

Poster Session 4: Mechanization of Conservation Agriculture

POSTER ABSTRACTS

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Evaluation of Zero Tillage and Early Sowing for Dryland Cropping in Syria

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Background

Traditional dryland cereal-legume cropping in West Asia involves multiple cultivations, heavy grazing, burning or harvesting of stubbles and late sowing, a system often termed conventional tillage (CT). Cereal yields are as low as 0.5 to 1 t/ha, well below attainable yields of 3-5 t/ha with 250-350mm rainfall. In contrast, in Australia, wheat yields have increased by 3% per year since 1900 through improved crop management and varieties, and many farmers approach attainable yields using zero tillage (ZT) with minimal soil disturbance, retention of stubbles, and early sowing to conserve moisture and increase crop production, profitability and sustainability (Sadras and Angus 2006). ZT has been adopted by nearly 90% of Australian farmers over the last 30 years and over 120 million hectares worldwide (Llewellyn et al. 2012; Derpsch et al. 2010). Strangely, it has been little researched, known or adopted in the Middle East. This paper reports on research undertaken in an Australian-funded project (2005-14) to develop and promote ZT to increase crop productivity, profitability and sustainability in northern Iraq and Syria.

Applications and Implications for Conservation Agriculture

The long-term trial on large plots has been effective in verifying and exposing ZT and early sowing as attractive cropping technologies. That the improved system (ZT early) gave higher yields than the traditional (CT late) in 15 of 16 year x crop comparisons (although only two were significant) is an important finding. Along with cost savings and sustainability benefits, it suggests that farmers should with little risk stop plowing and adopt ZT and early sowing in their cropping operations.

Experimental Approach

As part of a program to verify, adapt, and raise awareness to the ZT cropping system, a long-term research trial was set up in 2006/07 at ICARDA in north Syria to evaluate responses of wheat, barley, chickpea and lentil in rotation to tillage (ZT vs. CT) and time of sowing (Early vs. Late). This paper reports grain yields over four seasons 2009-12. Treatments (tillage, crops, time of sowing) were replicated four times. ZT was not cultivated and CT cultivated 2-3 times, with stubble retained. All plots were sown with the same ZT seeder and received similar management within crops. Early sowing was in early November and late sowing \approx 4 weeks later. Harvests were of whole plots (12 x 65m).

Results and Discussion

For grain yield, there was a 4-way ANOVA interaction due to different effects of tillage (T) and time of sowing (TOS) in different crops and years, not unexpected with four crops tested under rainfed conditions over four years. ZT and CT yields were similar in most year-crop-TOS combinations (23 out of 32). ZT was higher than CT in five combinations for chickpea (08-09 E and L, 09-10 L, 10-11 E and L) and two combinations for lentil (10-11 E and L). ZT yielded less than CT only in wheat (09-10 L) and lentil (11-12 E). Early and late sowing gave similar yields in most year-crop-tillage combinations (27 out of 32). Early was better than late sowing in four combinations of wheat (09-10 ZT), barley (11-12 CT) and lentil (10-11 CT and ZT), whilst late was better than early only in chickpea in 09-10 ZT (Table 1).

Grain yield is the primary focus for cropping farmers, and is a good integrator and indicator of best cropping practices. ZT and early sowing were compatible and attractive cropping technologies for wheat, barley, chickpea and lentil with little risk for farmers, giving similar or better yields for ZT compared to

CT in 94% of year-crop-TOS combinations and for early compared to late sowing in 97% of year-crop-T combinations. ZT with early sowing is not difficult to implement, provides flexibility and cost savings in cropping operations, and maximizes chances of high yields and profits across favorable and unfavorable years. It can be used wherever farmers grow crops and have access to a ZT seeder. The widespread use of ZT and early sowing around the world, and their impressive performance in Syria, suggest farmers across the Middle East should eliminate plowing and adopt ZT with early sowing in their cropping operations.

The trial, on large plots with each of the main crops represented each year, had credibility with farmers and raised awareness and experience of the ZT system for hundreds of scientists, extension officers, farm machinery manufacturers and farmers who visited ICARDA each year, and has been instrumental in promoting considerable adoption and impact of ZT in Syria and Iraq as described by Piggin et al. (2011).

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Table 1. Year x tillage x crop x time of sowing interaction on grain yield ($\text{kg}\cdot\text{ha}^{-1}$ and $\log_{10} \text{kg}\cdot\text{ha}^{-1}$).

Year (rainfall)	Tillage	TOS	Wheat		Chickpea		Barley		Lentil	
			kg/ha	(log10)	kg/ha	(log10)	kg/ha	(log10)	kg/ha	(log10)
2008-09 (291mm)	CT	E	1513	(3.179)	450	(2.651)	2372	(3.375)	1192	(3.076)
		L	1333	(3.125)	377	(2.574)	2106	(3.323)	968	(2.980)
	ZT	E	1603	(3.206)	704	(2.848)	2532	(3.403)	1103	(3.039)
		L	1426	(3.154)	576	(2.754)	2365	(3.374)	1000	(2.994)
2009-10 (270mm)	CT	E	1785	(3.245)	615	(2.782)	2154	(3.316)	899	(2.950)
		L	1756	(3.235)	544	(2.730)	2421	(3.371)	702	(2.843)
	ZT	E	1890	(3.276)	556	(2.708)	2302	(3.346)	842	(2.919)
		L	1296	(3.093)	978	(2.990)	2467	(3.391)	769	(2.878)
2010-11 (259mm)	CT	E	556	(2.737)	449	(2.634)	1510	(3.177)	688	(2.837)
		L	536	(2.718)	491	(2.670)	1333	(3.122)	489	(2.674)
	ZT	E	652	(2.808)	585	(2.768)	1189	(3.074)	1247	(3.096)
		L	651	(2.809)	740	(2.860)	1317	(3.109)	747	(2.871)
2011-12 (453mm)	CT	E	4024	(3.602)	1261	(3.079)	5494	(3.740)	1267	(3.092)
		L	3782	(3.575)	1135	(3.047)	4121	(3.609)	1358	(3.129)
	ZT	E	4590	(3.657)	1209	(3.072)	5137	(3.708)	866	(2.928)
		L	3604	(3.555)	1374	(3.128)	4089	(3.608)	1189	(3.070)

LSD (0.05) = (0.120)

Sugarcane in No-tillage and Liming Long-term Experiment: Fifteen Years of Results

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Background

In Brazil the sugarcane crop is cultivated in almost 9.2 million hectares, which 60% of plantations are concentrated in Sao Paulo state. The government of Sao Paulo State has mandated (Act # 47,700 of March 1st, 2003, regulates the law # 11,241 of September 19th, 2002) that in flat (less than 12% of slope) sugarcane production areas feasible for mechanical harvest, the use of fire to reduce biomass before harvesting must be banished completely up to 2021, but recently this deadline was anticipated to 2014. Due to this social pressure, nowadays the majority of fields are harvested without burning (around 80 %), then a great amount of straw (average 15 Mg of dry matter per hectare each year) is deposited over the soil surface. In 1997 farmers started to develop planter machines to sow soybean under sugarcane straw in order to save time and cash and is today a successful case. On the other hand, there are few scientific results about no-tillage or conservation agriculture principles applied for sugarcane crop.

