Australian Government

Australian Centre for International Agricultural Research

Final report

project

Overcoming Agronomic and Mechanization Constraints to Development and Adoption of Conservation Agriculture in Diversified Rice-based Cropping in Bangladesh

project number	LWR/2010/080
period of report	April 2012 – October 2017
date published	4 November 2019
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final report number	FR2019-107
ISBN	978-1-925747-94-2
published by	ACIAR GPO Box 1571 Canberra ACT 2601 Australia

Contents

1 Acknowledgments

Senior staff of BAU, BARC, BARI, BRRI supported the project in many ways and their special contributions are gratefully acknowledged:

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Funding support:

Additional funding support has been provided for specific project and related activities as follows:

Crawford Fund

Visit by Taslima Zahan from BARI, Mrs Selina Jahan from BRRI, and Nur Nobi Mia from IDE for a three-week training program in Australia on "Training in research techniques to investigate weed control by herbicide application in conservation agriculture. Including herbicide use for safe and effective weed control, herbicide screening of crops for herbicide tolerance" during 2nd to 18th September 2014. This was jointly supported by ACIAR, the Crawford Fund and the project.

John Dillion Fellowship

Awards to Prof Dr Mahfuza Begum; Prof Dr Rafiqul Islam; Prof Dr Lutful Hassan who were supported by the project and participated in the John Dillon Fellowship training course in Australia.

Endeavour Post Doctoral Fellowship

Prof Dr. Abdul Kader, Bangladesh Agricultural University.

Conference Funding

Funding support from CIMMYT and FAO for CASH-I. Funding support for CASH-I, CASH-II and MTURT Conference from ACIAR.

2 Executive summary

The aim of the project is to develop, and accelerate the adoption of conservation agriculture (CA) for selected soils, crops and cropping systems in Bangladesh so that agriculture can benefit from cost-saving crop production technologies and sustainable resource management. The objectives are to – i) Improve adoption of CA led by service provider networks; ii) Design minimum tillage planters for improved operation and effectiveness; iii) Redesign best-practice crop agronomy to optimize it for different types of minimum tillage, targeted crop rotations and key soils; iv) Quantify the benefits of CA for soil fertility; and v) Develop capacity for on-going research and development of CA in Bangladesh.

Current on-farm practice of CA in Bangladesh is accelerating. In 2013-14, about 440 hectares of crop were sown with strip planting or zero tillage. In the 2016-17 Rabi season, planting using CA principles with the Versatile Multi-crop Planter (VMP, pulled by two-wheel tractor (2WT)) covered 1,500 ha in the working area of this Project. In Durgapur Upazilla, where a concentration of effort on VMP promotion and extension has occurred in the last 5 years, the 2016-17 Rabi season VMP planting by 32 local service providers (LSP) covered 4.5 % of the total crop area. In three Blocks (sections serviced by an Extension officer covering ~1,000 ha), CA planting reached 10-16 % of all Rabi season crops. This is evidence that the Project investment is accelerating early adoption by farmers where Project programmes have built farmer confidence in the technology, the planters improved by the Project are available, and the LSP trained by the Project have established custom hire businesses to provide planting services.

The acceleration of CA adoption is based on a number of key interventions by the Project:

- 3,414 demonstrations over 5 years on CA planting with rice, maize, wheat, lentil, chickpea, jute, mung bean to improve farmer's awareness of the benefits of CA, and to boost their confidence in its reliability and adoptability as a technology;
- Training of 7,456 farmers (including 2,327 women) on CA, minimum tillage and safe use of herbicide. Training of 318 operators, Department of Agriculture Extension (DAE) Officers, BARI, BRRI Technicians, and Herbicide Dealers. Training to 55 government extension officers on CA;
- 116 field days, farmer focus group discussions and promotional meetings organized over 5 years where 10,894 participants attended;
- Consistently large benefits from CA for adopting farms. CA technology used by farmers saved 34 % of labour cost, 31 % of seed applied, 6 % of fertilizers, 32 % of pesticide cost and lowered total cost of production up to 10% for production of lentil, mustard, maize, and wheat (Miah et al., 2017);
- The development of non-puddled rice transplanting to minimise soil disturbance in the monsoon season. For the non-puddled rice transplanting there was generally no rice grain yield difference on farmers' fields compared to conventional tillage and puddling but 2/3rd of them had increased gross margin;
- Relative yield increases of 28 % for lentil, 19 % for mustard, 6 % for wheat by farmers who adopted CA planting using the VMP;
- Profit increases of 47 % for lentil, 55 % for maize, 560 % for mustard and 76 % for wheat by farmers who adopted CA planting using the VMP;
- Continuous improvement of the VMP for greater reliability of seed metering, reduced planter weight, increased strength of critical parts and decreased costs of manufacture;

Incentives, training and mentoring provided to new LSP to develop a viable custom hiring business by planting crops;

Profitable business model for LSP that generates about $2,100 extra profit per year by custom hiring the VMP for planting services for 4-6 months per year. The breakeven planting was 7.8 ha per year, while on average LSP planted 19 ha.

Empowering farmers and LSP to drive the development and promotion of CA by the formation of a network known as the Conservation Agriculture Service Providers Association (CASPA) with over 9,800 members;

Manufacturing and distribution of the VMP taken over by Hoque Corporation as a commercial partner which has further improved the VMP (version 13) and sold 146 units;

Provision of low interest loans for 80 % of the cost of a new VMP alone or with the 2WT as a package by the National Bank. 100 purchasers have availed themselves of this facility;

Partnership with the Barind Multi-purpose Development Authority (BMDA) to engage the National Bank in providing loans.

The Mid-Term Review in 2014 was a critical pivot by the Project towards accelerated commercialization and communication of the project outputs widely amongst next users and end users (extension agencies, farmers, service provider, NGO and policy makers). Under new management arrangements, a Project Implementation Office (PIO) was set up in Dhaka under a letter of agreement between Bangladesh Agricultural University (BAU) and Murdoch University: the PIO has been fully functional since 1st August 2015.

Significant achievements have been made in machinery capability. The Project-sponsored PhD Fellow, Md. Anwar Hossen, BRRI, Gazipur developed the non-puddled rice transplanter; Md. Sanowar Hossen from BAU evaluated the lever-operated sprayer for weed control and made recommendations for more effective spray devices for herbicide application; Dr. Md. Enamul Haque, developed the Versatile Strip Seed Drill (VSSD), and substantial improvement has been made on the Versatile Multi-crop Planter (VMP) leading to the release of Version 13 in 2016 to Hoque Corporation for manufacturing. Five local manufacturers of the VMP and VSTP led to sales of 238 units (the project-supported target was 54 units) including 44 units exported to nine countries. The Project trained 318 Local Service Providers (LSP), technicians from the National Agricultural Research System (NARS), NGOs, the private sector; and 43 mechanics of VMP/VSSD and manufacturing factory/repairing workshops.

The commercialisation strategy is based in part on creating demand from farmers in CA planting services. This work is focussed in 6 hubs of activity that roughly correspond to a Union administrative area. Within these areas, 6,611 farmers have hired or used the VMP/VSTP to sow lentil, mustard, mungbean, sesame, jute, wheat, maize, rice, chickpea, etc. and the planting covered more than 1,500 ha in the 2016-17 Rabi season.

To scale out the project's CA practices and the use of the VMP, the project identified 216 farmers' groups working in 9 districts (with a membership of 9,800 farm families) and established the Conservation Agriculture Service Providers Association (CASPA). In collaboration with the CASPA and DAE, the project: established a total of 3,414 farmers' participatory demonstrations (farmers contributed most of the inputs, and the project provided only the critical inputs) on minimum tillage, residue retention, crop rotation, weed management, non-puddled rice establishment, etc.; trained 7,456 farm families on CA and integrated weed management practices, and safe use of herbicide; organized 116 Field Days, Focus Group Discussion sessions and promotional meetings that reached 10,384 farmers most of whom are retaining some level of crop residue, practicing crop rotation (e.g., lentil adoption in Durgapur; mustard between two rice crops at Gouripur); practicing of strip planting systems for non-rice crops and non-puddled rice establishment.

Hoque Corporation has begun developing the market for VMPs by setting up distribution and sales networks and developing a supply chain to manufacture component parts, maintain quality control of products and the VMP, seeks orders and deliver on time and provide after sales service. Since 2016, Hoque Corporation have worked with the Project, in the working hubs, to sell the VMP where demand has been created and there is already a supply chain for spare parts, there are trained mechanics and established LSP who can mentor the new LSP. An important component of the commercialisation model developed with Hoque Corporation is the training of LSP in the operation of the VMP and related services such as weed control. New LSP are provided with repeated training sessions during the first 1-2 years after purchasing the VMP. Experienced operators are engaged to provide training and to mentor the new LSP. In addition to the Project supported sales (21 in 2015, and 36 in 2016), the National Bank in 2016 provided a 3-year loan package for 62 new LSP in Nagoan Upazilla, Rajshahi to each buy a new 2-wheel tractor and VMP. Apart from the training provided by the project to the selected LSP, no other project support or incentives were provided for the National Bank programme. The sales programme with the National Bank was entirely handled by Hoque Corporation. It has continued in 2017 with 39 LSP signing up for National Bank loans for the VMP and 2WT.

To communicate the findings, the project scientists published 32 papers in peer reviewed journals; 11 additional manuscripts have been submitted; and an additional 14 manuscripts are under preparation. A total of 110 abstracts have been published in national and international conference proceedings. The project developed a Newsletter with an email circulation of over 2,500 of which 60 % are in Bangladesh. Four Newsletters were produced. The newsletter is re-circulated by Dr Amir Kassam in the Global CA Community of Practice newsletter.

To share the project findings and engage a wider community of interest in CA in Bangladesh, the project organized three conferences: the 1st Conference on Conservation Agriculture for Smallholders (CASH-I) in Asia and Africa was held during December 2014 where 159 scientists from 20 countries attended. A total of 64 scientific papers were presented and papers published on-line in the Proceedings. The Minimum Tillage Unpuddled Rice Transplanting (MTURT) Conference was held at the Bangladesh Rice Research Institute during 16-17 September 2015 where a total of 174 participants attended. During the MTURT Conference 13 technical papers on non-puddled rice establishment were presented. The 2nd Conference on Conservation Agricultural for Smallholders (CASH-II) will be held at the Bangladesh Agricultural University, Mymensingh during 14-16 February 2017. A total of 55 papers were presented and there were 236 attendees from Bangladesh and abroad. The papers were published on-line in the Proceedings.

The project made significant contributions for the development of capacity in key aspects of CA research (weed control, machinery development, soil fertility, cropping systems). The project offered 8 PhD scholarships (target was 4) [including 4 John Allwright Fellowships] for BARI and BRRI scientists and 22 MS (target was 7) fellowships. Four PhD and 22 MS Fellows already submitted their thesis; and 2 PhD Fellows have been awarded; 1 submitted in September, 2017; and the other will submit within November, 2017. The project supported a total of 126 scientists, university professors, extension officers, and private sector personnel to attend short-term training, seminar, meetings, conferences at home and abroad to publicise the project outcomes. Furthermore, the project scientists had given more than 20 seminars in Argentina, Bangladesh, Cuba, India, Nepal, Australia, Zambia, Vietnam, Malaysia, Vietnam, Philippines, China, etc. on CA in Bangladesh.

During the Project, most of the NARS institutions, agricultural universities, extension and development agencies, policy makers have begun to give priority to CA research and many of them included CA research in their annual research programs. The Government of Bangladesh developed a policy paper "Agricultural Research Vision 2030 and Beyond: Research Priorities in Bangladesh Agriculture" where CA research and development was

given higher priority. To promote the merits of CA to policy makers, the Project has developed Policy Briefs on “CA and Mechanisation in Bangladesh, “Minimum Tillage Upnuddled Transplanting of Rice” and the participants of the CASH-II Conference endorsed a document called “The Mymensingh Declaration” that summarises the benefits of CA and made recommendations for further development and adoption of the technology by farmers.

Soil puddling for transplanting rice seedlings is the limiting factor for the adoption of CA in rice-based cropping systems. The project has developed novel strip-tilled non-puddled rice transplanting in minimally-disturbed soil. Grain yield increases (by up to 12 %) were recorded with the longer-term practice of non-puddled rice together with strip planting of other crops in the rotation, while yield loss was reported rarely found relative to puddled rice. The land preparation cost was reduced significantly by non-puddled rice establishment. More than 3,000 farmers have practiced the non-puddled rice establishment in project working districts.

The effects of CA on soil properties and crop production in rice-based cropping systems in Bangladesh were assessed at six long term experiments. The first two experiments were started by Md. Ariful Islam in 2009 and are now growing crop 23. After 2.5 years in both legume- and cereal-dominated rotations, the soil organic carbon (SOC) concentration, SOC stocks and labile carbon (C) fraction at 0-7.5 cm soil depth were greater in strip planting (SP) than conventional tillage (CT). By contrast, the SOC concentration and storage, and water soluble carbon (WSC) increased at 7.5-15 cm soil depth in bed planting (BP) compared to CT and SP. Soil C losses through the emission of CO2 were greater in CT than SP and BP. The relative efficacy of tillage in storing SOC was in the order of SP>BP>CT. High residue retention increased SOC concentration, SOC storage, WSC and CO2 emission from soil. In the cereal-dominated rotation, SP sequestered 0.44-0.20 Mg C/ha annually while CT caused 0.41-0.66 Mg C/ha loss at 0-15 cm soil depth. In contrast in the legume-dominated rotation, neither CT nor SP sequestered SOC but SP reduced the loss by 0.40 Mg C/ha annually compared to CT. Based on the C balance, it is estimated that annual organic matter inputs of 4 Mg C/ha under SP and 8 Mg C/ha under CT condition in the legume-dominated system, and 2 Mg C/ha under SP and 7 Mg C/ha under CT condition in the cereal-dominated system, would be required to maintain SOC at the antecedent level. Application of SP and higher level of residue (HR) has potential for increasing carbon sequestration and N accumulation while reducing N losses, hence improving soil properties and thereby crop growth and yields, within 2-3 years in rice-based systems of Bangladesh.

Nazmus Salahin, established a three-year long term experiment for his PhD at Rajbari on "Influence of minimum tillage and crop residue retention on soil organic matter, nutrient content and crop productivity in the rice-jute system". The research concluded that the minimum tillage practices ([SP] and ZT (zero tillage) increased SOM, total nitrogen (TN), and the extractable S & Zn contents in the uppermost 0-5 cm soil layer. The changes occurred at 0-5 cm soil depth where the soils were enriched with SOM and TN content by about 20 % under ZT and SP relative to CT practices. The 50 % residue retention significantly increased SOM, TN, extractable P, K, S, Zn and B contents. The SP and higher crop residues conserved more soil water and resulted in the lowest soil penetration resistance values compared to other tillage practices and lower residue retention. The SP practices grain yield of rice and lentil and yield of jute fibre, but not the grain yield of wheat. Higher residue retention increased the yield of jute fibre, rice and wheat. Based on average gross margin and benefit-cost ratio (BCR), SP with 50% residue retention combination was more profitable for T. aman rice, jute and wheat production than other tillage and residue retention combination.s The study suggests that SP coupled with higher residue retention is a suitable tillage-residue management system for rice-jute based cropping that improves soil fertility, farm profitability as well as productivity of crops.

Weeds are a major challenging factor for all crop production. Weed control by herbicides has become the standard practice of > 75 % of rice farmers in Bangladesh. However,

there has been limited research on the effect of herbicides use on weed control, especially for strip planting and crop residue retention. Ms. Taslima Zahan conducted PhD research on "Effect of herbicides on weed and crop in rice-wheat-mungbean cropping pattern under conservation agriculture". From her experiments it was confirmed that the best weed control for SP was obtained from sequentially applied pyrazosulfuron-ethyl, orthosulfamuron and butachlor + propanil that provided similar or better grain and straw yield of rice as weed-free control and gave the highest net benefit among all treatments during both years. Moreover, she concluded that herbicides applied in non-puddled transplanted aman rice had no residual effects on the succeeding crops of wheat, lentil or sunflower. Another of her experiments confirmed that the tolerance level of rice cultivars to high rates of herbicides are herbicide type, crop and variety specific. Finally, she has concluded that rotational application of the selected herbicides in rice-wheat-mungbean pattern could be effective to control weeds in rice and wheat under CA system as those herbicides had no residual effect on the succeeding crops, moreover almost all rice and wheat varieties were tolerant to herbicides at the recommended rate.

