regulation was attributed to the cover crop impact on water stress. In the moderate yield environment, cover crops increased YLWS. Associated with increased water stress was down regulation in 2 of the 3 genes associated with mineral nutrition and one of the two genes associated with photosynthesis. Findings from this study suggest that cover crops may reduce yields through increased water stress. This risk is increased by planting the cover crops early.

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Mechanization of Conservation Agriculture in Zambia: Lessons Learnt and Future Directions

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Background

In Zambia, CA emerged to mitigate the impact of frequent droughts. Since the mid-1990s, several programmes have been implemented focusing on the promotion of CA as an avenue for increasing productivity, reducing soil degradation and lowering production costs. The Ministry of Agriculture and Livestock (MAL) in Zambia has a vision to scale out CA to 600,000 smallholder farmers by 2015 as it is seen as a sustainable approach to increasing farm productivity and production. However, scaling out CA has been limited due to the need for constant intense extension efforts to support adoption, as well as poor access to CA equipment and machinery by the majority of small-scale farmers.

CA mechanization options for smallholder farmers

The following options are those being promoted and adopted:
Ripping with draught animal power (DAP). Ripper tines are locally manufactured in Zambia and are fairly easy to attach to a mouldboard plough frame (replacing the plough body). While this option offers opportunities for expansion of the area under smallholder farmer CA, access to draught animal power may be limited.

Increasingly popular is the concept of agricultural contractors. These are generally tractor operators equipped with three-point mounted rippers who offer ripping services to farmers in their localities.
No-till planting can be achieved with manual, draught animal and tractor-powered planters, although manually operated jab planters, popular in many other countries, do not seem to have been attractive to Zambian smallholder farmers. DAP planters have been well received with Brazilian makes making the greatest impact.

Tractor-mounted direct planters are available on the market in Zambia. Again it is Brazilian equipment which is favoured and the Saro Company imports them. Tractor-mounted planters are only suitable for smallholder farmers if a reliable service can be offered by a well-trained private sector contactor.

Improving access to CA equipment

Farm machinery is usually an expensive item for smallholders to acquire, but this does not mean that mechanization of CA should be beyond their reach. The provision of CA services by well trained and equipped service providers is one answer to address this situation (FAO, 2011). Market appraisal, choosing the right equipment, learning how to operate and maintain the machinery and ensuring that the business is profitable are all areas where guidance may be required. The service providers will also require access to other stakeholders, including finance providers, mechanical repair services and spare-parts dealers.

CA equipment has been made available to smallholder farmers by the private sector (specifically the AFGRI Company) and FAO. Candidates suitable to be FAO-supported farmer-contractors are initially identified by MAL extension staff in consultation with the community. Final validation is done by FAO and MAL in collaboration with the Zambia National Farmers' Union (ZNFU).
The use of e-vouchers promotes farmer-driven and market-friendly development (FAO, 2012); the system, operated by FAO, is used to stimulate the demand for CA services from the newly equipped service-

provision entrepreneurs. E-vouchers are issued to lead farmers and can be used both for CA services and for approved inputs such as herbicides, fertilizer and seed, as well as CA tools. The e-vouchers are redeemable directly by the mechanization service providers and at competing agro-dealer outlets.

Recouping the investment

Until very recently there were two methods of recouping the loan investment made by farmers in CA machinery, the AFGRI model and the ZNFU model.

AFGRI

Smallholders wishing to avail themselves of the AFGRI tractor and CA machinery package take out a loan repayable over three years, currently there are 28 participating service providers. Today a number of other private sector banks and financial institutions have imitated this financing model to offer a competitive leasing/loan agreement. This has enabled potential service providers to have more choice about what machinery makes and models to buy (any type of tractor model and machinery that is available in Zambia) and what type of loan/leasing agreement to be taken. Participating banks allow for the machinery in question to be used as collateral. The increased competition has generally led to better lending terms for the clients and has helped to accelerate the number of CA agricultural machinery service providers.

ZNFU

The ZNFU set up a revolving fund in 2010 in order to collect funds emanating from the sale of FAO- supplied CA equipment. The central idea was to recoup funds from the recipient farmers and to channel them into future purchase and distribution of appropriate CA equipment to new CA service providers. There are two classes of entrepreneur farmers who are targeted by the project, one group is provided with tractors and their associated equipment; and the other are farmers who are provided with DAP powered no- till planters and knapsack sprayers.