Results

The sugarcane straw provide significant changes on the crop system, such as; to control the soil erosion (Prove et al., 1995), to control of weeds (Cristoffoleti et al., 2007), to reduce the greenhouse gases emissions from the soil (La Scala et al., 2006), to increase the soil organic matter and to increase the soil moisture (Bolonhezi et al., 2010). On the other hand, the great amount of residues increase the cost with tillage in almost 30%, consequently is desirable the adoption of conservation soil management to cultivate leguminous used as crop rotation and to grow sugarcane.

Applications and Implications for Conservation Agriculture

The principles of Conservation Agriculture (CA) are very important to develop a sustainable sugarcane crop system. The great amount of residues after harvesting is favourable to use no-tillage system for cash leguminous in rotation and for sugarcane grown in sequence. Commercial fields experience shown that the adoption of CA principles for green harvested sugarcane crop system reduce up to 40% the costs with increase on stalk yield, save time and increase soil organic carbon.

Experimental Approach

In order to study the interaction of lime rates and soil management, it was installed a trial in 1998, using a commercially harvested green sugarcane field at its 5th ratoon, which had been planted in 1993. This long-term experiment is in an eutrophic Clayed Rhodic Hapludox (Oxisol) located at Experimental Station of APTA, Ribeirão Preto city, Brazil. It was adopted a randomized complete block design in a split-plot scheme, with four replications. The main plots two soil managements CT(moldboard plowing, 30 cm depth followed by two applications of offset disk harrow) and NT (crop residues left on its surface after spraying the area with 3.6 kg h⁻¹ a.i. of glyphosate) and the subplots consisted of four dolomitic limestone (0; 2,0; 4,0 and 6 Mg ha⁻¹). The limestone was applied at three times (in 1998, 2003 and 2008), even before planting soybean (*Glycine max*) as a crop rotation, followed by sugarcane crop. At the beginning of the experimental period, soil chemical characteristics were determined (at 20 cm-depth) according to methods described in van Raij et al. (2001), and the main results were pH (0.01 M CaCl₂) = 4.8; SOM = 31 g dm⁻³ and base saturation (V) = 41 %. It has been evaluated the agronomic and

technological characteristics of soybean and sugarcane; as well as the changes on the physical and chemical soil properties.

Results and Discussion

Soybean grain yield was not influenced at the first renew, but significant reduction in no-tillage was observed at the second renovation. In the third planting of soybean (round-up ready cultivar), no difference was verified on the grain yield. The stalk yield in the cane plant (IAC 86-2211) was significantly higher in no-tillage (140 Mg ha^{-1}) than conventional (111 Mg ha^{-1}). In the second cycle (from 2003 to 2008, cv. IAC 91-2218) it was observed a linear response to stalk yield. For the current variety IACSP95-5000 (planted in 2010), the same quadratic trend was verified (average of cane plant and first ratoon) for both soil managements with the highest stalk yield (143 Mg ha^{-1}) was found in no-tillage at lime rate of $2,0 \text{ t ha}^{-1}$.

Significant changes on soil chemical and physical properties were found in the uppermost layers (0-5 and 5-10 cm) in no-tillage. Nevertheless, the non-exchangeable Ca and Mg contents (non reacted fraction) increased 14 times after three applications in no-tillage. According to Segnini et al. (2013), regarding at 7 years, the adoption of NT resulted in annual C retention rates of $1.63 \text{ Mg ha}^{-1} \text{ year}^{-1}$, while the association between straw on the soil surface and CT during sugarcane replanting accumulated only $0.67 \text{ Mg ha}^{-1} \text{ year}^{-1}$. The key answer to this result is the maintenance of root biomass in the no-tillage system, because all treatments received the same amount of straw after harvesting.

It could be concluded that after fifteen years of association between no-tillage and green harvested sugarcane, the stalk yield and carbon stock is increased and the surface liming changed soil properties below 20 cm depth.

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Conservation-Agriculture Seeders for Smallholder Farmers

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BACKGROUND

Conservation Agriculture (CA) is a set of managerial and technical alternatives which will, in both the short-term and long-term, accomplish the “3-Ws”: to store Water in the soil, to save the Water stored in the soil, and to efficiently utilize stored soil Water for beneficial crop production. Water enables agriculture. The active part or focus of “conservation” in CA is the conservation of available water (Rockstrom, et al. 2009). The focus on water conservation is very helpful, for it provides the following criteria: Any proposed component of CA must be evaluated relative to its potential impact on any or all of the “3-Ws”. CA is the best-known method at this time for the accomplishment of current and future food sustainability (Hobbs, 2007).

The “managerial and technical alternatives” alluded to in the above definition of CA indicate that CA is not a fixed one-size-fits-all agricultural cropping procedure, but rather it is a set of alternatives which comply with guiding CA principles. These principles have been found to be valuable, useful, and in some cases necessary to be compatible with, and hopefully accomplish, two of the UN Millennium Development Goals (United Nations, 2000):

Goal 1: Eradicate extreme poverty and hunger;

Goal 7: Ensure environmental sustainability.

Established CA cropping will produce field conditions with old-crop residues partially-to-fully covering the soil surface. Old-crop stalks/stubble may be standing, lying across the rows, shredded, or flattened by use of a crimper or roller. In addition, FYM and minerals may have been distributed on the surface. CA seeders and other mechanization field implements must be successfully operated in these field conditions with minimum disturbance of the soil coverage to maximize soil-water conservation. At this time, for smallholder village farmers, cropping mechanization may involve manual, animal-draft, and/or 2-wheel tractor (2WT) methods and power sources. All comments, below, are for dryland/rain-fed cropping and may not apply to irrigated cropping.

Development of crop seeders for CA has targeted row-crop seeding under upland, dryland/rain-fed conditions. This target was selected because in many such regions it is water conservation, as provided in CA cropping systems, which is needed for the farmers to produce sustainable livelihoods. Row-crop seeding was selected because grain and oil-seed crops, grown in spaced rows, are their predominate enterprises.

The economies of these upland village farmers are minimal, so the goal was to develop and introduce the least costly “powered” mechanization implements to operate under the field conditions found on such farms. Powered implements were chosen as the next developmental step above manual field operations, and a 1-row seeder powered with a small 2WT was the lowest-cost entry into these CA technologies..