To investigate the probable changes of weed dynamics due to adoption of CA, the project sponsored Mohammed Mobarak Hossain to conduct a PhD study. He confirmed over three consecutive years (2013-14, 2014-15 and 2015-16) that, compared to CT, in SP application of pre-emergence herbicides followed by post emergence controlled weeds most effectively having a weed control efficacy of 79%. Retention of 50% residue reduced the weed pressure by 38% compared to 20% residue. Weed free condition in SP yielded the highest amount of grain but the highest BCR (32% higher over CT) was calculated from SP with the application of pre-emergence herbicides followed by post emergence. The lowest BCR was recorded from CT. Retention of 50% residue increased the grain yield by 4% and BCR by 9% over 20% residue. Data of seed bank study reveals that, after the two years field trial, CT enriched the weed seedbank status by 13% while SP reduced seedbank status by 17%. Residue retention diminished the weed seedbank by 11%. In the long-term experiments, after 3-5 years, the weed seedbank was reduced by 30-35 % by SP and increased residue compared to the current conventional practice.

A life cycle analysis (LCA) conducted in 2014 by John Allwright Fellow, Khairul Alam, suggests that minimum tillage non-puddled transplanting with residue retention decreased greenhouse gas (GHG) emissions by 23-29 % compared to the conventional puddling and transplanting in the Boro rice season. In a following LCA for Aman (monsoon) rice, it was found that GHG emissions were no different between the rice established by non-puddled transplanting with increased residue (the CA practice) and puddled soils with low residue retention (the conventional practice). However, when the soil C sequestration of the non-puddled soils was included in the LCA, the CA system decreased the LCA GHGs from 1.4 to 1.2 t per tonne of rice grain.

Nurul Hasan Mahmud, John Allwright Fellow has studied the effects of CA after 4-5 years on water balance. In 2015, there was no difference in the amount of water applied with tillage or residue treatments. In 2016, SP received 40-42 cm more water than conventional tillage plots. Shifting from continuous flooding to alternative wetting and drying (AWD) reduced the amount of irrigation water by about 20 cm for all tillage treatments. Irrigation was less in 2015 plots with plastic lining in the bunds to 15 cm below the soil surface, suggesting that the lining reduced seepage losses. High under-bund seepage in 2016 was attributed to the high hydraulic conductivity of the bunds. In addition the fields surrounding the plots were not irrigated until 20 days later which may have exacerbated water movement under the bunds to these adjacent fields. This study was conducted with groundwater level 10-12 m below ground level from transplanting to harvest of the season, which is also a determining factor in increasing percolation losses in the minimum tillage plots. In 2017, with later planting of the Boro rice, and more effective control of seepage under the bund, there was no significant effect of SP in irrigation water requirement.

Where SP had been practiced continuously for 5-7 years wheat crops required 11-33% less irrigation water compared to conventional tillage. The SP wheat also had higher yield in 2 out of the three years. Water savings in the SP are attributed to the lower bulk density of the soil in the root zone that helps retaining more water compared to tilled soils.

In summary, CA is being adopted in areas where there have been repeated demonstrations of the technology on farmers fields, and there are trained LSP willing to sow CA crops with the reliable VMP. In three Blocks, CA planting reached 10-16 % of all Rabi season crops in 2016-17. A substantial body of research has demonstrated the benefits of CA and mechanised planting for cost savings, yield increases in many cases, increased profit in most cases and substantial labour saving. Improvement in soil quality has been demonstrated in long term experiments together with reduced GHG emissions. Those farmers who adopted CA have achieved substantial yield increases with wheat, mustard and lentil. For all of those crops, as well as maize, profit increased substantially with CA practices.

Based on the potential yield increases and costs savings to farmers, adoption of CA and the VMP planting services by only 2.5 % of all farmers in Bangladesh could directly generate an additional $ 25-45 million per year of value to farmers.

3 Background

Agriculture in Bangladesh is facing the ongoing challenge of increasing food security for its growing population (currently 164 million people (www.worldometers.info/world-**population**/**bangladesh**-**population**/*)* and expected to reach 205 million by 2050 (BBS, 2011)) and improving overall land use sustainability, while decreasing costs of crop production to increase farm profitability. The nation-wide spread of mechanised tillage with two-wheel tractors (2-WT) and development over the past decade of a range of minimum tillage planters for 2-WT, provide a platform for implementing conservation agriculture (CA) principles that will decrease costs of crop production (less fuel consumption, decreased labour requirements) and improve the fertility of soils in Bangladesh. Evaluation of the new Versatile Multi-crop planter (VMP) in 2009-2011, under LWR 2005/001, showed promising results for the establishment and yield of a range of crops in rainfed cropping systems using this novel, light-weight and low-cost planter made entirely in Bangladesh. Other planter options suitable for 2-WT were also developed under LWR 2005/001. However, systematic work is now needed on the implications of CA adoption in rice-based systems and on acceleration of adoption of planters for crop establishment on farms. Furthermore development of CA in Bangladesh, incorporating the new planters, requires on-going research and development to ensure that crop yields are at least maintained using CA approaches; that cost-effective planters are matched to a range of soils, crops and cropping systems; and that effective strategies are developed and evaluated for the engagement of service providers, extension, machinery manufacturers and farmers in the implementation of a form of CA suited to the more marginal cropping areas of Bangladesh (i.e. rainfed and supplementary irrigation areas rather than fully irrigated areas).

Hence the aim of the project was to develop and accelerate the adoption of CA for selected soils, crops and cropping systems in Bangladesh, especially in rainfed areas and those with supplementary irrigation, so that farmers and households can benefit from cost saving crop production technologies and sustainable resource management.

The project was focussed on target areas to provide a range of soils and cropping systems for the evaluation of CA: Rajshahi; Mymensingh, Rajbari, and Thakurgoan. In each of these areas the project has established cropping systems experiments designed to evaluate the most suitable minimum tillage options, and key limitations and profitability of CA applied to rice-based cropping. Experiments were conducted mostly on farms involving farmers' groups and service providers, where aman (monsoon) rice, rabi season (cool and dry) (oilseed, pulse or wheat), and Kharif 1 (pre-monsoon) crops such as Aus rice, mung bean or jute will be included, depending on their local suitability. These was supplemented by research and development focussed on improvements in minimum tillage machinery, starting with the VMP design; field experiments designed for the diagnosis of agronomic constraints in CA related to weeds, nutrition, diseases and insects: and studies on improvements in soil fertility associated with minimum tillage, increased retention of crop residues and more diverse crop rotations including pulses and oilseeds. The project was focussed on developing capacity for on-going CA development by engaging post-graduate students in producing research outputs, with strong support from the university sector (particularly BAU) and the national agricultural research system (BARI, BRRI).

To accelerate the development and adoption of CA in Bangladesh, a network of farmers, service providers, extension officers, NGOs and machinery manufacturers was established, starting in target areas. The purpose of this network is to identify constraints to adoption of CA in the machinery and related-services value chain, and advocate for research and development on relevant minimum tillage machinery, crop agronomy and soils involving specific cropping systems. This network serves as a vehicle for dissemination of findings to farmers. The project complemented other investments in

Bangladesh in irrigated cereal cropping systems by targeting diverse rice-based crop rotations in rainfed and supplementary irrigation areas (e.g. SRFSI), as well as focussing on CA adoption.

In south-west Australia, research will focus on overcoming one of the key barriers to farmer adoption of wide row spacing for cereals by examining weed control and nitrogen fertiliser management. This research supports the development of practices that make cropping better adapted to variable climate, which is a major constraint to resilient cropping in this rainfed environment.

Linkages will made with associated CA research activities in neighbouring regions of West Bengal and Bihar of India and Nepal with similar rice-based cropping systems (through SRFSI) and with East Africa (Ethiopia, Kenya, Tanzania, Zimbabwe) (through FACASI and the Africa Conservation Tillage Network).

4 Objectives

The principle the aim of the project is to develop and accelerate the adoption of CA for selected soils, crops and cropping systems in Bangladesh, especially in rainfed areas and those with supplementary irrigation, so that farmers and households can benefit from cost saving crop production technologies and sustainable resource management.

The project objectives were:

1. Improve adoption of CA led by a service provider network.
2. Design minimum tillage planters for improved operation and effectiveness.
3. Redesign best-practice crop agronomy (including adjustment of seed rate, row width, weed control, crop rotations and fertilizer management) to optimize it for different types of minimum tillage, targeted crop rotations and key soils.
4. Quantify the benefits of CA for soil fertility.
5. Develop capacity for on-going research and development of CA in Bangladesh.

5 Methodology

Objective 1:

The development of CA in the present project was pursued as a partnership of farmers, local service providers (LSP) and machinery manufacturers with researchers and extensionists. Experience elsewhere in the world suggests that such partnerships are conducive to innovation, adaptation of technology to farmer needs and adoption on farms (e.g. Brazil- Pieri et al. 2002). Adoption of CA is in part facilitated by: on-going machinery modifications to allow more flexibility in seeding; development of cost-effective spray technology; improved crop resistance to stubble-borne diseases; more diverse crop and rotation options; breeding herbicide resistant crops; and the use of broad spectrum herbicides (Thomas et al. 2007). Most of this set of facilitators for the adoption of CA was pursued in this project.

During 2012 to 2014, IDE pursued strategies for the commercialization of VMP through the involvement of Alim Industries Ltd., Sylhet and ACI Motors Ltd., Dhaka; and sold 8 and 12 subsidised units of VMP to projects in 2012 and 2013. ACI Motors sub-contracted Janata Engineering Workshop in 2014 to manufacture and sell the VMPs. However, due to low quality of materials used to manufacture the VMPs, most of them had repeated breakages during field operation. Six VMP were procured from Alam Engineering Workshop to replace the defective planters. Neither of the strategies were successful in attracting additional sales; indeed, the poor quality VMP hampered attempts to interest LSP. Furthermore, due to the unproven market demand for VMP, the bigger manufacturers were unwilling to invest in demand creation activities or further development and production of VMP.

The project established service provider networks in each target area and supported the development of capacity in planter operation, crop agronomy and weed control. One-on-one training and group training were provided by the project scientists for LSP. The VMP supply chain has been established with the involvement of a private company: Hoque Corporation (HC), Dhaka was contracted to commercialize 54 units (18 and 36 units targeted in 2015 and 2016, respectively). In collaboration with Project Implementation Office (PIO), HC fostered demand creation among farmers and LSP through demonstrations, focus group discussion. They also provided quality assurance and service after sales while the PIO provided price support for LSP (50 and 25 % in 2015 and 2016, respectively). In addition, the Project partners included financing institutions (e.g., National Bank Ltd.) and established the Conservation Agriculture Service Providers Association. Other partners were the government extension agencies (DAE and BMDA). As a result, during 2015 and 2016 a total of 106 VMPs were sold including 62 units by full-cost sale. In-collaboration with BMDA, and the National Bank Ltd., Hoque Corporation, identified a successful approach to marketing machinery under agricultural loan packages and marketed 60 units of VMP during 2016-17 and 41 units in 2017-18 (HC expecting to sale about 70 units of VMP during 2017).

With the VMP, over 3,000 sites have been planted on farmers' fields in 11 districts in Bangladesh: of these about 10 % were supported by ACIAR project LWR 2010-080 while the rest paid full commercial fees for planting services. Four service providers who purchased the VMP at the discount rate offered by the project have planted different cops including wheat, maize, lentil, chickpea, mustard, rice, etc. in different tillage modes and covered around 1,500 ha. These and new LSP formed the CA Service Providers Association. The uptake of their minimum tillage planting services was a positive indication of interest by farmers in adopting minimum tillage for planting crops. In addition, rapid adoption of other CA principles e.g., retention of crop residue (10-20 cm above ground), introduction of legume (lentil) or mustard between two rice seasons (aman and

boro) were the other indications that farmers are ready to accept key elements of the CA package.

Service providers individually and as groups were engaged to plant and manage CA demonstrations and field days in the target localities (i.e. Rajshahi, Rajbari, Mymensingh). Together with farmers, they were engaged to evaluate the success or weaknesses of crops. The advice of LSP was regularly sought (especially at the twice-yearly training sessions) on aspects of the planter design and operation that need improvement and other constraints to adoption of components of CA.

To support the LSP, training of local mechanics in machinery workshops to manufacture components (e.g. openers) and repair planters was carried out at Rajbari, Rajshahi, and Mymensingh by the project group and BAU. Input from LSP ensured that the training was relevant to maintaining field operations of the planters.

A total of 116 field days were organized at the locations of demonstrations and field trials in Rajbari, Rajshahi Mymensingh and Thakurgoan where more than 10,894 attended. The aim of these field days was to promote CA to farmers and demonstrate the technologies involved. The field days featured the LSP drawing on their experience with the CA technologies.

In order to assess the impact of the project's development and advocacy for the CA approach, a baseline study was be carried out by BAU in Year 1 to assess, in the target areas, whole farm economic performance of early adopters of CA components (e.g. users of minimum tillage, herbicide weed control), and non-adopters. This was followed in Year 4 by a study of whole farm economic performance by the Economic Division of BARI of non-adopters, the early adopter group and farmers who have, over the life of the project, began to adopt elements of CA (Miah et al. 2017).

Objective 2:

Planter improvement: The existing VMP was evaluated and improved to: maximize the residue handling capacity; improve durability, and; improve seed and fertilizer placement. For enhanced crop establishment, we also examined options for improved shape of the furrow opener, and modifications to the rotary shaft, power transmission, rotary blade, etc. The planter modification was carried in collaboration with private partner (Hoque Corporation). Improved versions (Version 11) of the prototype were provided to Hoque Corporation and Alam Engineering for bulk manufacturing and up scaling of production. After each planting season, the planter performance data was collected through stakeholders' meetings and necessary plans were made for further improvement of the planter leading to release of Version 13 by Hoque Corporation. This process was followed up to the end of the project. In Year 2, detailed drawings of the VMP (based on Version 9) specifications were prepared to facilitate up-scaling of production.

Sprayer technology: Cheap, inferior quality knapsack-type backpack sprayers are commonly used in Bangladesh for the application of pesticides and fungicides. The nozzles are poor quality and produce coarse-size droplets with huge potential for spray drift which reduces efficacy and increases the risk of off-target damage. The same types of sprayers are used for the application of herbicide with low efficacy and potential for drift onto non-target crops and harm to operators and bystanders. The project involved a MS Fellow from BAU to collect locally available sprayers and nozzles and test them. The MS Fellow was able to identify more effective and affordable sprayers and nozzles for farmers with demonstrated efficacy for herbicide spraying (detail report is available in the MS Thesis and CASH-I Conference Proceedings).

Non-puddled transplanting: Non-puddled rice transplanting seems promising and effective for rice-based CA systems (Haque et al., 2011 and Haque et al., 2016). Preliminary work in Bangladesh commenced on a mechanized transplanter. These transplanters are based on traditional soil puddling which is detrimental to soil structure and not suitable for CA. Through the involvement of a Ph.D. student, the project developed the transplanter that

can transplant rice seedlings in non-puddled conditions. The research was carried-out at the BRRI Gazipur and BAU campus.

Objectives 3 and 4:

Cropping systems: In target areas, cropping systems experiments was established and run for 5 years on farms, with input from all key disciplines (weed science, nutrition, soil science, agronomy, agricultural engineering, value-chain and extension). These experiments examined crop specific responses as well as emerging longer-term trends (e.g. in weeds). These experiments were the prime locations where expertise of the project and other activities were implemented. A systems approach to CA was used. All experiments were in rice-based rotations and involve 2-3 crops per year with other crops in the rotation chosen for local relevance. Two such experiments were established in Rajshahi under LWR 2005/001 in October 2010 and continued up until now. Cropping systems experiments examined tillage types (strip, bed planting and conventional tillage) and crop residue levels (50 to 100 % retention; 0 to 20 % retention) in rabi season (lentil or wheat), kharif 1 (mung bean or jute) and kharif 2 (rice) seasons. New experiments at BAU, Mymensingh and on a farmer's field in Rajbari were similar in design to the existing trials. Three PhD projects were largely based at these experiments (soil science, water balance and weed science). A weed science study focussed on the shift in weed seedbanks in the soil, emergent weeds and residual weeds under different tillage and residue retention levels at the four long term sites. The aim was to identify trends in weed populations that occur under minimum tillage and to identify new weeds that were likely to hamper the success of CA in farmers' condition. The second PhD student focussed on soil fertility trends under minimum tillage and residue retention. The aim of this study was to determine whether minimum tillage impairs nutrient availability in crops and then to set up further field and glasshouse experiments that explore mechanisms. These sites were also used by John Allwright Fellow, Ariful Islam who was studying soil organic carbon accumulation under different tillage and crop residue retention scenarios and its implications for soil nitrogen forms and availability.

Information on inputs and labour requirements, together with yield will be compiled from these sites by Dr Haque to provide the basis for an analysis after 4+ years on the changes in crop profitability in CA compared to conventional tillage.

The cropping systems trials were used for identification of emerging constraints under minimum tillage such as soil or residue borne diseases or insect pests. We have involved two MS students and a Plant Pathologist from BAU to make such diagnoses.

Agronomic and soils studies: Complementing the cropping systems trials was a range of specific field experiments that was the target key constraints for agronomy, weed control and soil properties. Most of these were carried out as MS and PhD projects and were established in the targeted areas to help disseminate better technologies at farmers' level in a timely manner.