Conclusions and Recommendations

CA has taken off in Zambia, it is well supported by the national government and promoted by international donors and NGOs. CA should be mechanized, either with tractor or draught animal power.

To achieve sustainability it is always best to involve the private sector (including the financial sector) in the provision and servicing of CA equipment. Importing machinery new to a country, and without the essential back up services, is a short-term technical fix but with little prospect of long-term sustainability. Credit arrangements and loan recovery should be in the private sector. The AFGRI model is admirable as it is run on entirely commercial lines. Roles and responsibilities are clearly spelt out at the outset and compliance with repayment schedules has been 100 percent. It is this model that has triggered the interest of other financial service providers to offer a similar model with more user choice in equipment selection. Managing a revolving fund is fraught with difficulties. It is extremely difficult to deal with payment defaults as there is no mechanism for asset recuperation and disposal to realize its value. The revolving fund as operated is eventually bound to run out of funds for several reasons; i) a 12 percent levy is charged for administering the fund – this means that the total fund is necessarily diminishing in size; ii) no provision is made for inflation so that funds being recuperated for a particular piece of equipment will not be sufficient to buy equivalent machinery in future years; iii) the valuation of the CA equipment does not always appear to take into account all the costs of transport, import and storage; and iv) it seems that not all CA contractors understand fully their obligation to supply services and repay the loans.

The use of e-vouchers is an excellent way for donors to kick-start the establishment phase of CA service contractors. But as the scheme matures and information about service provision becomes more widely known, then the vouchers should be phased out. This has now happened in Zambia.

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Appropriate and Equitable Mechanization in Africa Through Conservation Agriculture, Use of Two-Wheel Tractors, and Involvement of the Private Sector

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Farm power: a major limiting factor to the intensification of agriculture in sub-Saharan Africa
Population is growing faster than food production in sub-Saharan Africa (SSA) and the difference between food demand and food production is not met by trade. Thus, while not denying the role of food import, agricultural production in SSA has to increase to improve food security in the region. Not only have SSA farmers to produce more, they also have to produce differently, as consumers of agricultural products are increasingly urban. This implies a gradual change in demand – with more milled and polished grains - and greater needs for transport from rural areas to urban centers. More produce to handle, more processing and more transport require more power. However, in contrast to other countries that experienced the Green Revolution (e.g. India), the farm power available per area of agricultural land has declined or at best stagnated in many SSA countries over the past decades, resulting in SSA agriculture increasingly relying on human muscle power. In addition, the quantity and quality of agricultural labour have also declined in many parts of the region. Therefore, (sustainable) intensification in SSA appears unlikely if the issue of declining farm power is not addressed (1) by reducing power demand through the adoption of power saving crop production systems such as conservation agriculture (CA), and/or (2) by increasing power supply through appropriate and equitable mechanization.

2. Conservation agriculture and small-scale mechanization: tapping the synergies
The elimination of soil inversion (the most energy-demanding farming operation in rainfed agriculture) in CA reduces power requirements and makes the use of lower powered and more affordable tractors such as two-wheel tractors (2WTs) a viable option for crop establishment. In turn, the spread of mechanization may increase the adoption of CA in SSA, as the lack of appropriate implements is recognized as one of the major constraints to CA adoption faced by African smallholders (Giller et al., 2009). The combination of mechanization and CA may also mitigate the soil degradation which is a frequently witnessed negative effect of mechanization (Mrema et al., 2008). Another potential synergy between mechanization and CA may come from the reduced use of crop residues for animal fodder that is expected from a shift from animal draught power to tractor power, resulting in an increased fraction of crop residue potentially available for surface mulching. Tapping these synergies between small-scale mechanization and CA is made possible by the recent development of seeders and other implements for 2WTs manufactured by newly emergent industrial economies such as India, China, Brazil, and SSA itself.

3. Making small-scale mechanization viable: the Bangladesh experience
Although Bangladesh is characterized by small and fragmented fields and relies on small machines, its agriculture is one of the most mechanized of South Asia, far more than India's, which relies on larger machines and receives far higher levels of public support (Biggs et al., 2011). Only about one in thirty farmers actually owns a 2WT, while the majority of farmers access mechanization by hiring service providers. This model of mechanization appears equitable as even the poorest farmers have access to 2WT-based services. This is made possible by the low cost of 2WTs – making their purchase possible for many farmers without support of a formal financial institution – and the use of the 2WT for multiple purposes including transport, post-harvest operations and water pumping, leading to high annual rates of return on investment (Diao et al., 2012). The success of this model also comes from the fact that it is

private-sector led, guaranteeing that the right machines are imported and sold at the right price (Biggs et al., 2011).