SEEDER DEVELOPMENT RESULTS

The tasks to be performed with a mechanized crop seeder in non-plowed, residue-covered soils have been determined by experimental-development to be as follows:

- 1) Initially clear a path through soil-covering stalks and residues for the row to be seeded;
- 2) Cut any remaining residues along the initial path;
- 3) Open a furrow in the soil to the depth required for seeding;
- 4) Meter and deposit seed into the opened furrow;
- 5) (Option) Meter and deposit fertilizers or other materials into the opened furrow;

- 6) Press the seeded furrow closed;
- 7) (Option) Provide a riding platform for the seeder operator.

We have determined that for typical small to medium amounts of old-crop residues on dryland/rain-fed CA fields, that a floating residue-rake wheel mounted at 30° to forward travel can be used to initially clear the bulk of residues from the row path. Remaining residues can be successively cut with a spring-loaded rolling disc blade. This system does not require excessive machine weight and provides for uniform seeding depth. The seeding furrow can be opened with a vertical shank, tipped with a narrow replaceable tip, for most types of soils and conditions. Seed and (optional) non-toxic rates of starter fertilizers can be metered into the opened seed furrow. The seeded furrow can be closed and pressed with a semi-pneumatic presswheel. The operator can stand on foot platforms on the presswheel to provide weight for soil penetration with the seeder components and furrow closing-pressing to finish the operation.

Row-crop seeders for CA which conform to the above functional requirements are now available. The typical configuration is as a 1-row seeder for rear-mounting on a 2WT; 2-row configurations are possible if 2WT traction is not limiting. New animal-draft versions are forthcoming. [disclaimer: the authors are designers and distributors of the *Morrison Seeders, CA-Seeder 1000*, manufactured under contract by SMTI of Erwin TN, USA].

APPLICATIONS FOR CONSERVATION AGRICULTURE

The 1-row CA Seeder described above can be used for the process of successively demonstrating and introducing CA cropping technologies in rural communities. As such, it is offered as a “tool” to enable these activities. The Seeder is commercially available so that interested farmers may become CA-farmers.

EXPERIMENTAL EVIDENCE

The 1-row CA Seeder described above is currently under comparative testing in East Africa and Mexico. Earlier unpublished use of this seeder design since 2009, in pre-production prototypes, has been initially successful in USA, Tanzania, and Ghana. Published results are forthcoming.

DISCUSSION

The managerial and technical alternatives of CA cropping are fairly broad in definition, but when it comes to the selection of seeders and other field implements to accomplish CA cropping, there are but a few options. Depending upon the crops being grown and the field conditions, some mechanization implements are currently available from several sources. In a few cases, there are choices between manufacturers for competitive implements. Selection of appropriate mechanization implements for particular needs should be done under advisement.

As developers, distributors, and advocates for CA, we have the responsibility to provide appropriate technologies at affordable prices to support the training programs and initial-adopter farmers as CA moves into the main stream of crop production on smallholder village farms.

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A New Wave of Conservation Agriculture Adoption on Smallholder Farms Using Planters for Two Wheel tractors: Progress and Bottlenecks for Adoption in South Asia

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Introduction

Worldwide, conservation agriculture (CA) has been adopted on over 110 million ha mostly in rainfed areas under large-scale agriculture. The benefits achieved by large-scale farmers from adoption of CA (significant reduction of fuel costs, increased soil water utilization, reduced turn-around-time, and labour requirements from tillage operations, and reduced machinery wear and tear) are of increasing interest in smallholder farmers. The 2-wheel tractor (2WT) is a potential power source for mechanized minimum tillage on small holder farms in Asia and Africa. The challenge remains to design planters operated by 2WTs, and demonstrate their effectiveness, reliability, and durability at a price that allows ready adoption in the target market, and then to develop a supply chain for commercialization of the planters. Over the recent decade, innovations made for wide range of 2WT seeding implements now permit reliable seeding into minimally disturbed soil and moderate levels of crop residue (Haque et. al., 2013). This provides a window of opportunity to develop CA cropping systems for small holder farmers, not only in terms of reduced soil disturbance but also with respect to biomass cover and crop rotation. The Chinese-made 2BG-6A for single pass shallow tillage planting (SPST) and Bangladeshi-made Versatile Multi-crop Planter (VMP) have been adopted by the smallholders' farmers and will be examined as case studies in the present paper. We synthesize past experience, lessons learnt, progress and bottlenecks for the development and adoption of 2WT-based minimum tillage planters that can accelerate the uptake of CA on smallholder farms in Bangladesh and elsewhere in Asia and Africa.

2wt-Based Minimum Tillage Planters Development

Initial developments with minimum tillage planting of crops using 2WT in Bangladesh were started in 1995 with the importation of the Chinese made 2BG-6A seeder (Haque et. al., 2013). A wide range of minimum tillage planters (some 2WT-based) have been developed locally since: i) single pass shallow tillage (SPST) planter; ii) strip tillage planter; iii) toolbar mounted bed planter; iv) SPST-based bed planter; v) rotary tillage-based single pass bed planter; vi) animal drawn converted to 2WT zero tillage planter; vii) toolbar frame zero tillage planter; viii) Versatile Multi-crop planter (VMP); ix) Versatile Strip Tillage planter (VSTP); etc. Descriptions of the features and utility of these planters are reported in Haque et. al. (2013) and Haque et. al. (2014).

Adoption of Minimum Tillage PLANTERS in Bangladesh

Since 1995, many attempts were undertaken to diffuse planters to farmers and local service providers (LSP) in Bangladesh. These attempts include: project-led procurement and sale to farmers; and involvement of research, extension, local manufacturing, and non-government organizations to popularize and sell the minimum tillage planters. Except the SPST and VMP, most of the above planters have not been adopted by farmers. Lack of adoption is attributed to: the absence of a commercialization plan to follow up on the R&D or weaknesses in the design or on-farm performance of the planters. The lessons learnt have been at the forefront of the programme to develop and commercialise the VMP. Firstly, the VMP was designed as multi-functional and multi-crop 2WT-based planter for smallholders with capability

for seed and fertilizer application in variable row spacing using single-pass shallow-tillage, strip tillage, zero tillage, bed planting, and conventional tillage.

The adoption of SPST and VMP planters started in 2003 and 2011, respectively, by engaging private companies from the beginning of the commercialization process. Until the end of 2013 more than 6,000 SPST and 110 units of VMP have been sold locally with 33 units of VMP exported to Asia, Mexico and East Africa. Since 2003, the total area coverage of SPST was estimated to be 215,000 ha but <15% for minimum tillage planting. Planting statistics were also gathered for a few VMP operated by LSP (Table 1).

Table 1: Planting services provided by selected LSP using the VMPs.