For VMP and other planters for 2-wheel tractors, it is necessary to determine optimum crop residue levels that can be retained while maintaining control over seed and fertiliser placement. Replicated experiments testing from 20 % (comparable to present retention of rice crops) to 100 % retention (the ideal for CA) were established at Rajbari, Rajshahi, Mymensingh and Thakurgaon while sowing into rice, wheat, lentil and mung bean residues. Machinery modifications to improve residue handling were designed and tested. Results were published by Haque et al. (2014).

With the improved control of seed depth under mechanised planting, lower optimum seed rates may be feasible. Previous research in LWR 2005/001 seems to confirm this for lentil and chickpea. Lower seed rate saves cost of crop establishment. Experiments were carried out at Mymensingh with varied seed rates under minimum tillage planting of mung bean by a MS Student. The result is available in the MS Thesis.

The promising early development of the non-puddled transplanting was investigated further to increase reliability of rice establishment relative to direct seeding. Field evaluation of both methods was conducted in cropping systems trials at Rajbari, Rajshahi, and Mymensingh. Additional trials were established with direct seeding and non-puddled transplanting of rice, under farmers' conditions in Rajshahi to test its robustness. This work was led by Dr Haque with support from LSP.

A targeted set of studies on herbicide effectiveness was planned. While glyphosate is commonly used as a pre-plant non-selective herbicide, the major knowledge gap in weed control is effective post-emergence herbicides. Firstly, field experiments were set up by a MS student to assess effectiveness of currently available herbicides for wheat, lentil, mung bean, jute and rice. This work was done predominantly at BAU with follow-up trials to confirm the most effective herbicides. Secondly, herbicide trials were tested for weed control in non-puddled transplanted rice and direct seeded rice. A PhD Fellow undertook this study. Further studies on herbicides effectiveness was targeted to the crop tolerance of herbicide residues and crop tolerance to selective herbicides. In intensive rotations, there are risks from the carryover of herbicide residues from one crop to the next with the possibility of toxicity. This question was studied by a MS and a PhD student initially at Mymensingh. In addition, Dr Haque evaluated the effectiveness of pre-plant and pre-emergence herbicides on farmers' crop rotations.

Safety training on the use of herbicides was provided to LSP, operators and farmers by PIO and BAU in all project working districts. In the target areas, we assessed farmers' herbicide uses/practices and their evaluation of the effectiveness of available herbicides. This was conducted during August and September in 2016 by PIO based on focus group discussions with farmers in target areas. The report was published in May 2017.

It is common during the conversion to minimum tillage to experience greater nitrogen deficiency in non-legume crops. In experiments at Mymensingh, 4 MS students were involved to determine effect of tillage on N fertiliser response in wheat, rice, and mungbean. Rates of N fertiliser was applied under strip tillage and conventional tillage. The aim was to establish whether N fertiliser recommendations need to be changed for minimum tillage planting of the cereals.

The greater climate variability experienced in recent years in southwest Australia has raised interest in whether wide rows reduce risks of crop loss in dry seasons. In wide rows, weed control may be more difficult and continuous row-on-row planting in wide rows may lead to nutrient stratification. Nitrogen rate and application method has a major influence on weed infestation. The aim of the research was to determine the effect of nitrogen and weed control on yields of wheat and legumes in wide row spacings. The main output was to determine optimum row spacing under variable climate in south-west Australia. Long term wide row trials were established at Cunderdin (medium rainfall; wheat-lupin rotation; sandy loam texture) and Merredin (low rainfall; wheat-chickpea rotation; clay loam soil). This research was led by DPIRD with support from Wendy Vance to examine soil water, crop nutrition and root growth implications of treatments. In the 3rd year, Round-up Ready canola was used to determine its effectiveness in controlling weeds.

Objective 5:

A major focus of the project was on training and capacity building to develop a core group of researchers skilled in aspects of CA. This was achieved through training MS and PhD students in components of CA. Twenty-two MS students (project target was 7) completions and 4 PhD completions plus three (original target was one) JAF were expected. Mostly BARI and BRRI scientists were engaged for PhD and MS students from BAU and Khulna University. The project team of BAU academics are experienced MS/ PhD supervisors who were able to provide quality research training and timely completions (4 PhDs have finished, 2 final drafts are close to submission). Students and supervisors was provided with frequent opportunities for presentations in meetings,

seminar and conference. Australian project staff worked with Bangladeshi collaborators to prepare grant applications to Kishi Gobashona Foundation (KGF). The aim was to enhance the capacity of collaborators to attract competitive grants for their research. The BARI Scientist (Dr Md. Ilias Hossain) and University Professors (Dr. M Rafiqul Islam and Prof. Dr Jahirudding) were successful to get two promotional projects from KGF at Rajbari and Mymensingh on CA. Linkages with related projects in Bangladesh were fostered to develop CA. Invitations to other ACIAR and USAID projects were made for the inception meeting when detailed project plans are made, and to subsequent annual review meetings, and to CASH-I and CASH-II conference. In collaboration with BAU, BARI, BRRI, BARC, BMDA, IRRI, CIMMYT, FAO, MU, PROVA, HC, etc. the project successfully held three conferences.

Regional linkages especially in West Bengal and Nepal were fostered to accelerate the development of CA in neighbouring countries with similar cropping systems to Bangladesh. Linkages was established through exchange visits and shairing outcomes of the project through CIMMYT-led SRFSI project activities, individual scientists interactions. In addition the project exported 2 VSTP and 3 VMP and conducted training for the operation, repair, maintenance in India (Jharkondh) so that experimentation on farms with CA can be promoted.

6 Achievements against activities and outputs/milestones

Objective 1: To improve adoption of conservation agriculture in Bangladesh through service provider networks

No.	Activity	Outputs/ Milestones	Due date of output/ milestone	Comments
1.1	Develop partnership with farmers, service providers and machinery manufacturers to accelerate the adoption of CA	Service provider groups established first in/Rajbari and Rajshahi.	May 2015*	Partnership developed with manufacturers (Hoque Corporation [HC], Alam Engineering, Alim Industries, ACI Motors, Janata Engineering) for complete VMP manufacturing. Partnership developed with manufacturers of components and spare parts through HC.
		Service provider groups established in Mymensingh and **/Thakurgaon	May-Oct 2015	224 service provider groups developed in 11 districts (Rajbari, Rajshahi, Natore, Bogra, Rangpur, Dinajpur, Thakurgaon, Ponchghor, Naogaon).
		Develop partnerships with service providers, farmers and manufacturers	Dec 2015	HC taken full responsibilities to manufacture and commercialize VMP since 2016 and involved National Bank Ltd. for credit facilities (up to 80%) for VMP purchase. BMDA and CASPA started wider promotion of VMP in Barind and in CASPA working districts. Developed partnership with Department of Agricultural Extension (Rajshahi, Bogra, Thakurgaon, Natore, etc.); Pulses Research Center and RARS-Barisal of BARI; Agronomy and Soil Science Departments of Bangladesh Agricultural University; CCDB, and Syngenta Foundation to sale/promote VMP for different projects. Established linkage with PRADAN in India and exported 3 units of VMP during 2017.
		Service provider groups complete first set of demonstrations and field days	June 2016	Completed first set demonstration and field days by service providers group (joint activity with Activity 1.2)
		Assess effectiveness of service provider network in CA adoption	March 2017	Assessment done. See below section.

		Final report on CA adoption in 6 study areas including economic social impacts of the technology on farmers, service providers and manufacturers	March 2017	Adoption study completed by the Socio-economic group of BARI. Detailed report submitted. The impact study confirmed that the adoption of CA has started. The rates of adoptions of crop residue retention (67%), crop rotations were 39%, and the minimum soil disturbance (strip planting) was 19% in the project areas. This study also, confirmed that the age, innovativeness, and extension contact of the farmers and availability of VMP had significant positive influence on the adoption of CA technologies. CA technology could save labour up to 34%, seed 31%, fertilizers 6%, pesticides 32% and total cost of production up to 10% in cultivating lentil, mustard, maize, and wheat (Miah et al., 2017). Again, it increased crop yield and net profit by up to 28% and 460% respectively (Miah et al., 2017).
1.2	Evaluate minimum tillage under farm conditions by service providers in a range of soils, crops, seasons, and agro-ecological zones	Complete demonstrations on tillage, residue, weed control, crop rotations in 3 target areas Set up demonstrations in 6 study areas	December 2012 in /Rajbari, Rajshahi, Mymensingh Repeating annually in 2013, 2014, 2015, 2016, 2017 including Thakurgaon also	Total 3414 (Yr1=465, Yr2-520, Yr3-552, Yr4-540, Yr5-1,437) demonstrations completed on tillage, residue, weed, crop rotation, non-puddled rice in study areas.
		Compile outputs of demonstrations and prepare key findings for reporting to farmers, extension and service providers	Oct 2015, March 2017	CA adoption study completed by Miah et al. (2017) In addition, demonstration results were compiled and shared with LSP and farmers; also, demonstration results are used to publish journal and conference papers.
1.3	Strengthe n a CA network of farmers and service providers	Select service providers, machinery manufacturers, researchers, extension and machinery manufacturers to form national CA network	June 2015	Established “Conservation Agriculture Service Providers Association (CASPA)” involving 9,800 farm families. Service providers of VMP led these events (reported in Activity 1.2) and more than 2000 male and female participants attended including local administration, extension officers, researchers, service providers, herbicide marketing company, herbicide dealers, and farmers.
		Complete first national CA network meeting and distribute summary of goals and planned outcomes	December 2015 and 2016	Completed 3 national CA Network meeting in Rajshahi. CA Farmers and Service Providers Congress was held on 18 Feb 2017
		Engage private sector by running workshops	Dec 2015 and Dec 2016	Engaged 9 workshop technicians for repairing VMPs in project working districts.

1.4	Train operators, farmers and DAE officers in the optimal operation of minimum tillage planters	Schedule and run training in each target area twice per year	March 2012 October 2012 and repeated each following year	Trained 318 operators, DAE Officers, BARI, BRRI Technicians, Herbicide Dealers (Yr1-20, Yr2-45, Yr3-0, Yr4-4, Yr-201). Trained 7456 farmers (including 2327 women) on CA, minimum tillage and safe use of herbicide. 55 Union Agriculture Officers and Sub-Assistant Agriculture Officers of DAE trained on CA.
1.5	Train mechanics in machinery workshops to manufacture and repair planters	Schedule and run training sessions	Sept/Oct 2015 and Sept/Oct 2016	Achieved with Activity 1.4 43 mechanics trained (Yr1-7, Yr2-7, Yr3-3, Yr4-3, Yr5-23) including on the job training at Hoque Corporation, Alim Industries, Janata Engineering, Alam Engineering
1.6	Field days, technical promotion and advocacy	Schedule field days in target areas involving service providers and farmers	March, August and December annually in target areas	116 Field days, FGD and promotional meeting, etc. organized (Yr1-13, Y2-7, Yr-37, Yr4-28, Yr5-14) where 10,894 participants attended
1.7	Value chain of machinery and related services sub-sector (Faridpur/ Rajbari, Rajshahi, Mymensingh, Dinajpur/Thakurgaon)	Complete value chain study on small farm machinery sub-sector with recommendations Complete study on crop residue utilisation with recommendations	31 December 2012 30June 2013	Study has not undertaken and MTR recommended used this fund for commercialization activities.
1.8	Regional Conservation Agriculture conference (Bangladesh)	Confirm funding with FAO Schedule date and distribute first announcement Finalise programme and participants Hold Conference in Bangladesh	January 2012 March 2012 June 2013 Dec 2013	Conference 1 (Conference on Conservation Agriculture for Smallholders in Asia and Africa): The conference was held from the 7 to 11th December 2014 at Bangladesh Agricultural University, Mymensingh, with a pre-conference tour from the 4th to the 6th of December. The conference was attended by 159 participants from 20 countries The conference Themes were addressed by 6 keynote presentations, 37 oral and 21 poster presentations. Proceedings in electronic version of the conference are available http://researchrepository.murdoch.edu.au/26081/

				Conference 2 Conference on Minimum Tillage Unpuddled Rice Transplanting was held 16-17 September 2015 at BRRI Gazipur. The workshop conference was attended by 174 participants from BRRI, BARI, BARC, Australian High Commission in Bangladesh, Ministry of Agriculture of GOB, Bangladesh, BAU, BAU, DAE, IRRI, Bangabandhu Sheikh Mujibor Rahman Agricultural University, Bangladesh Institute of Nuclear Agriculture (BINA), CCDB, BRAC, VMP and VSTP Service Providers, farmers During the workshop a total of 13 technical papers on unpuddled rice were presented. Proceedings in electronic version of the conference available. Field Crop Research agreed to publish Virtual Special Issue; several papers are already published while others are under review. Two of those submitted by the project were rejected, while 3 are still under review.
				Conference 3 (2nd Conference on Conservation Agriculture for Smallholders [CASH-II] The 2nd Conference on Conservation Agriculture for Smallholders (CASH-II) was held from 14 to 16 February 2017 at the Bangladesh Agricultural University, Mymensingh, Bangladesh. The conference was attended by 234 participants from five countries (Bangladesh (225), India (3), Australia (4), South Korea (1), and USA (1). This conference was designed to present the current status of CA for smallholders, establish linkages among the collaborators and to chart a course for future developments that can help farmers to find CA an attractive option. The conference was a platform to share success stories, identify barriers to development of CA and identify the key strategies that facilitate the adoption of CA. There were four main themes for papers: 1. Design and development of machinery, implements, and tools 2. Soils, water and weed management and agronomy 3. Commercialization and adoption of CA-based technologies and practices 4. Policy and institutional framework During the conference the themes were addressed by 4 keynote presentations, 26 oral and 25 poster presentations.

1.9	Increase demand for CA through increased numbers of service providers	Develop package to test the role of incentives for service providers and manufacturers Select new service providers Review effectiveness of package and revise if necessary	June 2015 June 2015 March 2016 and Dec 2016	Developed incentive packages for new LSP (50, 25, and 0% price support for year 1, year 2, and year 3, respectively; 30 bigha tillage cost per VMP @Tk. 300, 350, 400 for year 1, year 2, and year 3, respectively). Developed incentive packages for manufacturers (modification of seeding mechanism; identification of sources of spare parts, establish linkage with farmers/LSP groups, mass promotion, establish national, regional and international linkage for marketing of VMP). Hoque Corporation established dealer/broker sales commission. DAE provides up to 70% subsidy to LSP for BARI-developed planter purchase; that creates challenges for VMP commercialization with 0% subsidy in new area.
		Report on adoption of CA planting services by service providers including economic and social impacts	March 2017	Miah et al. (2017) submitted the final report.
1.10	Promote private sector development and marketing of quality VMP/VSTP	Develop partnerships Develop marketing programmes with manufacturers Document the business models of successful service providers Run training programmes for service providers	June 2015 Dec 2015 Dec 2015 Dec 2015 and Dec 2016	Finalized the commercialization strategy with the private partner (Hoque Corporation) targeting sales of 54 units (but achieved 106 units) of VMP during 2015-16 and 2016-17. With lower effort, HC continuing commercialization activities of VMP. Until mid-October, 2017 a total of 41 new LSP registered for purchasing the VMP (20 already handed over); however, HC expecting to sale about 70 units of VMP during 2017. Signed agreement with Hoque Corporation for commercialization of VMP and VSTP. Training programmes achieved with activity 1.4 and activity 1.5 Used FFGD to elicit components of LSP business model. Dr Monayem Miah of BARI reported on the business model of 18 LSP
1.11	Implement quality assurance / quality control (QA/QC) programmes for VMP/VSTP manufacture	Develop quality assurance and quality control programmes for VMP/VSTP manufacture Report on effectiveness of quality assurance and quality control (QA/QC) programme	July 2015 Dec 2015 and Dec 2016	Project staff and Hoque Corporation staff were fully engaged during manufacturing for QA/QC. Faults with VMP were identified and fixed or parts replaced under an after sales agreement provided by Hoque Corporation.

1.12	Communications of CA	Prepare draft CA Manual to summarise recommended practices and identify gaps and update over time Complete VMP video in Bangla and English Complete VMP operating manual in Bangla and English Prepare CA and mechanisation briefing note Hold briefing meetings on CA and mechanisation with policy makers and lending agencies	Oct 2015, Oct 2016, and March 2017 Dec 2015 Dec 2015 June 2015 Dec 2015 and Dec 2016	CA Manual prepared with the involvement of CA scientists from BARI, BRRI, BAU, DAFWA and Murdoch University. Video on VMP was made on the version 9 of VMP; however, significant modification of VMP was done; further video based on version 13 is required. Fund is not available to prepare version 13. In future based on the funding availability a new video will be prepared. The Project prepared a policy briefing note on CA and mechanisation. Held many briefing meetings on CA and mechanization with policy makers (BAU, BARC, BARI, BRRI, SRDI, DAE, Secretary - MOA, Governor - Bangladesh Bank, Chairman-BMDA, BSMRAU, etc.)
1.13	Exit strategy from the manufacture and marketing of machinery	Hold meeting with other projects promoting adoption/ commercialisation of planters and small-scale farm machinery to identify successful approaches Appraisal report of different approaches to commercialisation	Dec 2016 March 2017	Organized meetings with BMDA, National Bank Ltd., Syngenta Foundation, Lanka Bangla Finance Ltd., Social Islami Bank Ltd., South Bangla Bank Ltd., Bangladesh Krishi Bank, RDA, GBK-Dinajpur, SME Foundation, BPP. Met with CSISA-MI and also with CIMMYT-led FACASI project in East Africa on a few occasions to discuss commercialisation approaches. In-collaboration with BMDA, National Bank Ltd., Hoque Corporation, identified a successful approach to marketing machinery under agril. loan packages and marketed 60 units of VMP during 2016-17 and 40 units planned in 2017-18. An analysis of the approaches tested for VMP commercialization can be found in CASH-II conference paper.