4. Delivering small-scale mechanization through the involvement of the private sector

The collapse of virtually all the government-run tractor hire schemes which were popular up to the 1990s in many SSA countries demonstrates the need for novel and innovative systems to deliver mechanization to smallholder farmers. It is widely understood that market systems offer the most effective means of replicating, disseminating and ensuring the uptake of new technologies (Magistro et al., 2007). Yet there are often weaknesses in technology market systems which inhibit the uptake of new and innovative agricultural technologies by capital-constrained smallholders. The ‘business model approach’ was successfully used in the commercialization of treadle pumps in Bangladesh (Magistro et al., 2007). This approach could similarly be used to foster adoption of 2WTs and their ancillary equipment in SSA, guided by the following principles. (1) The emergence of private rural service providers should be facilitated, as smallholders in SSA will not often be in a position to purchase 2WTs individually. (2) Although one model may be selected initially, it is important to allow for flexibility, as business models are dynamic in nature and should adapt over time to the ever-changing local context. (3) In areas where markets are weak and farmers are vulnerable, an honest broker (e.g. an NGO) may be needed. (4) Mechanization business models may need to be linked to output business models, as market-oriented enterprises are needed in order to generate the necessary cash flow to cover the charges for hiring services. (5) The range of services offered may need to be broadened to include non-agricultural operations to maximize mechanization use rates. (6) The cost of mechanization services may be reduced by bundling services and products. (7) Kick-start ‘smart’ subsidies may be required for private sector to invest in mechanization service provision.

5. Why should it work this time?

Past initiatives of promoting mechanization in SSA have generally failed (Mrema et al., 2008). The lack of demand for mechanization and the lack of supporting infrastructures were major reasons for this failure. As agriculture in SSA has become more intensive and more commercially oriented, we are confident that this demand has increased. Moreover, the boom in ownership of motorcycles and auto-rickshaws in many SSA countries has been accompanied by the development of repair services and increased availability of fuel and lubricants that could benefit 2WT market systems. The approach used by the past initiatives may have also been inappropriate, with a focus on large machines not suitable for small and fragmented fields, and too costly for many African smallholders and private sector hire-service providers, and a reliance on the public sector that led to inefficient and uneconomic government-run tractor hire schemes. Appropriate and equitable mechanization may be achieved by using two-wheel tractors – which are not powerful enough to plough in the rainfed conditions but perfectly suited to CA – and involving the private sector through business model development.

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Strategic Tillage: Is it a Threat to Conservation Agriculture?

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Introduction

Conservation agriculture (CA) practices that included no-till (NT), stubble retention and crop rotations have revolutionised agricultural systems by allowing growers to manage greater areas of land with reduced energy and machinery inputs. Significant benefits in yield and crop performance have accrued, especially in lower rainfall regions, while erosion control and improved soil health have also occurred. Despite these tangible benefits, a recent survey of 55 growers and advisors in north-eastern Australia indicated that diseases such as crown rot (caused by *Fusarium pseudograminearum*) and yellow leaf spot (caused by *Pyrenophora tritici-repentis*) and hard-to-kill weeds such as fleabane (*Conyza bonariensis*), feathertop Rhodes (*Chloris virgata*) and glyphosate resistant barnyard grass (*Echinochloa crus-galli*), tend to be bigger problems in NT than in systems where tillage is regularly used. For these regions many growers are shifting towards a flexible approach to tillage performing some soil disturbance (Argent *et al*., 2013). However, growers who practise strict CA systems are concerned that even a single tillage operation may undo the positive benefits of CA systems on soil condition. Those promoting ideas of strictly no soil disturbance predict irreparable damage to soil from ST (Grandy et al., 2006), while others suggest either little or no impact (Wortmann et al., 2010). To resolve the conflicting issues surrounding the use of occasional strategic tillage (ST) in CA systems, this research aims to determine impacts of ST on productivity, profitability, soil health and the environment under varying soil and climatic conditions.

Materials and Methods

Five fields were selected on long-term NT soils (black-, brown-, and grey-Vertosols, a grey Dermosol and a brown Sodosol) to represent typical CA farming systems across north-eastern Australia. All sites received tillage treatments to depths between 0.15 and 0.20 m (tine, and/or disc or prickle chain harrows) in March 2012. Soil samples, sub-sampled at 0-0.1 m, 0.1-0.2 m and 0.2-03 m, were obtained prior to sowing of crops in both years and analysed for soil quality attributes.