Period	No. of monitored LSP	Planted area (ha)	Provided services to farmers #	Cultivated crops
Nov. 2010 - May 2011	4	87	456	Wheat, rice, lentil, jute, mustard,
Nov 2011 - May 2012	3	46	147	chickpea, maize, mungbean, potato,
Nov 2012 - May 2013	6	38	221	unpuddled rice, red amaranth, etc
Nov 2013 - April 2014	7	69	418	

Lessons Learnt

To stimulate the adoption of 2WT-mounted minimum tillage planters, a multi-pronged approach is suggested based on our lessons learnt: on-farm evaluation of planters for reliable performance and durability; continuous improvement of planters to enhance crop establishment; demonstrations and field days to create awareness of and raise demand for the minimum tillage planters; use of smart subsidies and incentives to encourage LSP to begin planting businesses and to encourage farmers to pay for planting services; development of skilled manpower for operating planters and related crop establishment services; engagement with importers or manufacturers to demonstrate the market potential. User groups involving early adopters of the technology (2WT LSPs) have a role in promoting adoption of minimum tillage planters and increasing the learning of skills by operators. Empowering LSP with better quality and multi-functional capabilities planters that could maximize profit is imperative for adoption. Cropping pattern and availability of herbicides in each area also influence the adoption of minimum tillage planters by smallholders.

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Agronomic and Economic Viability of Controlled Traffic Farming in Alberta

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Background

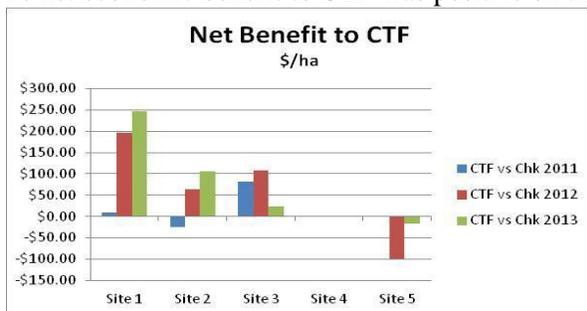
Controlled Traffic Farming Alberta (CTFA) was a three-year on-farm research project (2011-2013) aimed at evaluating the agronomic and economic viability of controlled traffic farming in Alberta. The project was funded by the Agriculture & Food Council, Agriculture and Agri-Food Canada and the CAAP program. Additional funding and help came from the Alberta Crop Industry Development Fund, Alberta Canola Producers Commission, Alberta Barley Commission, Alberta Pulse Growers, Alberta Wheat Commission, Farmers Edge, Beyond Agronomy, Point Forward Solutions and Agricultural Research and Extension Council of Alberta.

Controlled traffic farming features permanent wheel tracks or tramlines, matching wheel bases (usually 120 inches or 3.658 meters), matching implement widths to multiples of the narrowest implement and farm layouts to allow for straight, long runs and to manage drainage. RTK/GPS is important to ensure accuracy and repeatability.

Results

One site (Site 4) did not have a check plot. Yields have been variable and three of four sites showed no significant differences in 2013. Water infiltration was significantly better for the CTF on three of four sites. Water use efficiency favored the CTF on one site and was better than the CTF on three sites. Fuel use has been inconsistent between the CTF and check plots.

The net economic benefit to CTF was positive on three of four sites.



Application and Implications for Conservation Agriculture

Soil compaction is an issue in many farming systems, especially as equipment gets larger and heavier. CTF is a long-term approach to reducing soil compaction by eliminating random wheel traffic and isolating traffic on permanent tramlines. Reducing and eliminating compaction maintains or improves soil quality. Soil that is not compacted has more pore space, better oxygen exchange, more pore space to store water in and better infiltration. Soil biological life is also enhanced. The ability to store more water and allow plant roots to access deeper into the soil profile has positive implications for climate change issues – both drought and excess moisture.

Controlled traffic when integrated into a conservation agriculture system can minimize the impact of wheeled traffic.

Experimental Approach

Five cooperators tested CTF on their farms. The cooperators were selected to represent a variety of soil and climatic conditions in Alberta. Site one near Jarvie is a sandy loam to sandy clay loam Dark Gray Luvisol soil. Site two near Lacombe is a sandy loam Eluviated Black Chernozem. Site three near Trochu is a clay Orthic Black Chernozem. Site four near Morrin is a clay to heavy clay Orthic Humic Vertisol. Site five near Rolling Hills is an irrigated fine sand to fine sandy loam Orthic Brown Chernozem. The growing season (> 5C) ranges from 175 to over 185 days but frost free days range from 105 to > 125 days.

Cooperators used their own field sized equipment for the project. Four of five had a check random traffic plot and a CTF plot. Plot sizes range from 40 acres to 320 acres. The same seeding implement was used on both the check and the CTF plot. Yield data was extracted from combine yield monitors. Yield data was analyzed in two ways. Blocks were selected on either side of the boundary between the check and CTF plot and statistics applied to determine significant differences. As well overall plot yields were recorded.

Water infiltration was measured using aluminum rings in trafficked and non-trafficked areas. One inch (2.54 cm) of water was applied and the time to infiltrate was recorded. Water use efficiencies were calculated using the formula: $\text{Spring Soil Moisture} + \text{Growing Season Rainfall} - \text{Fall Soil Moisture} - 90 \text{ mm Evaporation Loss}$.

The economic analysis used comparative budgets and net present value analysis.

Background soil information, bulk densities, pore space, available water holding capacity and soil penetration resistance were determined. Weed communities have been tracked for three years.

Results and Discussion

Few conclusive observations can be drawn since we have only three years of data and are dealing with a biological system. We have observed that CTF makes on-farm research far easier, extremely accurate and repeatable. Savings in fuel, field efficiencies, timing and new techniques may result in significant gains from adopting CTF. CTF is opening up a world of new possibilities such as in-crop banding of nutrients and more targeted pesticide applications.

Soils seem to be changing, as noted by the significant infiltration gains in the CTF. It may take more time for soils to repair themselves. Heavy clay soils seem to be responding sooner than loam and sandy loam soils. Tramlines have held up well but will need to be repaired in low spots. Almost no soil erosion has occurred in the tramlines.

We will continue to measure and record data such as fuel use, water infiltration, weed communities, yield, and costs. Soil properties such as biological life, bulk density and penetration resistance will be measured in the next few years.

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Diesel Subsidies and Sustainable Agriculture in the Mexican Bajío: The Wrong Policy?