During implementation of the project the study areas were refined to Rajbari and Thakurgoan

* Bold text indicates new activities for the Variation or additional/ new dates for achievement

** Text with strikethrough line has been deleted as an activity/ milestone based on the recommendation of the Mid Term Review

PC = partner country, A = Australia

Objective 2: Design minimum tillage planters for improved operation and effectiveness

No.	Activity	Outputs/ Milestones	Due date of output/ milestone	Comments/Achievements (June 2015 to June 2016)

2.1	Continuous improvement of planter machinery	Identify planter defects and situations where different planter features are needed Trial modifications to reduce weight of VMP/ VSTP	May and October 2012 and annually Dec 2015	Released Version 13 of VMP in 2016 with driving seat for operator's comfort and easy transport. arrangement. 3D and 2D Manufacturing drawings of VMP for Version 10 released. Finally released Version 13 with further improvement on - (i) rotary shaft for varied row spacing; (ii) shank of the furrow opener to increase its strength (iii) seed-boot and fertilizer-orifice of furrow opener were modified to minimize seed and fertilizer contact. Based on feedback from operators who found seed rate calibration difficult, seven vertical meters for different seed size have developed to regulate the seed rate without further calibration. Also, to optimize the price, minimize the weight, and balance the weight, substantial improvement was made on VMP during 2015 and 2016.
2.2	Spray technology evaluation and improvement	Setup experiments to test effectiveness of different spraying devises for weed control Report on best practice for spraying	Sept 2012 November 2012 and annually Dec 2015	Study was done by a MS Student on "Performance Evaluation of Compressor and Lever Operated Type Sprayers for Weed Control". Extended abstract paper presented in CASH Conference 2014. CA manual describes best practice for spraying.
2.3	Unpuddled transplanter	Select PhD candidate Evaluate existing designs of transplanters that could be fitted to the 2-WT planters Test transplanters for effectiveness Report on effectiveness of transplanters Submit PhD thesis and draft papers	January 2013 December 2013 December 2014 and Dec 2015 December 2015 December 2015	Unpuddled transplanter developed by the PhD student (from BRRI), Md. Anwar Hossen. PhD thesis accepted, degree awarded. Completed the modification on a mechanised rice transplanter in strip unpuddled rice transplanting. Drafted 3 journal papers on evaluation of transplanters in unpuddled soil.
2.4	Minimum tillage planters for 4-wheel tractors (Bangladesh)	A preliminary evaluation of planters suited to 4-wheel tractors (<50 hp) in Bangladesh in the project study areas	March 2013	It was not possible to identify an interested student to undertake this review. Project Variation removed this Milestone.

PC = partner country, A = Australia

Objective 3: Redesign best-practice crop agronomy (including adjustment of seed rate, row width, weed control, crop rotations and fertilizer management) to optimize it for different types of minimum tillage, targeted crop rotations and soils.

No.	Activity	Outputs/ milestones	Due date of output/ milestone	Applications of outputs
3.1	Determine optimum crop residue levels (Rajbari, Rajshahi, Mymensingh, Thakurgaon)	Establish trials with variable levels of crop residue and assess success of crop establishment under minimum tillage Complete report	Dec 2012 June 2014	One experiment was completed by Ariful Islam in April 2013 and results are available in the thesis. A detailed analysis was completed on residue levels in on-farm experiments and demonstration to determine effects on success of crop establishment. An extended abstract was presented at CASH Conference which is available on request. Further information is provided in the CA Manual
3.4	Develop reliable rice establishment methods for minimum tillage	Establish trials with direct seeding and unpuddled transplanting of rice Establish unpuddled transplanting demonstrations in study areas	Aug 2012, repeated in Aug 2013, 2014	Two direct seeded rice (DSR) trials were established; significantly lower grain yields were reported in DSR compared to non-puddled or puddled transplanting. Further trials are needed of DSR with reduced seed rate and nutrient management. For non-puddled establishment, 1,037 (Yr1-46, Yr2-256, Yr3-115, Yr4-620) farmers adaptive trials/demo completed.
		Hold seminar on Minimum Tillage Unpuddled Transplanting of Rice		The Minimum Tillage Unpuddled Rice Transplanting (MTUPRT) workshop was held at BRRI where a total of 174 national and international scientists, extensionists, policy planners attended.
		Report and journal papers on unpuddled transplanting technologies	Aug 2015 Oct 2015 Jan 2016	Published a paper, Haque et al., 2016 in Field Crops Res. http://dx.doi.org/10.1016/j.fcr.2015.10.018 During the conference a total of 13 technical papers on MTUPRT of rice were presented. Field Crops Research agreed to publish a Virtual Special issue on Minimum tillage rice in 2017 with Drs Bell and Haque as Guest editors. Subsequently Dr Liz Humphreys has taken over most of the editing. Three project papers are under review.
3.6	Long term trends in weeds, pests and disease	Select PhD candidate Establish weed seedbank studies at cropping systems trials	Jan 2012 Dec 2012	Seedbank study completed. Results available in the extended abstract of CASH-II conference proceeding.
		Complete thesis on weed seedbank dynamics under different tillage types	Dec 2016	The complete draft is with supervisors for revisions. The plan is to submit by December 2017.

		Monitor each crop in cropping systems trials for emergence of new patterns in pests and diseases	Dec 2012 and annually	No evidence of differential disease expression or insect infestation in strip planting or with increased residue retention has been observed in the other 5 long term experiments. Two leaf diseases of rice were identified (sheath blight and bacterial leaf blight) at BAU farm in the long-term experiment. After scoring of the symptoms and identification of the disease it was concluded that strip planting had no effect on disease incidence or severity but increased residue retention did.
		Incorporate findings in Herbicide training courses and CA Manual	Aug 2015 and Dec 2016	Incorporated in the CA Manual.
3.7	Assess effectiveness of herbicides for wheat, lentil, mung bean, jute and rice (Faridpur/Rajbari, Rajshahi, Mymensingh)	Select MS student Establish herbicide trials for un-puddled transplanted rice and direct seeded rice Complete thesis Select MS student Establish herbicide trials for lentil and mung bean Complete thesis Submit KGF application on effectiveness of herbicides for mung bean and lentil	Jan 2012 August 2012 June 2013 Sept 2012 March 2013 June 2014 March 2013	Mr. Sultan Ali, MS Fellow completed research on Effect of seed rate on yield performance of three mungbean varieties under strip tillage system. Thesis submitted and degree awarded in May 2014. Md. Shamsuzzaman Shameem, MS Fellow completed research on " Response of jute, mungbean and sunflower to the residual toxicity of herbicides used in wheat under strip tillage system". Thesis submitted and degree awarded in December 2014. KGF did not call for any new proposals at this time.
3.8	Safety training on herbicides	Provide training on safe storage and use of herbicides and safe disposal of empty containers Conduct before and after assessments of learning about safe use of herbicides and prepare a report on efficacy of training Select Bangladesh trainer(s) for 2016 course Incorporate findings in CA Manual	Annually with training on operation of planters December 2015 and 2016 Aug 2015 December 2015 and 2016	Achieved with activities 1.3, 1.4 and 1.6. The training to be carried out by Dr Abul Hashem on safe storage and use of herbicides and safe disposal of empty containers was cancelled due to political instability, however, Dr Hashem had informal meetings with stakeholders on use and safety with herbicides. Plans to hold a follow training were not implemented due to security issues that prevented participants from travelling. Before and after herbicide use assessments (see Activity 3.9) conduced by farmers' focus group discussions. CA Manual sections about herbicides completed. Draft CA Manual completed.
3.9	Assess farmers' herbicide uses/practices and evaluation of effectiveness of available herbicides	Complete focus group discussions with farmers in target areas	December 2013	Survey conducted with 285 farmers in September 2016 in the project area. Data presented in 7th World Congress of CA, Argentina. Manuscript is under preparation for journal publication.

3.11	Crop tolerance to selective herbicides	Select PhD student Establish experiments on crop tolerance to selective herbicides Complete thesis Incorporate findings in Herbicide training courses and CA Manual	Sept 2013 March 2014 Dec 2015 Aug 2015 and Dec 2016	Mrs. Taslima Zahan, PhD Fellow completed field experiments of “Effect of herbicides on weeds and crops in rice-wheat-mungbean cropping pattern under conservation agriculture system”. Thesis submitted in September 2017: still under evaluation. Incorporated findings in the CA Manual

PC = partner country, A = Australia

Objective 4: Quantify the benefits of CA for soil fertility

No.	Activity	Outputs/ milestones	Due date of output/ milestone	Comments/Achievements (June 2015 to June 2016)
4.1	Maintain two established long term trials (Rajshahi)	Assess medium term changes (i.e. after up to 5 years) in soil organic matter and nutrient forms under different tillage methods Complete PhD thesis Support two new JAFs to implement studies	Dec 2012 and annually thereafter June 2015 Dec 2015 and 2016	Ariful Islam awarded PhD degree in 2017 based on soil changes under crops 1-7 in two long term experiments. These two experiments have been continued by another John Allwright PhD Fellow (Khairul Alam) who has completed 2 years of mustard at Durgapur and chickpea at Godagari followed by unpuddled boro and aman rice in Durgapure and jute in Godagari. Khairul's PhD thesis is expected to be completed by the end of 2017. Mr.Hasan Mahmud, SSO, BRRI continued as a John Allwright Fellowship with PhD research on "Effects of minimum tillage in rice-based rotations on water balance". He conducted field trials at Durgapur, Godagari, and Thakurgaon on trafficking effects on soil strength and on water balance from November 2015. Nurul's PhD thesis is expected to be completed by June 2018. Mr.Praya Lal Chandra Paul, SO, BRRI was selected for PhD program of John Allwright Fellowship to conduct "Assessment of the short to medium term effect of conservation agriculture on soil salinity and cropping system productivity in salt-affected regions of the coastal zone of Bangladesh". Priya Lal's project is now supported by the CSIRO Project LWR/2014/073, Cropping System Intensification for the Coastal Zone of Southern Bangladesh and West Bengal.

4.3	Determine effect of tillage on N fertiliser response (Mymensingh)	Select MS student Establish N response trials Complete theses Prepare journal paper on findings after 4 years	Jan 2012 and Jan 2013 Dec 2012 and annually to 2016 June 2014 December 2016	Completed 4 MS Ms. Sarmin Shahanaz. - "Requirement of Nitrogen for T. Aman Rice under Strip Tillage System" June 2013. Ms. Sutapa Karmaker - "Nitrogen Requirement for T. Aman rice under Strip Tillage System at Two Residue Retention Levels" June 2014. Mr. M. Mortuba Ali - "Requirement of Nitrogen for the Wheat-Mungbean Cropping Sequence under Strip Tillage System" June 2014. Mr. Sahed Hasan - "Crop Response to Nitrogen Fertilizer under Strip Tillage and Residue Retention in the Wheat-Mungbean-T. Aman Pattern", June 2015. Kader et al. submitted a paper for a Special issue of Field Crops Research on “Minimum Tillage Rice Establishment, on Strip planting decreases nitrogen fertilizer requirements while retention of more residue increases them in a rice-wheat-mungbean sequence on a subtropical floodplain soil.”

PC = partner country, A = Australia

Objective 5: Develop capacity for on-going research and development of CA in Bangladesh

No.	Activity	Outputs/ milestones	Due date of output/ milestone	Applications of outputs
5.1	Training MS students in components of CA	7 MS student completions in total 2-4 completions per year	June 2013 and annually	Total 22 MS Students Completed Abdullah- Al- Musabbir. Performance study of Versatile Multi Crop Planter with Different Types of Blade. Department of Farm Power and Machinery, Bangladesh Agricultural University. June 2014 Azit Kumar Dass. Adoption of conservation agriculture practices in Bangladesh. Department of Agricultural Extension Education. Bangladesh Agricultural University, Mymensingh. June 2013 Juthi, Z. Yield response of mungbean to different tillage options under different soil moisture levels in southwestern Bangladesh. Agrotechnology Discipline, Khulna University, Khulna. 2016. M. Mortuba Ali. Requirement of Nitrogen for the Wheat-Mungbean Cropping Sequence under Strip Tillage System. MS Thesis, Dept of Soil Science, BAU. 2014. M. Ripon Hossain. Nitrogen Requirment of Crops Under Strip Tillage System at Two Residue Levels in the Rice–Wheat-Mungbean Pattern. MS Thesis, Dept of Soil Science, BAU. 2016. M. Shamsuzzaman Shameem. Response of jute, mungbean and sunflower to the residual toxicity of herbicides used in wheat under strip tillage system. Department of Agronomy, Bangladesh Agricultural University, December 2014. M. Sultan Ali. Effect of seed rate on yield performance of three mungbean varieties under strip tillage system. Department of Agronomy, Bangladesh Agricultural University, Mymensingh, May 2014. Md Sanowar Hossen. Performance evaluation of Compressor and Lever Operated Type Sprayer for Weed Control. Department of Farm Power and Machinery, Bangladesh Agricultural University. June 2014. Md. Asif Iqbal. Yield performance of four aman rice varieties under minimum tillage unpuddled rice transplanting system. Department of Agronomy. Bangladesh Agricultural University, Mymensingh. 2015 Md. Riaz Hasan. Effect seed rate on the yield performance of wheat under strip tillage system. Department of Agronomy, Bangladesh Agricultural University, Mymensingh.

				Md. Sabbir Hossain. Modification of VMP for better residue handling capacity. Department of Farm Power and Machinery, Bangladesh Agricultural University, Mymensingh. 2016. Ms. Nahida Sharmin. Assessment of soil weeds seedbank status in long-term trials of conservation agriculture. Department of Agronomy, Bangladesh Agricultural University, Mymensingh. 2017. Ms. Priyanka Chakrobarti. Performance of T.Aman rice varieties under unpuddled transplanting systems. Department of Soil Science, Bangladesh Agricultural University, Mymensingh. 2014. Ms. Sultana Razia. Study on weed seed distribution in different depth of soil under long-term conservation agricultural system. Department of Agronomy, Bangladesh Agricultural University, Mymensingh. 2017. Muhammad Shahinur Islam. Utilization of Crop Residues and Crop-Livestock Interaction in Rural Household in Bangladesh. Department of Animal Science. Bangladesh Agricultural University, Mymensingh. June 2013. Prokash Chandra Biswas. Grain yield of mungbean under different tillage by Versatile Multi-crop Planter in southwestern Bangladesh. Agrotechnology Discipline, Khulna University, Khulna. 2016. Rafia Akhter. An Economic Study on Conservation Agriculture in Rural Areas of Bangladesh. Department of Agricultural Economics. Bangladesh Agricultural University, Mymensingh. December 2013 Sabab Farhan. Effects of Conservation Agriculture and Nitrogen Fertilization on Carbon Footprint in the Wheat-Mungbean-Rice Cropping System. MS Thesis, Dept of Soil Science, BAU. MS Thesis, Dept of Soil Science, BAU. 2016. Sahed Hasan. Crop Response to Nitrogen Fertilizer under Strip Tillage and Residue Retention in the Wheat-Mungbean-T. Aman Pattern. MS Thesis, Dept of Soil Science, BAU. 2015. Sarmin Shahanaz. Requirement of Nitrogen for T. Aman Rice under Strip Tillage. System. MS Thesis, Dept of Soil Science, BAU. 2013. Sutapa Karmaker. Nitrogen Requirement for T. Aman rice under Strip Tillage System at Two Residue Retention Levels. June 2014. MS Thesis, Dept of Soil Science, BAU. 2014. Trisha Paul. Influence of Conservation Agriculture and Nitrogen Fertilization on Soil Properties in Rice Based Cropping System. MS Thesis, Dept of Soil Science, BAU. 2016.