Results and Discussion

Imposition of one-time tine-tillage in otherwise NT system significantly lowered in-crop weed populations in all the soils after 3 months (Table 1). 12 months post tillage; weed population was significantly lower in grey Vertosol and grey Dermosol but increased significantly on brown Sodosol. Soil bulk density in top 0.1 m soil depth was quite variable and not significantly affected by tillage except in brown Sodosol, although it tended to decrease in all soils except grey Dermosol. There were no significant differences in soil moisture resulting from tillage prior to seeding except in black Vertosol in 0-0.1 m soil depth, however all soils tended to decreased soil moisture due to higher evaporation rates in tilled soil. One-time tine-tillage had no significant effect on soil organic carbon mass; however, it tended to slightly decrease in 0-0.1 m soil depth. The impacts on particulate organic carbon were only significant (P<0.05) in grey Vertosol after three months. One-time tillage tended to lower available P in 0-0.1 m soil depth at all sites, however, significant differences were obtained only in grey Vertosol. Total microbial enzymatic activity between tine-tillage treatment and NT did not differ significantly in any soil. Grain yield overall showed slight positive impacts in both years; however differences were not significant except in brown Sodosol (P=0.06) in the first year. Brown Sodosol recorded a decrease in yield in 2013, a likely result from a significant increase in weed population. Based on farmer costs of tillage, the net returns per hectare from one-time tillage, using either chisel or offset disc in long-term NT systems, were estimated to range from $-24.9 to $103.6. Introduction of a single tillage operation in continuous NT showed a slight increase in simulated sediment loss. There were no significant differences between different tillage implements on agronomic or soil health attributes (results not shown).

Table 1. Occasional strategic tine-tillage impacts in otherwise long-term no-till farming systems

	Grey Vertosol		Brown Sodosol		Grey Dermosol		Black Vertosol		Brown Vertosol
	3m	12m	3m	12m	3m	12m	3m	12m	3m
Weeds *(#/m2)*	↓	↓	↓	↑	↓	+	+	+	↓
$BD_{0\text{-}10cm}$ (g/cc)	-	-	-	↓	-	+	-	-	-
$SW_{0\text{-}10cm}$ (mm)	-	+	-	+	-	+	↓	+	-
$SOC_{0\text{-}10cm}$ (t/ha)	-	-	-	-	-	-	-	-	-
$POC_{0\text{-}5cm}$ (t/ha)		↓		-		-		+	
$P_{0\text{-}10cm}$ (mg/kg)	↓	-	-	-	-	-	-	-	-
$TMA_{0\text{-}10cm}$ (µg/h/g)	+	-	-	+	-	-	-	-	
$MB_{0\text{-}10cm}$ (µg/g)				+		+			
Yield (t/ha)	+	+	↑	-	+	+	+	+	+
Net return ($)	-	+	+	+	+	+	+	+	+

↑, significant (P<0.05) increase; ↓, significant (P<0.05) decrease; +, increase; -, decrease; 3m, 3 months after tillage; 12m, 12 months after tillage; TMA, total microbial activity (*µg/mL FDA/g soil/hour)*; MB, microbial biomass (µg C g^{-1}soil); BD, bulk density (g/cc); SW, soil water (mm); SOC, soil organic carbon (t/ha); POC, particulate organic carbon (t/ha); P, available (Colwell-P) mg/kg.

Implications

Tillage treatments generally had no significant impacts on soil health attributes expect on texture contrast (brown Sodosol) and soils with weakly structured A-horizons (grey Dermosol). A potential negative effect from tillage was the reduced soil moisture in most soils, although under the seasonal conditions with good rainfall between tillage and the sowing of the crops did not adversely affect productivity.

Reduced weed pressure resulting from ST has significant implications for managing resistant and hard-to-kill weeds; however increase in weed population at one site suggest that understanding weed seed bank at a given site or farm would be key factor to implement successful ST. Most studies conducted in USA and Europe suggests that one-time tillage in NT systems could improve productivity and profitability in the short term; however in the long-term, the impact is negligible or may be negative (Dang et al., 2014). For many Australian farmers, maintaining farm profitability is a priority, and this is likely to dictate its adoption. However impacts on soil health and environment, especially the risk of erosion and the loss of soil carbon, will also influence a grower’s choice to adopt ST. We anticipate that inclusion of ST in NT systems would offer management flexibility and is likely to improve farm profitability with less reliance on pesticides/herbicides.

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