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Introduction

In 2003 Mexico launched a large agricultural diesel subsidies program which aimed to improve the competitiveness of cereal producers in the country. One specific objective of the program was to eliminate the gap between the amount paid for diesel by farmers in Mexico compared with their counterparts in the US. Currently the level of subsidies received by Mexican farmers is adjusted annually in accordance with world oil prices, and this approach has generated a heavy financial burden to the Mexican federal government. In the year 2013, almost 50% of the total direct subsidies distributed to the agricultural sector went to direct diesel subsidies, accounting for 62.4 US\$ million from a total budget of 125.4 US\$ million. With subsidized diesel in place, it is not surprising that adoption of technologies that reduce diesel consumption offer no strong market incentives for farmers. Why should a farmer invest in order to adapt his machinery and learn how to manage a different cropping system such as conservation agriculture (CA) if the resultant savings on diesel consumption have no positive impacts on economic returns? Our research measured the current net returns $\text{ha}^{-1} \text{ year}^{-1}$ differences within three different cropping systems (conservation, conventional and hybrid) in a high-yielding Mexican region known as the *Bajío*. Then three different scenarios were built with 10%, 20% and 30% price increments for diesel in order to assess the effects of these changes in the net returns $\text{ha}^{-1} \text{ year}^{-1}$ for the three systems.

Materials and Methods

A survey was conducted among 304 farmers in the two Mexican states of Guanajuato and Michoacán between August and September 2011. A two-stage stratified random sampling design was used. To calculate the net returns $\text{ha}^{-1} \text{ year}^{-1}$ we used partial budgets following the methodology described by Boughton (1990). We utilized standard prices for the inputs in order to avoid regional price distortions. Also a standard price for grain and fodder units was used. All the calculations were standardized for one hectare per farmer and calculated for the whole year, i.e. two cycles – winter (wheat-barley) and summer (sorghum-maize) – were added, and when the winter cycle was not present the summer cycle was equal to the total year. In order to compare the means on net returns $\text{ha}^{-1} \text{ year}^{-1}$ of the three different systems, two statistical methods were utilized; the first was a *t*-test with Welch correction, and the second a genetic matching.

Results and Discussion

Both statistical methods suggested that under the current situation, CA farmers and hybrid farmers net returns $\text{ha}^{-1} \text{ year}^{-1}$ do not have significant differences. However, when the three scenarios were tested, the gap between the two systems increased (Table 1). This showed that with an increment in diesel prices, CA outperformed the hybrid system. Nonetheless, the CA system was not immune to the diesel price increments, as net returns $\text{ha}^{-1} \text{ year}^{-1}$ also decreased but by a smaller magnitude (Table 1). CA farmers still utilize diesel for a series of agricultural activities such as sowing, fertilization or harvest. However, the diesel litres saved by avoiding soil disturbances (tillage, sub-soiling, etc.) by CA farmers rendered them more resilient to diesel price increments than their hybrid counterparts. When just the Welch *t*-tests were used conventional farmers seem heavily outperformed by the other two systems. However, access to irrigation was one of the most pronounced differences between the characteristics of conventional farmers and the other two groups. A large part of the variation on net returns $\text{ha}^{-1} \text{ year}^{-1}$ was explained by this

factor. When the genetic matching was applied in a bid to control this effect, the differences between conventional farmers and the other two groups in terms of net returns $\text{ha}^{-1} \text{ year}^{-1}$ clearly diminished (Table 1). The farmers using the hybrid system have stopped tilling the soil in the summer cycle but still use mechanical soil disturbances in the winter cycle. This system has some of the advantages of CA input and time savings in one cycle, but lacks the technical know-how needed for residue management in the long term. Nevertheless some of the long term positive effects of CA on soil's physical, chemical and biological characteristics are also lost. When subsidies were partially removed in the hypothetical scenarios, CA had increasingly positive differences on net returns $\text{ha}^{-1} \text{ year}^{-1}$ when compared to the hybrid system.

Table 1. Actual and three modeled scenarios on net returns $\text{ha}^{-1} \text{ year}^{-1}$ differences between conservation, hybrid and conventional systems in the Mexican *Bajío*, using Welch *t*-test and genetic matching.

Net return $\text{ha}^{-1} \text{ year}^{-1}$	Conservation	Hybrid	Conventional	Welch <i>t</i> - test		
	1	2	3	1 vs 2	1 vs 3	2 vs 3
Actual (US\$)	1661.2	1532.9	848.5	0.211	<.000***	<.000***
Scenario 1 (US\$)	1469.1	1244.2	704.2	0.027**	<.000***	<.000***
Scenario 2 (US\$)	1324.5	1014.2	530.2	0.001***	<.000***	<.000***
Scenario 3 (US\$)	1209.4	872.1	432.2	<.000***	<.000***	<.000***
Genetic Matching conservation as treatment						
	<u>1 vs 2</u>	<u>1 vs 3</u>	<u>2</u>	<u>3</u>		
Actual (US\$)	1491.9	1381.4***	1403.1	1011.1		
Scenario 1 (US\$)	1352.5**	1305.5***	1211.7	711.2		
Scenario 2 (US\$)	1259.5***	1179.9***	934.2	477.9		
Scenario 3 (US\$)	1166.6***	1054.4***	756.6	2544.7		

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Conclusions

Currently, subsidized diesel prices mean that the hybrid system is today the economically sound option for farmers producing cereals in the *Bajío*. However, when higher diesel prices are modeled, CA savings on diesel result in a clear advantage for obtaining net returns $\text{ha}^{-1} \text{ year}^{-1}$. If the *Bajío* is going to continue as a high-yielding cereal production region in the long term, diesel subsidies have to diminish. Instead of spending up to 50% of the federal agricultural budget every year on diesel direct subsidies, the resources could be allocated to develop and facilitate technical advice for farmers, machinery adaptation, institutional innovations, soil and water conservation payments, etc. It is clear that the market distortions on the diesel markets are discouraging CA adoption and other diesel-saving technologies. Low price diesel does not send the right market incentives to farmers to improve their cropping systems and make them more input efficient. Under the current dominant cereal production systems (hybrid and conventional) the *Bajío* will further degrade its soil and will continue to rely on intensive and inefficient use of inputs in order to sustain its historically high yields.

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Weed Incidence, Control and Grain Yield Losses in Conservation Cropping Systems of North Africa

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Background

Conservation Agriculture (CA) is being promoted as an alternative to conventional cropping practices in Morocco, Algeria, and Tunisia for increasing crop yields and conserving soil resources (Ben Moussa-Machraoui *et al.*, 2010; Rahali *et al.*, 2011; Mrabet *et al.*, 2012). Weed growth and effective weed management have been identified as major limitations to the adoption of CA and for increasing crop yields across the region. Improved weed management is being assessed across research platforms in three countries within the framework of an ACIAR (Australian Center for International Agricultural Research) funded project on conservation agriculture.

Experimental approach

The three platforms belong to three different agro-ecosystems. The Tunisian platform, Fernana (North West of Tunisia) is characterized by an average of 800 mm of rainfall and a farming system mainly based on cereals (wheat & barley) and legumes associated with livestock. The Moroccan platform, Chaouia/Ouardigha (Central Morocco), is characterized by low and variable rainfall (300-350 mm), and a farming system based on the integration of crop and livestock. The Algerian platform, Setif (North Eastern of Algeria), is characterized by variable rainfall (330-400 mm), and a farming system based on cereals with important livestock component.