5.2	Training of PhDs in CA	4 PhD completions	Dec 2016	8 PhD Fellows enrolled (4 from project at BAU; other 4 John Allwright at Murdoch Univ) Enrolled at BAU Engineer Md. Anwar Hossen, SSO, FMPHT Division, BRRI, has been awarded the PhD degree. His thesis topic was " Development of rice transplanter for un-puddle condition". Mr. Nazmus Salahin, SO, Soil Science Division, BARI, completed his final thesis revisions and academic counsil of BAU has been approved his thesis and is waiting for syndicate announcement. His thesis topic is " Influence of minimum tillage and crop residue retention on soil organic matter, nutrient content and crop productivity in the rice-jute system". Ms. Taslima Zahan, SO, OFRD, BARI submitted her thesis which is under examination. Her thesis topic is "Tolerance of Rice, Wheat, Lentil and Mungbean to Selective Herbicides in Minimum Tillage Cropping Systems". Md. Mobarak Hossain, Dept. of Agronomy, BAU, submitted final draft of his thesis to supervisor and expecting to final submission by December 2017. His thesis topic is " Weed Seed Bank Dynamics in Conservation Agriculture.
		Support 2 new JAFs	Dec 2015 and 2016	John Allwright Fellows at Murdoch Univ. Md. Ariful Islam, SO, PRC, BARI, Ishurdi, Pabna has been awarded PhD degree. His thesis topic was "Effect of Conservation Agriculture Practices on Crop yield and Soil Properties in Rice-based Cropping systems in Bangladesh" Md. Khairul Alam, SO, Soil Science Division, BARI, completed field and lab works, thesis writing is going on, with a plan to submit by the end of December 2017. His research topic is " Assessment of Soil Carbon Sequestration and Climate Change Mitigation Potential Under Conservation Agriculture (CA) Practices" Mir Nurul Hasan Mahmud, SSO, IWM Division, BRRI, completed field experiments and is writing his thesis. Thesis will be submitted by June 2018. His research topic is "Effects of minimum tillage in rice-based rotations on water balance". Priya Lal Chandra Paul, SSO, IWM Division, BRRI completed the first season of 5 field experiments. The field research will be continues up to 2019. Expecting to submit final thesis by December 2019. His research topic is "Assessment of the short to medium term effect of conservation agriculture on soil salinity and cropping system productivity in salt-affected regions of the coastal zone of Bangladesh".

		Conduct training in research methods and writing for peer reviewed journals	Dec 2016	Organized grant writing course for capacity improvement of young scientists of BAU, BARI, BRRI, NGO during 8-9 Feb 2013 and 19 participants attended in this training course. PhD Fellows have agreed to write sections based on their work for the CA Manual. Journal and conference papers are in publishing pipelines (please see in Section 3.5)
5.4	Maintain linkage with related projects to develop CA in Bangladesh	Invite other ACIAR projects to Inception meeting and annual review meetings Meeting with Project Leader of SRFSI project	Jan 2012 and annually Sept 2015 and 2016	Maintained linkages with ACIAR funded Rice-Maize and Short Duration of Legumes projects and other CA projects like CSISA, ANEP, etc. through sharing project outcomes, meetings, visit, etc. The project stakeholders have met the Governor and senior officers of Bangladesh Bank (Central Bank of Bangladesh); Secretary of Agriculture Ministry, GOB; Managing Director and Directors of BASIC Bank; Director General and Directors of Department of Agricultural Extension (DAE); Executive Chairman and Member Directors of Bangladesh Agricultural Research Council; DG and Directors of BARI and BRRI; Vice Chancellors, Faculty Deans, Department Heads and Professors of Bangladesh Agricultural Research University and Khulna University; Executive Director and Directors of Krishi Gobeshona Foundation; CIMMYT-CSISA, SRFSI, various donor agencies including USAID and DFID to share the project progress and outcomes. Prof Dr Richard W. Bell and Md. Enamul Haque met with Dr Gathala and Dr Tiwari on eight occasions mostly recently in Sept 2016, and when we attended the Annual Progress and Planning Meeting of SRFSI in Rangpur in Sept 2017.

5.5	Develop regional linkages especially in West Bengal and Nepal to foster CA	Identify collaborators in West Bengal/ Bengal and Nepal Invite collaborators in Nepal and W Bengal to Regional CA Conference in 2014 Research exchanges through collaboration with SRFSI	Jan 2012 Jan 2013 2012 onwards	Prof. Dr. RW Bell and Dr. Md. Enamul Haque gave keynote lectures and attended various meetings to share the project outcomes through seminars in Bangladesh, India, Malaysia, Nepal, China, Vietnam, Zambia, etc. Dr Md. Enamul Haque visited India and Nepal in 2013 to establish linkages among the scientists, extensionists, and private sector stakeholders working for smallholders' conservation agriculture and farm mechanization; to understand the agriculture of Bihar, West Bengal and Orissa; Nepali agriculture in plain land (Tarai) and assess the suitability to collaborate/upscale the LWR-2010-080 project activities, including 2WT-based farm machineries i.e., VMP, mini mill, strip tillage unpuddle transplanting of rice, etc. Prof. Mahfuza Begum, BAU; and two PhD Fellows (Mrs. Taslima Zahan and Mohammed Mobarak Hossain) participated in the 25th Asia Pacific Weed Science Conference, Hydrabad, India during 16-19 October 2015 to present three papers in the conference. A total of 174 national and international scientists, extensionists, policy planners attended the MTUPRT. During the workshop a total of 13 technical papers on MTUPRT of rice were presented. Dr. ME Haque and Md. Mizanul Hoque from Hoque Corporation visited China to establish linkage with Chinese manufacturers to produce and market VMP and other ag. equipment in Bangladesh. Dr TP Tiwari as Project leader of SRFSI was invited onto the Organising Committee for the CASH-II conference to be held in Feb 2017. Dr Mahesh Gathala was invited to submit manuscripts on minimum tillage rice establishment from SRFSI project work. Dr ML Jat attended the CASH-II conference and gave Keynote talks; also, he presented a paper of Ghatala et al., about CA program in CIMMYT. Prof Bell and Dr Haque attended the Annual Review meeting of SRFSI in September 2017 at Rangpur.

PC = partner country, A = Australia

7 Key results and discussion

Objective 1: Improve adoption of CA led by a service provider network.

The Project trained 318 Local Service Providers (LSP), technicians from the National Agricultural Research and Extension System (NARES), NGOs, the private sector; and 43 mechanics of VMP/VSSD and manufacturing factory/repairing workshops. A total of 6,611 farmers have hired/used VMP/VSTP to sow lentil, mustard, mungbean, sesame, jute, wheat, maize, rice, chickpea, etc. and covered more than 1,500 ha in the 2016-17 Rabi season.

In 2016, the project identified 224 farmers' groups working in 9 districts (with a membership of 9,800 farm families) and established the Conservation Agriculture Service Providers Association (CASPA). It established its headquarters at Durgapur, Rajshahi, adopted a constitution and elected office bearers. In collaboration with the CASPA and DAE, the project: established a total of 3,414 farmers' participatory demonstrations (farmers contributed most of the inputs, and the project provided only the critical inputs) on minimum tillage, residue retention, crop rotation, weed management, non-puddled rice establishment, etc.; trained 7,456 farm families on CA and integrated weed management practices, and safe use of herbicide; organized 116 Field Days, Focus Group Discussion sessions and promotional meetings that reached 10,894 farmers most of whom are retaining some level of crop residue, practicing crop rotation (e.g., lentil adoption in Durgapur; mustard between two rice crops at Gouripur); practicing of strip planting systems for non-rice crops and non-puddled rice establishment.

Soil puddling for transplanting rice seedlings is the limiting factor for the adoption of CA in rice-based cropping systems. The project has developed novel strip-tilled non-puddled rice transplanting in minimally-disturbed soil. Grain yield increases (by up to 12 %) were recorded with the longer-term practice of non-puddled rice together with strip planting of other crops in the rotation, while no yield loss was reported over puddled rice. However, land preparation cost reduced significantly by non-puddled rice establishment (Fig. 1).

In the on-farm comparisons of strip-tilled non-puddled rice transplanting in minimally-disturbed soil, few farmers obtained lower yields than the conventionally tilled and puddled fields (Fig. 1). In aman season 53 out of 66 farmers who practiced strip-tilled non-puddled rice transplanting reported higher net returns than in conventionally tilled and puddled while 49 out of 66 farmers reported higher yield (Figure 1). In boro season of 2013, 2014 and 2015, the net return was higher in 90 - 92 %, of cases in strip-tilled non-puddled rice transplanting while 75 % had the same or higher grain yield.

More than 3,000 farmers have practiced the non-puddled rice establishment in project working districts during the project life.

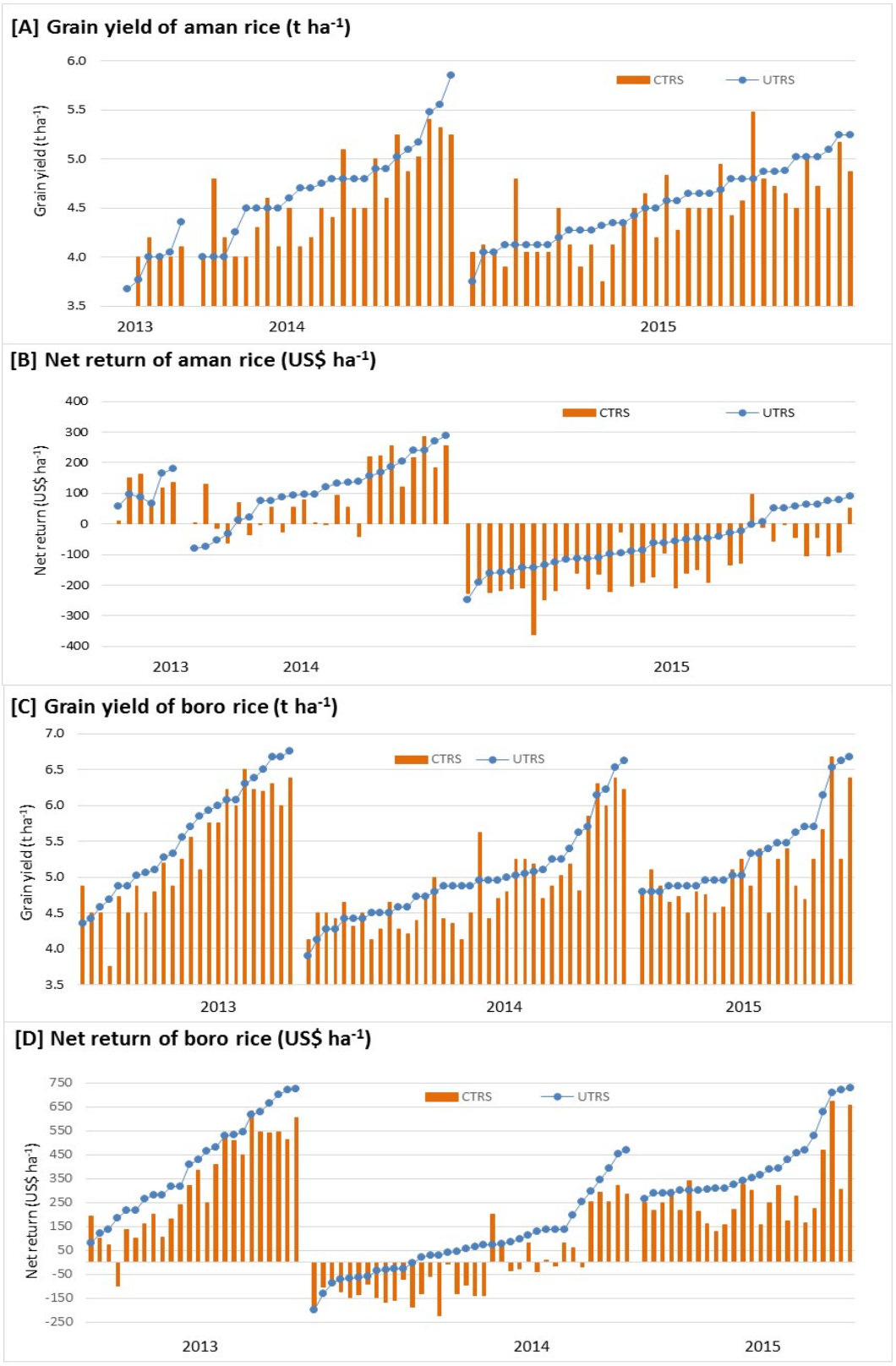

Figure 1: Individual farmers' aman rice [A] and boro rice [C] grain yield (t ha^{-1}), net return of aman rice [B] and boro rice [D] comparison between Unpuddled transplanting of rice seedling (UTRS) [blue line with round bullets] over Conventionally-puddled transplanting of rice seedling (CTRS) [orange coloured bars] during 2013, 2014 and 2015.

During 2012 to 2014, IDE developed strategies for the commercialization of VMP through the involvement of Alim Industries Ltd., Sylhet and ACI Motors Ltd., Dhaka; and sold 8 and 12 subsidised units of VMP to projects in 2012 and 2013, respectively; a further 24 units of VMP were exported to Mexico (15 units), Zimbabwe (3 units), Ethiopia (3 units), Kenya (2 units), and 1 (unit) to India through HC. ACI Motors engaged Janata Engineering Workshop in 2014 to manufacture and sell the VMPs. However, due to low quality of materials used to manufacture the VMPs, most of them had repeated breakages during field operation. Six VMP were procured from Alam Engineering Workshop to replace the defective planters. Neither of the strategies were successful in attracting additional sales; indeed the poor quality VMP hampered attempts to interest new LSP in the planters. Furthermore, due to the unproven market demand for VMP the bigger manufacturers were unwilling to invest in demand creation activities or further development and production of VMP. However, since 2015 after ending the partnership with IDE, the LWR-2010-080 project has implemented two models for VMP commercialization that are showing promising signs of success as follows:

Model 1: Since the Rabi season of 2015, HC has sold 156 units (21, 94 and 41 units in 2015, 2016 and 2017, respectively: additional orders likely in 2017) of VMP, one unit was exported to Myanmar in 2016 and three to India. Hoque Corporation and the PIO worked together for demand creation in six target hubs and ensured quality production and delivery of VMP on time. In 2015, 2016 and 2017, both PIO and HC identified interested new 2WT service provider groups in project working hubs, because - i) most of the service providers had 2WT which is essential to operate planters/implements and they had the financial means to buy VMP; ii) they are well known in their community for selling tillage services; iii) they are business-minded, risk takers who are open to try and adopt new technologies compared to traditional farmers; iv) they have mechanical skill and require minimal training on VMP operation and maintenance; v) they already are a trusted source of advice to farmers in their locality; vi) LSP have established linkages with extension agencies, CASPA, local administration and farmers of their community.

The live demonstration of VMP operation and on-farm demonstration of crop performances by LSP for establishing wheat, onion, garlic, lentil, chickpea, mungbean, jute, etc. were organized at Union level by PIO and HC to create demand for the VMP. The interested LSPs were asked to register with a deposit of Tk. 10,000-12,000 as a down-payment before the Rabi season. The PIO arranged VMP operation, repair and maintenance training programmes in mid-October to early-November of each year prior to handover of the VMP to LSP. During the training program, the LSP deposited 50 % of the VMP price with HC. During mid-November to early-December, HC handed over the VMP to the LSP. Service providers paid the remaining 50 % of the cost during hand over of the VMP. For initial demand creation from new LSP, the LWR-2010-080 project provided 50 % and 25 % price support for 18 and 33 units of VMP in 2015 and 2016, respectively. No price support was provided for the sale of 41 units of VMP in 2017. In 2017. the National Bank has provided 80 % of the cost of VMP (and 2WT), with the LSP having to provide 20 % cash deposit. Additionally, the project provided free training to LSP on repair and maintenance of VMP, follow-up meetings with LSP, and with HC organized farmers' field days for demand creation at farmers' level. These Project activities created confidence by farmers, LSP, and involved stakeholders (e.g., DAE, BMDA, National Bank, etc.) in VMP adoption and commercialization.

Model 2: As the use of VMP could save irrigation water and reduce the cost of crop cultivation, the BMDA sought assistance from PIO and HC to promote VMP in Naogaon district in 2016 and 2017. In collaboration with BMDA and National Bank, the PIO and HC identified 62 and 15 new LSP in Naogaon district, in 2016 and 2017, respectively; where, the National Bank provide a 3-year loan package of Taka 170,000 to each LSP (after registration, Tk. 50,000 to buy a VMP and Tk. 120,000 for a 2WT) without any property mortgage. Each LSP provided a down payment of Tk. 10,000-12,000 to HC to confirm registration. The project organized the VMP training program as in Model 1. The BMDA engaged Chittagong Builders or local dealers to deliver 77 2WT units (62 and 15 units of

2WT in 2016 and 2017, respectively) in Naogaon. On behalf of the LSPs, the National Bank has settled the payment with HC and Chittagong Builders or dealers after successful handover of the VMP and 2WT.

Since 2010, a total of 243 units of different models of VMP have been manufactured and sold (143, 63, 23, 12, and 2 units by HC, Alam Engineering, Alim Industries, Janata Engineering, and Tongi Engineering, respectively) locally and 44 units exported to 9 countries (Mexico - 15, India - 14, Ethiopia - 6, Vietnam 2, Zimbabwe 2, Kenya 1, Myanmar 1, Tanzania 1, and Uganda 1).

During 2012 to 2015, 2016, and 2017; a total of 6, 18, 50 VMPs were monitored closely to collect performance data. The adoption of VMP by farmers to grow various crops has been increasing over the period. On an average, each VMP covered 6.5 ha during 2012-2013; average planting area increased to 11.7, 12.5, 13.7, and 18.9 ha and served 31, 87, 93, 56, and 75 farmers during 2012-13, 2013-14, 2014-15, 2015-16, and 2016-17, respectively. In 2017, 18 LSP were purposely selected from Rajshahi, Thakurgaon, Mymensingh, and Rajbari districts for a study of their business model. The study revealed that LSPs effectively utilized VMP and PT for 4-6 months (Miah et al. 2017). They received Tk. 1,42,434 (with price support on VMP) and Tk. 1,36,134 (without price support) per year as net income. The average payback periods were 0.72 and 0.98 years with and without price support, respectively. The annual break-even use of VMP is 7.8 ha.

Working with multi-stakeholders is critically important for commercialization of new agricultural technology. The LSPs and farmers are cautious to invest money for new farm implements as many of them had been cheated or had bitter experience to get proper services from private companies after purchasing implements. Involvement of universities (e.g., BAU, Murdoch University), extension agencies (e.g., DAE and BMDA) and strong coordination through PIO has built the trust among the LSPs and farmers to buy and adopt the VMP.

Based on farmers' requirements, ongoing modification of the VMP during 2015 and 2016 has significantly reduced the market price, and its weight, and improved weight balancing, while maintaining assurance of high quality production. Seven vertical meters with different seed apertures have developed and supplied with the VMP to regulate the seed rate without further calibration. Also, significant improvement was made on the shank of furrow openers to increase the strength, while the seed-boot and fertilizer-orifice of the furrow opener were modified to minimize seed and fertilizer contact. This improvement has strengthened confidence by LSP and farmers in the use and performance of the VMP.

In conclusion, both the commercialization models implemented by PIO are showing signs of success, although, the scenarios, mode of operation and strategy of both models were different.

Objective 2: Design minimum tillage planters for improved operation and effectiveness.

During the project implementation period (April 2012 to August 2017) significant achievements has been made. The Project-sponsored PhD Fellow, Md. Anwar Hossen, SSO, BRRI, Gazipur successfully developed the unpuddled rice transplanter; MS Fellow, Md. Sanowar Hossen from BAU evaluated the lever-operated sprayer for weed control; the Project Coordinator, Dr. Md. Enamul Haque, developed the Versatile Strip Seed Drill (VSSD), and made substantial improvement to the Versatile Multi-crop Planter (VMP) leading to the release of Version 11 in 2015. Since HC took up manufacture and sales of the VMP in 2015, they have made further improvements to the VMP seed metering, seed boxes, tynes and paint work. While five local manufacturers were engaged to manufacture and market the VMP and VSTP and sold 243 units (the project total target was 54 units) during the project including 44 units exported to nine countries, only HC has been proactive in developing the machinery and the markets.

The field capacity of VMP was 0.07 ha/hr for SP which was 34 % higher than for CT. Land preparation cost by VMP was decreased by up to 75 % for single pass compared to CT. The VMP was capable of sowing many crops from small jute seed (2 g/1000 seeds) up to maize (160 g/1000 seed). The VMP weighs 133-152 kg and ex-factory price is US$900. Significant variation was observed on field capacity when operated for CT, SPST, SP, ZT and BP: 0.03, 0.07, 0.07, 0.06 and 0.05 ha hr^{-1}, respectively (Table 1). Fuel consumption was highest for CT (33.1 l ha^{-1}) and lowest in ST (5.83 l hr^{-1}) by VMP (Table 1). The SPST, SP, ZT and BP by VMP saved 38, 82, 50 and 13 % diesel fuel over CT. The maximum cost (US$ 41.47 ha^{-1}) of land preparation and seeding was incurred in case of CT system and the lowest (US$ 10.27 ha^{-1}) for ST (Table 1). Compared to CT, planting by SPST, SP, ZT, and BP systems lowered costs by 52, 75, 23, and 13 %, respectively (Table 1). Seeding by VMP with a vertical plate seed meter, about 96 % of maize plants were placed 180 to 260 mm apart (mean 205 mm; SE ± 3.9 mm) with a single-pass operation. The spacing between plants was more uniform even than maize planted by hand in well-prepared land after four tillage operations (data not shown here).

Table 1. Effect of tillage mode by the Versatile Multi-crop Planter on fuel consumption, field capacity, labour requirement and cost of land preparation and seeding of lentil, chickpea, mung bean and black gram in clay soil at High Barind Tract, Rajshahi, Bangladesh, 2010-11. Summarised from Bell et al. (2017)

Tillage type	Field capacity (ha/hr)	Fuel consumption (l/ha)	Labour requirement, (person-hr/ha)	Cost of land preparation and seeding[a], (US$/ha)
Conventional tillage (4 tillage passes)	0.03c	33.1a	48.1a	41.5a
Single pass shallow tillage	0.07a	20.6c (38)	15.4c (68)	19.8d (52)
Strip planting	0.07a	5.83e (82)	15.3c (68)	10.3d (75)
Zero tillage	0.06ab	16.6d (50)	17.3c (64)	18.1c (23)
Bed planting	0.05b	28.9b (13)	23.9b (51)	28.8b (13)
LS	**	**	**	**

Values in parentheses indicate the percent saving over CT. Values in a column, followed by a common letter are not significantly different at P < 0.01 by Duncan's Multiple Range Test.

[a]Considering variable costs for labour (land preparation @Taka 30 and seeding @Taka 20/ha); diesel fuel (@Taka 45/l). 1 US$ = 68 Taka

The VMP is a unique multi-functional and multi-crop planter powered by 12-16 hp 2WT with capability for seed and fertilizer application at variable rates, depth and row spacing using SPST, SP, ZT, BP, and CT. The shaft and brackets designed for the VMP achieve improved flexibility for multi-crop planting and capacity for rapid adjustment of row spacing on a field-by-field basis. The seed metering arrangement appears to outperform other planters for 2WT in Bangladesh. By using the VMP, the establishment costs for various crops in different tillage systems were significantly reduced compared to CT. Planters such as VMP now have proven capability and performance to develop CA practices across a wide range of cropping systems used by smallholder farmers in Asia, Africa and other regions.

Objective 3: Redesign best-practice crop agronomy (including adjustment of seed rate, row width, weed control, crop rotations and fertilizer management) to optimize it for different types of minimum tillage, targeted crop rotations and key soils.

Weeds are a major challenge for crop production everywhere. Weed control by herbicides has rapidly become popular in Bangladesh. To assess present herbicide, use in Bangladesh, a study was carried out by Haque et al., (2017) in nine districts involving 287 farmers. Respondent farmers who practiced conventional cropping had an average 1.26 ha farm size and 66% had 5-20 years of farming experience. Respondents estimated that hand weeding increased weed control costs over herbicide uses by 108 to 597% for the main cultivated crops: monsoon and irrigated rice, wheat, maize, potato, onion, garlic, lentil, chickpea, mustard, jute, mungbean, sesame, and vegetables, during 2015-16. In 2015-16, about 85 % of respondents used herbicides (30% herbicides only and 55% herbicide+one hand weeding) and only 14% used hand weeding alone to control weeds in their crop fields; whereas, five years back it was only 19% by herbicide+one hand weeding and 81% was sole hand weeding. The respondents also confirmed that at present about 87% of farmers used herbicides to control weeds in their localities and 98% farmers bought the herbicides from local dealers. The crop-wise herbicide use in their localities were 75, 78, 55, 56, 60, 48, 76, 51, 48, and 45 % for monsoon rice, irrigated rice, wheat, maize, jute, mustard, potato, lentil, chickpea, and mungbean, respectively. Farmer focus group discussion suggest that more than 75 % of rice crops have herbicide weed control and more than 45 % of a range of other crops. This change has largely occurred in the last 5 years due to labour shortages.

Relative to the current use of herbicides there has been limited research on the efficacy of herbicides for weed control, especially for strip planting and with crop residue retention. Ms. Taslima Zahan conducted PhD research on "Effect of herbicides on weed and crop in rice-wheat-mungbean cropping pattern under conservation agriculture". From her experiments it was confirmed that the best weed control was obtained from sequentially applied pyrazosulfuron-ethyl, orthosulfamuron and butachlor + propanil that provided similar or better grain and straw yield as weed-free control and gave the highest net benefit among all treatments during both years. Moreover, she concluded that herbicides applied in non-puddled transplanted aman rice had no residual effects on the succeeding crops of wheat, lentil or sunflower. Another of her experiments confirmed that the tolerance level of herbicides are herbicide type, crop and variety specific. Finally, she has concluded that rotational application of the selected herbicides in rice-wheat-mungbean pattern could be effective to control weeds in rice and wheat under conservation agricultural system as those herbicides had no residual effect on the succeeding crops, moreover almost all rice and wheat varieties were tolerant to herbicides at the recommended rate on the product label. Rice varieties ,BRRI Dhan33 and BRRI dhan56, and wheat varieties, BARI Gom 21, 24, 26 and 28, could be selected if higher dose of herbicides need to applies to suppress heavy weed infestations.

To investigate the probable changes of weed dynamics due to adoption of CA, the project sponsored Mohammed Mobarak Hossain to conduct a PhD study. From his study, it was confirmed over three consecutive years (2013-14, 2014-15 and 2015-16) that SP application of pre-emergence herbicides followed by post emergence herbicide controlled weeds most effectively with a weed control efficacy of 79%. Retention of 50% residue reduced the weed pressure by 38% compared to 20% residue. Weed free condition in SP yielded the highest amount of grain but the highest BCR (32% higher over CT) was calculated from SP with the application of pre-emergence herbicides followed by post emergence. The lowest BCR was recorded from CT. Retention of 50% residue increased the grain yield by 4% and BCR by 9% over 20% residue. Data of seed bank study reveals that, after the two years field trial, CT enriched the weed seedbank status by 13% while SP reduced seedbank status by 17%. Residue retention diminished the weed seedbank by 11%. After 3-5 years of continuous CA practice, the weed seedbank was reduced by 30-35 % by compared to the current conventional practice. Hence, in the medium to long term there is likely to less difficulty suppressing weeds in the CA fields.

Objective 4: Quantify the benefits of CA for soil fertility.

The effects of CA on soil fertility and crop nutrition in rice-based cropping systems in Bangladesh was assessed by Md. Ariful Islam. After 2.5 years in both legume- and cereal-dominated rotations, the soil organic carbon (SOC) concentration, SOC stocks and labile carbon (C) fraction at 0-7.5 cm soil depth were greater in SP than CT. By contrast, the SOC concentration and storage, and water soluble carbon (WSC) increased at 7.5-15 cm soil depth in bed planting (BP) compared to CT and SP. Soil C losses through the emission of CO2 were greater in CT than SP and BP. The relative efficacy of tillage in storing SOC was in the order of SP>BP>CT. High residue retention increased SOC concentration, SOC storage, WSC and CO2 emission from soil. In the cereal-dominated rotation, SP sequestered 0.44-0.20 Mg C/ha annually while CT caused 0.41-0.66 Mg C/ha loss at 0-15 cm soil depth. In contrast to the legume-dominated rotation, neither CT nor SP sequestered SOC but SP reduced the loss by 0.40 Mg C/ha annually compared to CT. Based on the C balance, it is estimated that annual organic matter inputs of 4 Mg C/ha under SP and 8 Mg C/ha under CT condition in the legume-dominated system, and 2 Mg C/ha under SP and 7 Mg C/ha under CT condition in the cereal-dominated system, would be required to maintain SOC at the antecedent level. Application of SP and higher level of residue (HR) has potential for increasing carbon sequestration and N accumulation while reducing N losses, hence improving soil properties and thereby crop growth and yields, within 2-3 years in rice-based systems of Bangladesh.

After 5 years under CA, the increase in SOC was 65-68 % at the long term experiments at Alipur and Digram. That is equivalent to an additional 3.8-4.2 t of C/ha in the soils after 5 years under CA (strip planting and increased residue retention) (see Table 2 for the results at the Digram site). Soil nitrogen storage also increased with the CA practices, which also decreased soil bulk density and increased soil porosity.

Table 2. Selected physical and chemical characteristics of the 0-10 cm soil layer of the studied area at Digram after five years of conservation agriculture practices (strip planting and increased residue retention). From Alam et al. (unpublished data).

Treatments	Characteristics					
	Bulk density (g cm^{-3})	Porosity (%)	pH (H_2O)	Total N (g kg^{-1})	Total organic C (t ha^{-1})	Microbial Biomass C (mg kg^{-1})
CTLR	1.53	40.5	6.10	0.49	6.43	93
CTHR	1.46	43.1	6.40	0.58	7.83	136
SPLR	1.50	41.9	6.40	0.59	9.00	84
SPHR	1.40	45.1	6.70	0.76	10.22	142
$LSD_{0.05}$(Tillage×Residue retention)	0.05*	0.81*	Ns	0.08*	0.53*	21.8*

[Legends:, CT – conventional tillage, and SP – strip planting; HR – increased residue retention and LR – farmers' practice].

Another Ph.D. Fellow, Nazmus Salahin, conducted research on "Influence of minimum tillage and crop residue retention on soil organic matter, nutrient content and crop productivity in the rice-jute system". The research at Rakbari on a light textured soil

concluded that the minimum tillage practices ([SP] and ZT (zero tillage)) increased SOC, total nitrogen (TN), and extractable S & Zn contents in the uppermost 0-5 cm soil layer. The 0-5 cm soil depth was enriched with SOM and TN content by 24 & 23 %, 23 & 18 %, and 11 & 9 % under ZT, SP and CT practices, respectively, in contrast with the initial values while the accumulation of extractable P, S and Zn followed the sequence as ZT>SP>BP>CT practice. The 50 % residue retention significantly increased SOM, TN, extractable P, K, S, Zn and B contents. Tillage and crop residue retention had significant influence on the soil penetration resistance (PR) and soil water content (SWC), but not soil bulk density. The SP and higher crop residues conserved more soil water and decreased penetration resistance values compared to other tillage practices and lower residue retention. The SP practices increased grain yield of rice and lentil and yield of jute fibre, but not the grain yield of wheat (Fig. 2). Higher residue retention increased the yield of jute fibre, rice and wheat.

Based on average gross margin and benefit-cost ratio (BCR), SP with 50% residue retention combination was more profitable for T. aman rice, jute and wheat production than other tillage and residue retention combination. The study suggest that SP coupled with higher residue retention is a suitable tillage-residue management system for rice-jute based cropping in the sustenance of soil fertility, farm profitability as well as productivity of crops.

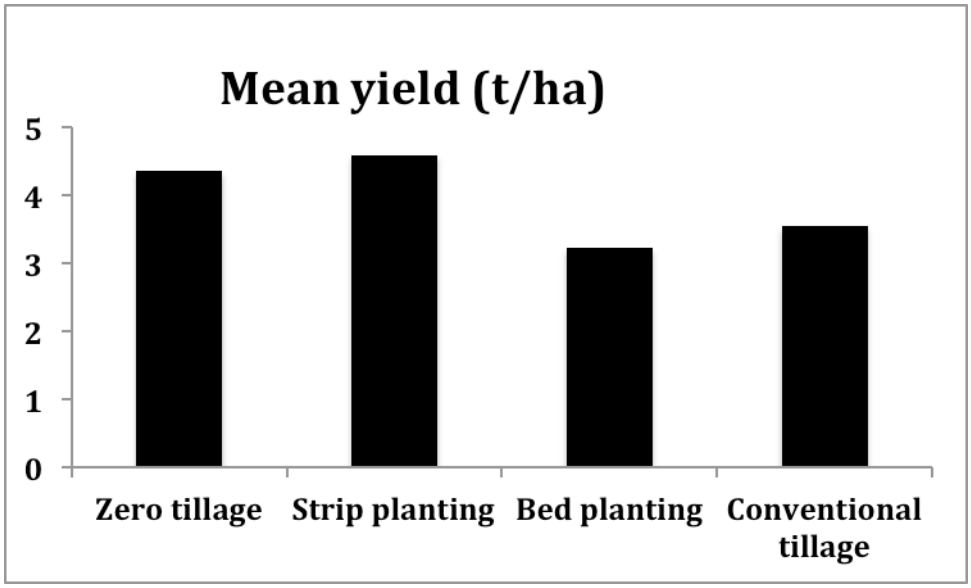

Figure 2 Mean fibre yield of jute (t/ha) over three consecutive years at Rajbari (Salahin et al. 2017).

Objective 4: Develop capacity for on-going research and development of CA in Bangladesh.

To communicate the findings, the project scientists published 32 papers in high impact factor journals; 11 additional manuscripts have been submitted; and additional 14 manuscripts are under preparation. A total of 110 abstracts have been published in national and international conference proceedings.