Weed surveys were conducted in all three platforms to characterize weed flora and identify weed problems. Weed seed bank was evaluated using the seedling emergence method (De Rouw *et al.*, 2014) on soil samples collected from the upper 10 cm soil layers from different sites in no-till systems. To determine the efficacy of herbicides on weed growth in no-till systems, herbicide treatments involving the application of glyphosate pre-plant and/or different herbicide combinations were applied at different timing of weed emergence (PRE and POST emergence herbicides) in different crops including lentil, small faba bean, wheat and barley crops. The effect of crop sowing date combined to herbicide treatments on weed growth was also studied. The efficacy of treatments was evaluated by monitoring weed biomass and densities before and after treatment using the quadrat method and by assessing crop yields in treated and untreated plots. Experiments were conducted in a randomized complete block with four replicates per treatment.

Results and Discussion

Weed surveys during the 2012/13 growing season revealed the occurrence of about 50 different species mainly belonging to *Poaceae*, *Apiaceae*, *Brassicaceae*, and *Asteraceae*. Major weed species in the three countries included rigput grass (*Bromus rigidus*), rigid ryegrass (*Lolium rigidum*), sterile oat (*Avena sterilis*), pignut (*Bunium bulbocastanum*), canarygrass (*Phalaris* spp.), sowthistle (*Sonchus oleraceus*), speedwell (*Veronica* spp.), cleavers (*Galium aparine*), wild mustard (*Sinapis arvensis*) and broomrapes (*Orobanche crenata* and *O. foetida*). Weed seed bank studies showed that viable seeds exceeded 6,000/m² in the upper 10 cm layer of soils. Weed densities after crop emergence were up to 1146 plants/m²

in barley, 96 plants/m² in a barley-field pea mixture and 300 plants/m² in lentils even after a pre-sowing application of glyphosate. The failure of pre-plant herbicide treatments to reduce weed densities in some cases may be due to improper application (sprayer calibration, rate of application, timing, etc.) and to the dominance of some perennial weed species such as friar's cowl (*Arisarum vulgare*).

Available herbicides for controlling annual grasses and/or broadleaf weeds in cereals and/or pulses include pendimethalin, simazine, clethodim, pyroxsulam, clodinafop + pinoxaden, iodosulfuron + mesosulfuron, tribenuron, diclofop + fenoxaprop, prosulfocarb, bentazone, clodinafop-propargil and sulfosulfuron. Weed control in *Vicia faba* var. *minor* using a combination of glyphosate pre-plant, simazine pre-emergence and clethodim post-emergence reduced densities of annual grass weeds by up to 90%, and increased grain yield from 0.4 to 0.9 t/ha compared with the untreated plots. In lentils, glyphosate applied pre-plant, simazine pre-emergence and quizalofop post-emergence decreased weed densities by 50 to 80% and increased grain yields from 0.8 t/ha in untreated plots up to 2.6 t/ha in the treated plots averaged over four sites. Increases in crop yields may be attributed to a better weed control with a combination of pre-plant, pre-emergence and post-emergence herbicides. Sowing durum wheat in November combined with the application of glyphosate pre-plant, pyroxsulam, clodinafop + pinoxaden and tribenuron post-emergence, resulted in up to 90% reductions in weed densities and increased grain yield from 2.0 t/ha in untreated plots to 5.9 t/ha in treated plots averaged over three sites. When sowing durum wheat in December, grain yield of untreated plots was 2.1 t/ha compared with 3.7 t/ha in untreated plots. Application of glyphosate pre-plant and diclofop + fenoxaprop and triasulfuron + dicamba post-emergence in barley resulted in a significant decrease in densities of most weed species. Weed densities were reduced by 50 to 80%, resulting in increases in barley grain yield from 2.1 t/ha in untreated plots up to 4.3 t/ha in treated plots averaged over four sites.

Applications and Implications for Conservation Agriculture

Weed management may be the biggest and the most difficult challenge for farmers adopting conservation agriculture in the region. Results of this study revealed a highly diversified weed flora, hence, intense weed pressure in crops. As during the initial stage of adoption, conservation agriculture relies to some extent on the use of herbicides, high weed densities would require a proper use of herbicides and alternative control strategies to keep problem weeds under control. Adequate herbicide application should be achieved prior to crop planting as well as during the growing season of the crop. Although chemical weed control is being used by some farmers, problems related to the ownership of the equipments including the sprayers, the affordability and availability of suitable herbicides and in some cases the lack of information on herbicide use and application are limiting the use of herbicides for weed control. For instance, in Morocco, the area of small grain sprayed with herbicides represents only 20% of the total area (Mrabet *et al.*, 2012). Therefore, chemical weed management needs to be improved, particularly in legume crops, in order for the farmers to rely on other weed management practices such as crop rotations and make use of integrated weed management techniques. Information on weed management is produced for each country within the framework of CANA (Conservation Agriculture in North Africa) project.

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No-Tillage: From Bernese Cantonal Promotion to Swiss Federal Agricultural Policy

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Background

Since the late 1950s agricultural production on arable land has been strongly intensified. Switzerland is characterized by sloping and undulating areas as well as a cool and wet climate with annual precipitations of 1000 mm and more. Therefore, soil erosion is a major concern in arable farming. In addition, axle-loads of farm machinery have increased significantly during the last decade resulting in pronounced soil compaction and decreased soil quality. As a consequence of primarily physical soil stress brought about by tillage and transport operations, the fertility of arable soils is at risk. A strategy of action introducing a practicable cropping system, which combines the conservation of natural resources with economic benefits, was required. Conservation agriculture – in particular “zero tillage” based on Manitoban experiences from the early 1980s (Sturny, 1982) – fulfils both these criteria.

Experimental Approach and Results

No-tillage and conventional plow tillage are being compared in a crop rotation without fallow period and application of mineral fertilizer only, in the long-term field trial «Oberacker» at the Inforama Ruetti in Zollikofen (near Berne) since 1994. The slightly humic sandy loam is a deep and nutrient-rich soil. The results obtained so far show continuous no-tillage of long duration to be an alternative to traditional plow tillage: no-tillage is ready to be put into agronomical practice, it leads to a biologically active soil of stable structure and thus of high load capacity, reduces the risk of soil erosion, the number of vehicle crossings and the consumption of fuel and presents an overall more favorable life cycle assessment (Schaller *et al.*, 2006).

After a 7-year conversion period, slightly higher plant yields of comparable quality were obtained in no-tillage, due to more soil water being preserved and continually delivered to plant roots, as well as to a higher N-efficiency. In both cropping systems only about 60% of the standard amounts of N-fertilizer were applied. Both systems are being established further and optimized with regard to environmental sustainability and energy consumption by including more legume crops, applying ammonium-based N-fertilizer, and by significantly reducing the application of glyphosate in no-tillage and the tillage intensity in conventional plow tillage (Sturny *et al.*, 2007).