The project organized three conferences: the 1st Conference on Conservation Agriculture for Smallholders (CASH-I) in Asia and Africa was held during December 2014 where 159 scientists from 20 countries attended. A total of 64 scientific papers were presented. An electronic version of the proceedings is available at http://researchrepository.murdoch.edu.au/26081/. The Minimum Tillage Unpuddled Rice Transplanting (MTURT) Conference was held at the Bangladesh Rice Research Institute during 16-17 September 2015 where a total of 174 participants attended. During MTURT

Conference 13 technical papers on non-puddled rice establishment were presented. The abstracts are available on request. Field Crop Research agreed to publish Special Issue of papers on non-puddled rice establishment and 3 papers are in review. The 2nd Conference on Conservation Agricultural for Smallholders (CASH-II) will be held at the Bangladesh Agricultural University, Mymensingh during 14-16 February 2017. A total of 55 papers have been received and about 234 attendees participated from Bangladesh and abroad.. Proceedings are available on line: http://researchrepository.murdoch.edu.au/id/eprint/36818/.

The project made significant contributions for the development on human resources. The project hosted 8 PhD scholarship holders (target was 4) [including 4 John Allwright Fellowships] for BARI and BRRI scientists and 22 MS (target was 7) fellowships. Four PhD and 22 MS Fellows already submitted their thesis; and the 2 PhD Fellows have been awarded degree, 1 submitted a final thesis in September, and 2 others will submit by December, 2017. The project supported a total of 126 scientists, university professors, extentionists, private sector personnel to attend short-term training, seminar, meetings, conferences at home and abroad to publicise the project outcomes. Furthermore, the project scientists had given more than 20 seminars in Argentina, Cuba, Bangladesh, Brazil, India, Nepal, Australia, Zambia, Vietnam, Malaysia, Vietnam, Philippines, China, etc. on conservation agriculture.

During the Project, most of the NARS institutions, agricultural universities, extension and development agencies, policy makers have begun to give priority to CA research and many of them included CA research in their annual research programs. The Government of Bangladesh developed a policy paper "Agricultural Research Vision 2030 and Beyond: Research Priorities in Bangladesh Agriculture" where CA research and development was given higher priority. Four of the PhD fellows and one of the Principal Investigators has obtained funds from Bangladesh sources to carry out further investigations on aspects of CA.
Briefing meetings were held with the Secretary of Agriculture, Government of Bangladesh, the Governor of the Bangladesh Bank and the Minister of Agriculture. Policy Brief on Conservation Agriculture and Mechanisation, and on Minimum Tillage Non-puddled Transplanting were prepared and used in these briefing sessions. A CA Declaration (the Mymensingh Declaration) was adopted by the participants in the CASH-II conference in February 2017.

8 Impacts

8.1 Scientific impacts – now and in 5 years

The project aimed to create novel contributions to science on effective CA practices for smallholder farms using minimum tillage implements mounted on 2-WTs. It developed new knowledge on - i) strip planting (Bell et al. 2017; Vance et al. 2015); ii) planting machinery development, performance (Haque et al. 2016, 2017); iii) agronomy for mechanised seeding with minimum soil disturbance and residue retention (Vance et al. 2016); iv) weed dynamics and weed management under CA (Hossain et al. 2014, 2017; Zahan et al. 2015, 2017); iv) crop rotation effects on soils and weeds (Hossain et al. 2015); v) mechanised transplanting of unpuddled rice (Hossen et al. 2015); vi) soil improvement (Islam et al. 2015; Salahin et al. 2017); vii) greenhouse gas emissions under CA (Alam et al. 2016); vii) water use under CA systems (Mahmud et al. 2017); viii) strip tillage non-puddled rice transplanting performance in farmers' fields (Haque et al. 2016); detailed water balance studies showed that wheat under CA (strip planting and increased residue retained) required 11-33 % less irrigation water than the convention practices,, and: commercialisation models for planters (Haque et al. 2017). The outcomes of this project will lead to sustainable agriculture systems in intensive rice-based cropping systems. Thirty-two papers have been published in international and national journals while another 11 are under review. The project also published 110 conference papers.

The paper by Johansen et al. (2012), which reviewed the state of play on CA for smallholders at the start of the project, has attracted 100 citations (Google Scholar 9 November, 2017); Haque et al. (2016) already has 13 citations for the study on non-puddled rice transplanting. It is already clear that minimum tillage non-puddled transplanting of rice ensures better crop yield, less fuel use for land preparation, reduced CO2 emission, and increased crop profit. Initial findings were published in 2016 (Field Crop Research Haque et al. 2016; Journal of Cleaner Production Alam et al.).

The project successfully organized the first Conference on Conservation Agriculture for Smallholders (CASH) in Asia and Africa in 2014 to assemble and document CA developments and to establish linkages among the collaborators working on CA for small holders. A total of 159 participants from 20 countries (mostly from Asia and Africa) attended. In this conference, 75 papers were presented of which 20 papers were from LWR-2010-080 project. The complete Proceedings are available on line: http://researchrepository.murdoch.edu.au/26081/. There have been 424 downloads of these Proceedings and many of the extended abstracts have been cited since 2014.

The follow-up CASH-II (www.cash-ii.com) was held during 14-16 February 2017 in Mymensingh, Bangladesh with financial support from Event Funding program of ACIAR. It featured the outputs of the present project and gathered the outputs of other CA researchers in Bangladesh to arrive at a clear understanding of advances, current best practice and remaining bottlenecks for future research. A total of 55 papers were presented on CASH-II themes of which 33 papers were from the LWR-2010-080 project. There have been 121 downloads of these Proceedings and many of the extended abstracts have been cited during 2017.

During this project, dozens of international conference papers on aspects of the VMP/VSTP development and evaluation, commercialization, non-puddled rice establishment, herbicide effectiveness, weed management, etc. have been presented and some of these have already being cited in the literature. Ethiopian scientists have concluded that the VMP is the best for wheat and maize planting following field evaluation on their soils. In most cases, minimum tillage systems by VMP/VSTP performed better

compared to conventional systems in terms of net benefit. Among the minimum tillage techniques, strip planting (SP) was generally the best.

The novel strip tillage non-puddled rice seedling transplanting has been investigated in all target districts of the project and consistently performed better compared to conventional puddled system that indicates an additional strategy for incorporation of CA practices into rice-based rotations. A 2-day workshop on Minimum Tillage Unpuddled Rice Transplanting (MTUPRT) was held at BRRI where a total of 174 national and international scientists, Agricultural University Professors, extensionists, donors, policy planners, local service providers, and farmers attended. During the workshop a total of 13 technical papers on MTUPRT of rice were presented. The proceedings and the report are available on request. A highlight of the workshop was to expose much of the research of LWR/2010/080 on MTUPRT to a broader audience. There was an overall acceptance of the validity of the research and that MTUPRT could play a valuable role in rice farming in Bangladesh. In addition, we were able to feature research undertaken independently by IRRI, BRRI and BARI on MTUPRT. Field Crops Research has agreed to publish a Virtual Special Issue on Non-Puddled Rice Establishment. Prof. Richard Bell and Dr. Md. Enamul Haque have contributed as guest editors, but of the editing has been undertaken by Dr Liz Humphreys. Of the papers submitted, 5 were contributions from the LWR-2010-080 Project, but two were rejected while others are still under revision.

Selection of herbicides with different modes of action is an essential tool to minimise the risk of herbicide resistance developing in weeds Under this project the study revealed that application of herbicides has significantly reduced weed infestation in wheat and rice fields under strip planting and provided up to 227 and 28 % higher grain yield of wheat and non-puddled rice, respectively, compared to non-weeded plot. No residual toxic effect of herbicides were found from herbicides applied to rice on following sunflower, wheat, mung bean crops. Similarly no toxicity was detected in mung bean grown after various herbicides were used to treat weeds in wheat.

Up to crop 7 in a rice-based rotation, there was no indication that strip planting nor increased residue retention altered the N fertiliser requirements for maximum yield of rice or wheat. Research results showed that both NH4-N and NO3-N levels in standing water were higher for conventional full-tillage-puddled rice establishment compared to strip tillage non-puddled systems. This result indicates that more N loss might occur for the case of conventional full-tillage-puddling and soil preparation compared to strip tillage.

In a preliminary screening experiment, the project evaluated 14 widely-grown rice varieties under strip tillage and non-puddled transplanting. Some varieties yielded better under strip tillage non-puddled establishment than others but more field testing is needed to verify the consistency of these results.

Research results also showed that the carbon sequestration was influenced by ($p<0.01$) tillage practices and residue retention levels. The carbon sequestration was positive and ranged from 35.2 to 288 kg C per ton of rice production. The carbon sequestration was higher in strip planting with high residue retention than those of other treatment combinations. The non-puddled transplanting of rice with low residue retention can potentially avoid 29% of the CO2–eq emissions by replacing traditional puddling of soil with low residue retention (Alam et. al., 2016). For the Aman season rice crop, non-puddled transplanting of rice with low residue retention decreased life cycle GHG emission by 22 % relative the traditional puddling of soil with low residue retention (Alam, unpublished data). While increased residue retention with non-puddled transplanting of rice was not as effective in saving GHG emissions (it increased CH4 emissions) as low residue retention, it produced greater rice yield and contributed to greater SOC and improved soil physical properties.

8.2 Capacity impacts – now and in 5 years

The project is implementing an innovative approach by engaging PhD and MS students from the NARS institutes and universities to carry out research projects and to build capacity for future research programs on CA in Bangladesh. A total of eight PhD (four enrolled at BAU and 4 at MU) and 22 Masters students (including 2 new students during 2015/16 at BAU and one for Khulna University) have been recruited to conduct research projects on: minimum tillage crop establishment methods in rice-based cropping systems; effective chemical weed control and safe use of herbicide; short and medium term changes in soil organic matter (SOM), performance of VMP in southern-Bangladesh; nutrient forms as well as the mineralization rate of SOM and crop residues under different tillage methods and crop residue management; effect of CA on water balance; soil carbon sequestration and climate change mitigation potential under CA practice; etc. Most recently the project nominated Priya Lal Chandra Paul, Scientific Officer, BRRI for a John Allwright fellowship on "Assessment of the short to medium term effect of conservation agriculture on soil salinity and cropping system productivity in salt-affected regions of the coastal zone of Bangladesh" at Murdoch University. His research will transfer to LWR/2014/073.

We held a two-day (8-9 February, 2013) training course at BAU on grant writing for capacity improvement. Nineteen participants attended the training course from NARS institutes, universities, and NGOs.

The project organized a 5-day CASH Conference at Mymensingh where 159 scientists from 20 countries participated to present 75 oral and posters. Most of the project scientists, MS and PhD students participated to present a paper and interacted with other participants. The second CASH, during 14-16 February 2017 (www.cash-ii.com), was another opportunity for project PhD and Ms students to develop their communication skills

A 2-day workshop on Minimum Tillage Unpuddled Rice Transplanting (MTUPRT) was held at BRRI where a total of 174 national and international scientists, extension officers, policy planners had attended. During the workshop a total of 13 technical papers on MTUPRT of rice were presented including papers by PhD students.

The project also renovated the net house of BAU to facilitate the weed seed bank study.

Several organizations including DAE, CIMMYT, IRRI, BARI, BRRI, BAU are conducting advanced research and promotional activities on the LWR-2010-080-developed technologies including non-puddled rice establishment. Former PhD students (Hossen, Salahin, Zahan, Islam) of the project have, since submitting their theses, obtained institutional or competitive external funds to commence new research on CA.

Department of Soil Science, Bangladesh Agricultural University secured 3-year funding from the Kishi Gobashona Foundation (KGF) to promote conservation agriculture in Muktagach and Donbari upazilas. The KGF project purchased the VMP for field planting and the LWR-2010-080 project scientists provided technical support and organised training for VMP LSP and operators.

8.3 Community impacts – now and in 5 years

The project was quite successful with engaging local administration, DAE officials, NGOs, local leaders, service providers and farmers. At the initial stage, the project worked in four districts, which expanded to nine districts based on requests by farmers and extension agents. A total of 138 farmers' groups (involving 7,801 farm families) came forward to pick-up and adopt the project technologies. These groups have signed Letters of Agreement with the project to disseminate CA and other technologies developed by the project. The project is providing support to establish linkages between the VMP commercialization partner (Hoque Corporation) and farmers' groups; and develop master trainers from the groups to train all farm families on the CA technology. These farmers'

groups also formed the “Conservation Agriculture Service Providers Association (CASPA)”.

Private companies were involved to manufacture, commercialize, and export the VMP. A total of 243 units of different models of VMP have been manufactured and sold (98, 63, 23, 12, and 2 units by Hoque Corporation, Alam Engineering, Alim Industries, Janata Engineering, and Tongi Engineering) locally and 44 units exported to 9 countries (Mexico - 15, India - 14, Ethiopia - 6, Vietnam 2, Zimbabwe 2, Kenya 1, Myanmar 1, Tanzania 1, and Uganda 1). Moreover, several small manufacturers deliver parts of the current version of VMP manufactured by Hoque Corporation.

One of the great successes of the project was to pilot the VMP commercialization. In collaboration with BMDA and National Bank Ltd., the PIO and HC identified new LSP in Naogaon district (62 for 2016 and 15 for 2017), where, the National Bank Ltd. provided a 3-year loan package of Taka 170,000 to each LSP after registration (Tk. 50,000 to buy a VMP and Tk. 120,000 for a 2WT) without any property mortgage. Each LSP provided a down payment of Tk. 10,000-12,000 to HC to confirm registration. The project organized the VMP training program. The BMDA engaged Chittagong Builders to deliver 62 units of 2WT to Nagoan in 2016 and 15 in 2017. On behalf of the LSPs, the National Bank Ltd. has settled the payment with HC and Chittagong Builders after successful handover of the VMP and 2WT. The National Bank has continued supporting a programme of loans in 2017. The loans are unsecured, but a 20 % deposit is required by the LSP purchaser. A feature of the current promotion strategy for the VMP is to gather groups of 25-40 farmers in the neighbourhood of the new LSP who will agree to purchase planting services. The assurance of planting business is a strong incentive for the new LSP to commit to a loan.

8.3.1 Economic impacts

During the reporting period the area coverage of the monitored VMP users was about 1,500 ha which provided planting services to 6,611 farmers who adopted VMP and CA technologies. From initial on-farm studies, we estimate these farmers have gained up to 38%, 8 % and 6 % more grain yield of lentil, mung bean and wheat, respectively, over conventional (Haque et al. 2013). The CA adopters obtained higher net return of A$ 439, A$ 112, and A$ 233 per ha for lentil, mung bean, and wheat, respectively over conventional methods. Haque et al. (2013) estimated the profit from non-puddled rice compared to conventional systems was A$ 126-152/ha. Farmers that used CA in a three-crop rotation (rice-wheat-mungbean) within a year achieved 29%, 54%, and 14% greater net profit (additional income of A$446/ year for a 1 ha farm) with aman rice, wheat, and mungbean crops, respectively, compared to farmers practicing conventional tillage. Based on the 1,500 ha of CA planting in 2016-17, the extra value created by the Project’s findings is $0.69 million.

In 2017, a study was undertaken to assess adoption levels and impacts on farm businesses (Miah et al. 2017). A total of 18 Local Service Providers (LSP) were purposively selected from Rajshahi, Thakurgaon, Mymensingh and Rajbari districts for this study. The study revealed that LSPs effectively utilized VMP and 2WT for 4-6 months. They received Tk. 1,42,434 (with subsidy on VMP) and Tk. 1,36,134 (without subsidy) per year as net income. The average payback periods were 0.72 and 0.98 years with and without subsidy, respectively. The annual break-even use of VMP is 7.79 ha, but average planting area was 21.7 ha. The LSPs experienced a considerable increase in their annual income (35 %). The increased incomes were mostly spent on nutritious food, land mortgage, and dwelling house construction. LSPs indicated that hindrances in their business were: no seating arrangement on the machine during ploughing (56 %), farmers’ lack of awareness about CA planting (44 %), and lack of skilled drivers (17 %).

Based on the above yield increases and cost savings, it is possible to estimate that the annual potential gain from 2.5 % adoption of CA and mechanized planting in Bangladesh (this is about the current level of CA adoption across Asia) is A$ 24 million (base year 2013-14) from the additional 23,500 t of aman rice; 43,000 t of boro rice; 2,000

t of wheat and 5,000 t of maize grain yield plus the value of cost savings to farmers. Additional value would be created by LSP and manufacturers and others in the value chain (mechanics, dealers, traders).

8.3.2 Social impacts

During last year, the project has raised awareness among more than 1,300 male and female participants who attended various dissemination activities on minimum tillage, residue retention, crop rotation, safe use of herbicide: participants included local administration, extension officers, researchers, service providers, herbicide marketing company, herbicide dealers, and farmers. Moreover, more than 9,800 farmers are enlisted to get training and adopt CA technologies.