Applications and Implications for Conservation Agriculture

In the canton of Berne, conservation tillage is being encouraged with financial incentives since 1993 (Schwarz *et al.*, 2007) – including a farmer-to-farmer approach. The farmers involved commit to loosening their soils just superficially during the transition phase from a plow to a no-tillage system or to refrain from soil loosening by direct seeding or planting right away without any soil disturbance. Innovative private contractors made a valuable contribution to promoting no-tillage techniques among farmers. At the same time, countrywide awareness about no-tillage was successfully raised through consulting, publications, field trials and demonstration plots, field days as well as the national discussion platform SWISS NO-TILL (<http://www.no-till.ch>). The area under no-tillage increased constantly, reaching 16,000 ha or nearly 5% of the arable land. In some parts of Switzerland the proportion of no-tillage fields has reached 10% (Schneider *et al.*, 2010).

Article 77a/b in the Federal Law on Agriculture establishes the provision of federal funds (80%) to supplement the cantonal incentives (20%) since 2008. The canton of Berne therefore launched a 6-year

“Soil Support Program” by farmers and soil experts to pursue a comprehensive and sustainable problem-solving approach to soil protection at the interface of water and air. It is based on voluntary participation and allows for financial incentives to implement different measures related to cropping systems that protect the soil (mulch-tillage, strip-tillage, no-tillage), to restore organic matter (crop rotation, soil cover over winter, undersown cover crops, abandonment of herbicides, manure composting) and to encourage ammonia-reducing techniques for the application of liquid manure (umbilical application system, soil-conserving undercarriages). This catalogue of measures is part of the program concept which, together with educational and extension components, constitutes an overall farmer-to-farmer approach, along with monitoring soil impact that includes plant protection and exposure measurements. Following completion of the program in 2015, these measures should be economically feasible without additional incentives and be pursued further. It thus provides the means to extend conservation agriculture to the entire area of arable land. Today about 7% of the Bernese cropland is under no-tillage agriculture.

Conclusion

On a national level within the agricultural policy and the payments framework for 2014-2017, a new tool including “payments for efficient use of resources” was introduced in 2014 providing several measures derived from the Bernese incentive Soil Support Program.



Fig. 1. Winter wheat – using one-third of the seed density – precision planting directly into an established cover crop composed of eight species. The green manure plants freeze off in winter and provide a protection against soil erosion, pesticide runoff, and nitrate leaching, among others. (Photo: W.G. Sturny)

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Decision and Duration Analysis of the Adoption of Zero Tillage: A Syrian case

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The decision of whether to adopt a new agricultural technology requires the producer to go through a decision making process which involves a sequence of sub-decisions. Astebro (2004) lists three main decisions that have to be made in stages during the adoption process. The first decision is whether to adopt the new technology which includes determining the new technology's compatibility and potential effect on the firm's profit margin both in the short and long terms. The second decision is on the intensity of adoption where decision on the extent to which the firm wants to exploit the new technology is made. The third and final decision is the speed at which the old technology is replaced by the new technology.

The purpose of this study is to investigate factors that influence the decision to adopt, the intensity of adoption and the speed with which adoption of zero tillage (ZT) takes place in Syrian agriculture. Analysis is based on a survey of 820 wheat and barley farmers from seven provinces of Syria. The Heckman selection model which is potent in correcting for self-selection bias was employed in this paper to analyze the decision and intensity of adoption of the ZT technology. The duration analysis approach which combines both individual adoption decisions and the cumulative aspect of innovation diffusion by adding a dynamic element to the dichotomous choice methods is used for analyzing the speed of adoption.

Model results indicate the importance of farm and farmer characteristics such as total area devoted to the production of wheat, farmer's education level, access to credit, and membership in cooperatives in influencing farmers' decisions on whether to adopt, how soon and on how big a land. These results stress the importance of studying farm and farmer characteristics in technology targeting especially in identifying the early adopters the success of which will influence the overall adoption rate. The number of extension visits related to ZT was found to be marginally effective in positively influencing the decision to adopt (3%) but having insignificant effect on the speed of adoption and a negative effect on the intensity of adoption which is counter intuitive. Participation in either field days or hosting demonstration trials increases the likelihood of adoption by 19% and 35% respectively while involvement in both field days and hosting demonstration trials leads to the highest probability of adoption (41%) showing that more exposure to the technology through visual and hands on experience increases the likelihood of adoption. The speed of adoption is also positively influenced by farmers' involvement in either of field days (5%) or hosting demonstration trials (21%). Once again, involvement in both field days and hosting demonstration trials leads to the highest increase in the speed of adoption (26%).

These results are consistent with the common saying "seeing is believing" where human beings in general tend to believe and accept what they see and perceive as good much more than what others tell or recommend for them. This is even more so when it comes to new technologies that might be different from traditional practice or difficult for the ordinary farmer to comprehend and implement. These results underline the important role of farmers' initial exposure to agricultural technologies in enhancing the extent and speed of adoption, and the effectiveness of linking research to development efforts through participatory methods.

Farmers who grow wheat alone or both wheat and barley are found to have higher likelihood of adopting the ZT technology and do so much faster than farmers cultivating barley alone. The type of crop the farmers grow however does not have significant effect on the intensity of adoption.

The policy implication of these findings is that governments of the developing world have to invest on reorienting their extension services more towards providing visual evidence and acquiring firsthand information through field days and hosting demonstration trials. Mechanisms that enhance formal and informal exchange of information among farmers (such as the farmer to farmer extension approach) need to be tested for effective technology transfer. Moreover, ZT technology promotion and extension should target farmers with large wheat farms as they are likely to be among the early adopters and also have higher potential to influence the diffusion process.

Keywords: Adoption; Duration analysis, Zero tillage; Selection bias

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Machinery for Crop Residue Management in No-till Systems for Sustainable Crop Production and Improving Soil Health

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Oral or poster presentation: Poster presentation

Review for inclusion in the following theme: Conservation Agriculture and Sustainable Intensification (production, profit, sustainability)

Background:

The twin challenges of South Asian agriculture; natural resource degradation and increasing food demand for burgeoning populations have recently been intensified with emerging climatic extremes. Conservation agriculture (CA) based crop management technologies have demonstrated potential to address these challenges. However, to accelerate the pace of adoption of CA in the region, development and adaptation of CA machinery are critical. In north-western Indo- Gangetic plains, combine harvesting of rice and wheat is now a common practice leaving large amount of residues in the fields. Farmers generally burn rice residues because as it interferes with tillage and seeding operations for the succeeding crops and it has no much economical use. Developing cost effective technique for efficient rice residue management was an important challenge for the farm engineers and agronomists.

Approach:

A four wheel tractor operated 'Turbo Happy Seeder' (THS) was developed which is capable of direct drilling in standing stubble as well as loose straw (Fig. 1). Operational costs for sowing wheat using THS is 50-60% lower than with conventional tillage (CT) based planting (Singh et al., 2008). The machine is now commercially available and seven manufacturers are already building this machine. However, even spreading of loose straw is a precondition for the smooth operation of THS and in view of labour scarcity, a straw management system was also developed as an attachment to the existing combine harvesters for uniform spread of loose straw. For large scale evaluation of this innovation, a total of 256 demonstration sites were established during 2007 to 2011 in different districts of Punjab, India under the Cereal Systems Initiative for South Asia (CSISA) project jointly by Department of Agriculture, Govt of Punjab, Punjab Agricultural University and service providers.



Fig. 1 Turbo Happy Seeder in operation

Results and Discussion:

The average wheat yield was significantly higher for THS than CT wheat plots. Additional advantages like, up to 60% less weed growth (Sidhu et al., 2007), irrigation water savings, soil health improvement and environment quality (Yadvinder-Singh et al., 2010) were also noted under THS technology. Canopy temperature measured in the last week of March which was 1 to 2.0 C° lower in THS plots than CT (Gupta et al., 2010). The lowering of canopy temperature can be very helpful in adapting to the adverse effects of terminal heat in wheat. The subsoil compaction (up to 20 cm depth) under different tillage options studied in 113 farmers' fields showed that soil strength was 25 % and 40 % less in the THS than CT and rotary tilled wheat fields, respectively. For sustainable intensification of RW system, short duration mungbean was directly drilled into wheat residue using THS, which produced 3% higher grain yield compared to CT system. A front mounted tractor operated knife roller was also evaluated to enhance the seeding efficiency of THS in tall crops like maize and *Sesbania aculeata* while mulching & seeding in a single pass. THS was also modified for band placement of urea between the two wheat rows in presence of surface residue. To speed up the adoption rate of THS technology, the Government of Punjab, India is providing 60-70% subsidy to farmers for buying THS (costing ~ US\$ 2000) considering it as an effective solution to manage crop residues without burning and promote CA in intensive cropping systems of South Asia. As part of promotional efforts, instead of penalizing farmers who burn residues, it will be better to provide an incentive of Rs. 1250 per ha to farmers who do not burn the residue. A first prototype of 0.9 m wide Mini Happy Seeder (MHS) for two wheel tractors for small & marginal farmers has also been developed which is capable of direct drilling wheat into ≤ 5 t/ha of rice residue (Fig.2). Provision has been made for the operator to ride on the MHS during its operation. It can be easily detachable from the two wheel tractor after seeding. The testing & field evaluations are in progress.



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High Capacity Tractor Operated Relay Seeder for Enhancing Productivity of Cotton- Wheat System in South Asia

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Background

Cotton -wheat (CW) is an important crop production system of north-western plains of India and adjoining areas of the Punjab-Sindh provinces of Pakistan. In this system, late harvest of cotton delays wheat sowing causing marked reduction in its productivity. However, the delay can be avoided by relay seeding of wheat in standing cotton. A two-wheel self-propelled relay seeder (RS) was successfully developed and evaluated for seeding wheat into standing crop (Buttar *et al.*, 2013). The timely sowing of wheat without any damage to cotton was demonstrated through engine operated relay planting. However, for popularising the relay planting in CW rotation in South Asia; self propelled small machine is insufficient, especially among the large farmers due to its low capacity (about 0.6 ha per day). Hence, there is a need of a tractor operated high clearance relay seeder which in one pass can plant a width equal to 3-4 rows of cotton crop.

Approach

A high clearance platform for a four-wheel tractor was developed in collaboration with CIMMYT-BISA, India, and PAU Ludhiana, India and a machinery manufacturer. This platform increases the ground clearance of the tractor to 115 cm to make the tractor move easily in standing cotton (usually 100 to 130 cm tall). The track width of tractor was also increased by 1.5 times the standard tractors (135 cm to 202.5 cm) available in India. This enables high clearance tractor to move in both 67.5 and 101 cm row geometries of cotton. A 15-row RS, consisting of three units of 5 rows each, placed 18 cm apart, was developed to sow wheat into 4 rows of cotton spaced at 101 cm in a single pass using the newly developed high clearance tractor platform (Fig. 1). Similarly, another 12 -row RS consisting of 4 sections of 3 rows each at 18 cm apart, was also developed to sow wheat in to 5 rows of cotton spaced at 67.5 cm row spacing (Fig. 2). The effective width of 15- and 12-row RS is 303 and 270 cm, respectively.

A replicated field trial to evaluate high capacity RSs in two cotton BT hybrids with different growth pattern was conducted at Borlaug Institute for South Asia (BISA), Ludhiana, India during 2013-14. The 4 treatments for 12- row relay seeder and 67.5 x 75 cm spacing were; (1) zero till openers for seeding wheat, (2) disc openers for seeding wheat, (3) strip till with tyne opener and (4) manual broadcast seeding of wheat. These were compared with conventional sowing of wheat after cotton harvest (conventional tillage and sowing with a seed-fertilizer drill). On-farm trials (0.4 ha each) were also conducted at three locations during 2013–2014 to evaluate the newly developed RS for wheat establishment in cotton in CW-dominated areas of south-western Punjab, India.

Results and discussions

Planting of wheat under conventional practice was delayed by 31 days compared with relay seeding in the replicated trial sown at BISA, Ludhiana, India. The movement of RS caused very less damage (2 to 3%) of standing cotton with the lowest damage for the disc furrow openers as the discs either cut the cotton stalks or rolled over it. While, tyne openers dragged broken shoots and branches of cotton. Seed cotton yield was similar in relay seeding and conventional practice; therefore, there was no adverse affect of relay seeding of wheat on the cotton crop.

Yield of wheat sown with the 12-row RS was 21, 9 and 16% higher than with conventional practice for strip tillage with tyne opener, zero till with tyne openers and disc openers respectively (Khan and Khaliq, 2005). The corresponding increase in wheat yield with the 15-row RSs was 26, 20, and 20%. The increase in wheat yield under relay seeding of wheat was primarily due to higher spike density. Similar trends were obtained for on-farm trials at Bathinda, India. Wheat yield of broadcasted wheat for 67.5 cm row spacing and 101 cm row spacing were 19 and 20 % lesser than conventional wheat. It may be due to poor plant establishment of broadcasted wheat. Development and evaluation of an innovative, high capacity tractor operated RS can facilitate direct drilling of wheat into standing cotton for timely sowing of wheat for enhancing wheat productivity and profitability of CW system in South Asia.

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Fig 1. 15 -row RS operated with high clearance tractor seeding wheat into 4 strips of standing cotton spaced at 101 cm

Fig 2. 12- row RS operated with high clearance tractor for seeding wheat into 4 strips of cotton spaced at 67.5 cm