8.3.3 Environmental impacts

The traditional tillage methods have various shortcomings, such as reduced soil organic carbon and decreased soil fertility, increased water loss, and increased irrigation water use. All planting operations under minimum tillage are done using a single pass operation, which ensures <25% soil movement. Crop establishment under minimum soil disturbance by VMP/VSTP could reduce by up to 85% (32 l per ha) the diesel fuel use that could reduce CO2 emission by 83 kg per ha per crop. During project life, farmers of the project area have reduced 124 t of CO2 emission from tillage. A life cycle analysis conducted by John Allwright Fellow, Khairul Alam suggests that minimum tillage non-puddled transplanting with residue retention decreased greenhouse gas emissions by 22-29 % compared to the conventional puddling and transplanting. Most of this can be attributed to less methane emissions. Further analysis of the greenhouse gas emissions is underway to include Rabi season mustard crops.

With the involvement of CASPA, the project has trained more than 10,000 farmers on CA and raised awareness on the safe use of herbicides/insecticides.

8.3.4 Policy impacts

The project has organized CA related seminars, workshops (including annual and mid-term review), symposia, conferences and continuously interacted with the leaders of researcher institutes and agricultural universities. They together with policy planners were invited to the above events.

The project also led the development of CA briefing notes on “CA and mechanisation” and on Minimum Tillage Unpuddled Transplanting of Rice” and circulated them to policy makers including Secretary, Ministry of Agriculture, Government of Bangladesh (GOB); DG and Directors of NARS institutions and Department of Agricultural Extension; Executive Chairman and Member Directors of BARC, Governor and Senior officials of Bangladesh Bank; Managing Director and Senior Officers of BASIC Bank; Vice-Chancellors and Faculty Deans of Agricultural Universities, etc. Briefing meetings were held with the Secretary, Ministry of Agriculture, Government of Bangladesh (GOB); DG and Directors of NARS institutions and Department of Agricultural Extension; Executive Chairman and Member Directors of BARC, Governor and Senior officials of Bangladesh Bank. Such initiatives created awareness among the policy planners and in the policy paper “Agricultural Research Vision 2030 and Beyond: Research Priorities in Bangladesh Agriculture” published by Bangladesh Agricultural, Research Council, the GOB has given higher priority to farm mechanization and CA research and development and included these topics in the policy document.

Many NARS institutions have begun to include CA research and development in their annual research plan. The Kishi Gobashona Foundation has funded at least one new project on CA.

At the CASH-II conference, delegates endorsed the Mymensingh Declaration, a statement of the principles and benefits of CA in Bangladesh, and recommendations for further development, promotion and commercialisation of the CA technology.

Following the CASH-II, Professor Bell Dr Haque and Professor Lutful Hassan of BAU met with the Minister of Agriculture, the Secretary of Agriculture, and Executive Chair of the BARC for a briefing on CA and the conclusions of CASH-II contained in the Mymensingh Declaration. The Minister observed that CA could be considered a modernised form of traditional farm practices in Bangladesh. She stated that Bangladesh could not afford to be complacent about agriculture and was open to innovations that were beneficial to soil health, improved farmers' income and livelihood and strengthened national food security.

8.4 Communication and dissemination activities

To develop CA briefing notes and manuals, the project has led the formation of a national level technical editorial committee on CA and mechanisation. Project stakeholders (BARI, BRRI, BAU, BARC, MU, BMDA) nominated scientists for the Editorial Committee to develop the CA briefing notes and manuals. The first draft of the CA Briefing Notes was completed and used in policy briefing sessions with the Secretary of Agriculture, Executive Chairman of BARC, DGs of BARI, BRRI, DAE and is under review. The Briefing Note on Unpuddled Rice Transplanting (English version) was finalized and distributed to all participants at the Conference in Sept 2015.

Four Bengali pamphlets on CA Project Briefing Notes, Versatile Multi-crop Planter (VMP) uses, Rice Seedling Transplanting in Unpuddled Field, and Safe Use of Herbicide were developed and widely circulated to farmers, extension officers, local service providers, manufacturers, researchers, local administrators, etc.

The Workshop on Minimum Tillage Unpuddled Rice Transplanting (MTUPRT) was held on 16 to 17 September 2015 at the Bangladesh Rice Research Institute (BRRI). The workshop was attended by 174 participants from BRRI, Bangladesh Agricultural Research Institute (BARI), Bangladesh Agricultural Research Council (BARC), Australian High Commission in Bangladesh, Ministry of Agriculture of GOB, Bangladesh, Agricultural University (BAU), Department of Agricultural Extension (DAE) of GOB, International Rice Research Institute (IRRI), Bangabandhu Sheikh Mujibor Rahman Agricultural University, Bangladesh, Institute of Nuclear Agriculture (BINA), CCDB, BRAC, VMP and VSTP Service Providers, farmers, etc. The MTUPRT workshop was opened by the Chief Guest Mr. Shyamal Kanti Ghosh, Secretary, Ministry of Agriculture, GOB. The Guest of Honour was HE Mr Greg Wilcock, Australian High Commissioner to Bangladesh; and the Special Guests were Dr Paul Fox, Country Representative, IRRI, Bangladesh; Prof. Richard W. Bell, Murdoch University, Australia; Dr Md Rafiqul Islam Mondal, Director General, BARI; Mr Md. Hamidur Rahman, DAE; Dr Abul Kalam Azad, Executive Chairman, BARC (The Director General of BRRI was overseas at the time). Dr Md Shahjahan Kabir, Director (Admin and Common Services), BRRI presided over the Inaugural session.

Prof. Dr. Md. Lutful Hassan, Prof. Dr. Richard W. Bell, Dr. Sultan Ahmed (MD, NRG, BARC), and Dr. Md. Enamul Haque met with Mr. Shyamal Kanti Ghosh, Secretary, Ministry of Agriculture of GoB and provided a power point slide presentation on CA. The Secretary showed great interest, asked many questions of clarification and finally declared that he was 100 % convinced of the merit of CA for Bangladesh. He invited the LWR-2010-080 project to work with its partners (BAU, BARI, BRRI) to prepare a proposal that he can review and forward to the Minister of Agriculture. The proposal should cover – i) International findings on CA; ii) Local R&D findings on CA; iii) Current projects on CA; iv) Proposed action plan for the GoB to consider. He also suggested that a seminar on the proposal could then be arranged to invite the Minister of Agriculture for a briefing. While the Editorial Committee had two meetings to scope its work, they have not yet produced a draft.

Prof. RW Bell, Md. Mizanul Hoque, and Dr. Md. Enamul Haque met with Khondoker Md. Iqbal, Managing Director BASIC Bank; Kanak Kumar Purkayastha, Deputy Managing Director; Abdul Qayum Mohammad Kibriya; Deputy Managing Director to brief them on the business case for CA based on farm benefits, LSP benefits, and national benefits. The Managing Director indicated that BASIC Bank was, in principle, willing to loan to Hoque Corporation (HC) for planter (and 2-wheel tractor) sales to LSP, provided HC supervises and collects loan repayments and is responsible for the loan administration. The Managing Director invited HC to prepare a proposal and business case that the BASIC Bank can assess.

Prof. Dr. Richard W. Bell, Prof. Dr. Lutful Hassan (Director BAURES), Md. Mizanul Hoque (Hoque Corporation), and Dr. Md. Enamul Haque met with the Governor and General Manager of Agriculture Program, Bangladesh Bank to brief them about the project and pursuit on soft loan for LSP to buy VMP. Based on Government policy and GoB financing, it provides funds for loans for approved programmes at reduced interest rates. Low interest loans are available under Ministry of Agriculture policy for specific crops. The Governor recommended that the mechanisation subsidy fund would be better used to lower loan interest rates, so that more people such as LSP can access the benefits. He suggested that we talk to MoA to get them to alter the mechanisation policy.

Prof. RW Bell, Dr. ME Haque, and Mr. MM Hoque met with the Director General, Director Field Crops, Project Directors of Agricultural Mechanization and Pulses crops, Department of Agricultural Extension and presented the power point presentation. DAE showed interest in CA and the VMP and agree to include VMP in the subsidy program.

A few seminars and meetings on CA and farm mechanisation were held at the Barind Multipurpose Development Authority (BMDA). Prof. Richard Bell, Dr. Md. Enamul Haque, and other project scientists presented papers covering the project's work on conservation agriculture and farm mechanisation.

Prof. RW Bell and Dr. ME Haque met several times with the Vice-Chancellor, Director BAURES, Dean of various Faculties, Bangladesh Agricultural University, Mymensingh; Director General and Directors of BARI, BRRI; Executive Chairman and Member Directors of BARC to brief them on CA Project progress. They also, met with the USAID, World Bank, AusAID, DFID etc. to share the project outcomes.

Prof. Richard Bell gave a series of keynote lectures during 27 June to 1 July in Delhi, Hyderabad and Kolkata on Conservation Agriculture and Mechanization for Smallholder Agriculture under the Australia-India Education Council Eminent Researcher Lecture Programme. YouTube video of the lecture at ICRISAT is available at:

https://www.youtube.com/watch?v=pJ4-XpMlRdg

The project developed four Newsletters with an email circulation of over 2,500 of which 60 % were in Bangladesh. The newsletter is re-circulated by Dr Amir Kassam in the Global CA Community of Practice newsletter.

PhD scholars and Professors attended international conferences in Canada (World Congress of Conservation Agriculture, Turkey (International Plant Nutrition Colloquium), Czech Republic (Weed Science), India (Asia Pacific Weed Science) and Australia (International Nitrogen Initiative).

The CA Manual has been drafted, mostly based on the present project's findings. Review comments will be sought from BARI and BRRI before a final version is released as an on-line document.

9 Conclusions and recommendations

9.1 Conclusions

Conservation Agriculture as a rice based system

The feasibility of CA as a rice-based system is best illustrated by six long term experiments, some of which have reached 21 consecutive crops. All of them include at least one Aman-season rice crop per year. Other crops include wheat, mustard, lentil, chickpea, jute, mung bean and Boro rice. The sites fall in different agro-ecosystem zones, with varied climate, soil type, land type (elevation) and hydrology. However, there are consistent findings: non-puddled rice in these experiments yielded the same as in conventional tilled-puddled soil or more. However, since there was evidence of increased deep percolation after 15 crops in the Alipur site, further studies are needed on the long term implications of the CA practice for water balance and crop water productivity.

There is evidence that soil properties improve (increased soil organic matter, increased soil nitrogen, lower bulk density, increased porosity) under the CA practice with strip planting and increased residue retention (see below), and that the weed seedbank diminishes (see below).

Importantly, the CA practice increases crop production, largely due to the increased yield of non-rice crops, and profit, by decreasing cost of crop production (reduced labour, fuel).

While most of the long term experiments were conducted on farmers' fields, there are still few farmer-managed fields where continuous CA practice has occurred for significant lengths of time. Targeting the early adopters of CA to assess the benefits accrued by farmers is therefore a priority for future research.

Non-puddled Rice Transplanting (NPT)

Zero tillage and strip tillage are the most common methods of NPT. Generally experiments examined a single crop of NPT of rice and showed that the first rice crop established by NPT produced similar yield to the conventional rice seedling establishment by transplanting on puddled soils. In the monsoon season, 38 on-farm paired comparisons in northwest Bangladesh produced no grain yield difference between NPT and puddled transplanted rice. However, in the dry-season irrigated season of 2012 (boro), the NPT increased average yield over 29 paired comparisons by 0.26 t ha^{-1}. From a further 66 rainfed monsoon (aman) and 84 boro crops during 2013 to 2015 in north and north-west Bangladesh, NPT of rice seedlings in strips produced similar or significantly greater grain (boro season of 2015) and straw yield (Haque et al. 2017).

In three long-term experiments with up to 15 consecutive crops since commencing strip tillage, NPT gave the same grain yield of rice as conventional puddling and transplanting. By contrast, at another three long term experiments, rice grain yield increased by 0.7 to 1.7 t ha^{-1} in all crops under NPT following strip tillage. Collectively, the replicated experiments and on-farms assessments of NPT demonstrate that it is reliably able to produce as much grain yield in the first crop as the conventional puddling of soils. Moreover, with continuation of minimum tillage by strip tillage the yield of both aman and boro rice crops equal or exceed those of the conventional puddling and transplanting of rice. With mechanised transplanting, the grain yield was also similar between NPT and conventional soil puddling for rice establishment (Hossen 2017). We conclude that changing to NPT represents minimal risk of yield loss for rice producers while providing labour, fuel and water savings (Haque et al. 2016).

First impressions of the performance of NPT are important for acceptance by farmers. Generally, results shown no yield change with NPT in the first crop compared to the conventional puddling of soil and transplanting. However, there are immediate savings in labour and water although for transplanting itself the labour requirement may increase. With continuous minimum soil disturbance and residue retention about 50 % of cases report increased grain yield with NPT rice and the remainder report no yield difference. Increased profitability is consistently reported from experiments and on-farm experiments and demonstrations.

Farmers' practice of NPT will provide a pathway for greater adoption of CA in rice-based systems. The knowledge base for NPT is still limited compared to puddling and transplanting. Hence many questions still remain about this practice. Further research is needed to define the domain of soil types, hydrology and farmer typology within the lowland rice-growing areas where this technology is suitable. The main consideration is whether enough of the key questions about its feasibility and profitability have been answered so that it can now be recommended to farmers. If not, what are the remaining research and practical questions that remain? There is also a need to demonstrate NPT in long term on-farm practice to establish confidence among target farmers in the technology and to identify emergent trends that need to be studied in detail before they become limiting factors for widespread adoption or practice.

Weed management- including the role of residue

From a number of experiments with both rice and wheat as well as mustard, the best weed control was obtained from sequentially applied pre-emergence and post emergence herbicides. Herbicides applied in NPT aman rice had no residual effects on the succeeding crops of wheat, lentil or sunflower. Phytotoxic effects of some herbicides were recorded in rice and wheat, depending on cultivar and rate of herbicide application. While almost all rice and wheat cultivars tested were tolerant to herbicides at the label rate, there were some exceptions. The implications of these findings is that screening of cultivars, especially new cultivar releases, needs to be institutionalised within national breeding programmes, since the use of herbicides for weed control (for conventional and CA practice) is quickly becoming the norm rather than an exception in farmers' fields.

A number of experiments confirmed that the benefit cost ratio with strip planting followed by the application of pre-emergence and post emergence herbicides was much greater than for the conventional tillage and hand weeding. Retention of 50% residue increased the grain yield by 4% and BCR by 9%. The seed bank study reveals that, after the two years field, CT enriched the weed seedbank status by 13% while SP reduced seedbank status by 17%. Residue retention diminished the weed seedbank by 11%. In the long term experiments, after 3-5 years, the weed seedbank was reduced by 30-35 % by strip planting and increased residue compared to the current conventional practice. Hence even though residue retention levels did not exceed 50 %, the increased residue helped to supress weeds and is a useful component of the weed control strategy of CA practice.

Soil health/quality improvement

Four long term experiments (Alipur, Rajshahi; Digram, Rajshahi; Baliakandi, Rajbari; Mymensingh), each with strip planting and increased residue retention as treatments for three crops per year, revealed that it takes 2-3 years to measure increases in soil organic matter under the CA practice. The soil organic matter increase is mostly confined to 0-5 cm depth, while at 5-15 cm levels either didn't change or even declined (at Mymensingh). Along with increased soil organic matter, soil nitrogen increases were also recorded at the Alipur experiment after 7 consecutive crops of strip planting and increased residue, reflecting an apparent retention in the soil of an additional 30 kg N/ha/crop. Despite the change in soil organic matter levels, there was no evidence that strip planting and

increased residue retention increased fertiliser N requirements of any of the six crops planted after the experiment commenced at Mymensingh.

At the Alipur long term experiment, there was increased root density at 10-20 cm depth in the strip planted plots with increased residue retention, but no measurable effect on soil strength after 7 consecutive crops. Three years later, the strip planted plots with or without increased residue retention had increased deep percolation of irrigation water. This suggests that over time the minimal soil disturbance caused by strip planting has weakened the plough pan and altered water balance. The implications of this change for water and crop productivity are still being investigated.

Versatile Multi-crop Planter (VMP)/ Versatile Strip Seed Drill (VSSD)

Development of CA as a feasible and profitable farm practice for small farms has been based on the performance and reliability of the VMP. The VMP is a unique multi-functional and multi-crop planter powered by 12-16 horsepower 2WT with capability for seed and fertilizer application at variable rates, depth and row spacing using single pass shallow tillage, strip planting, zero tillage, shallow beds, and conventional tillage. The shaft and brackets designed for the VMP achieve improved flexibility for multi-crop planting and capacity for rapid adjustment of row spacing on a field-by-field basis. By using the VMP, the establishment costs for various crops in different tillage systems were significantly reduced compared to conventional tillage. A related planter which only has strip tillage capability is the Versatile Strip Seed Drill (VSSD). The VMP has been shown to operate reliably in diverse soils and conditions and with a wide range of plant species. It can be used to develop CA practices across a wide range of cropping systems used by smallholder farmers in Bangladesh as well as elsewhere in Asia, Africa and other regions where small farms and the 2WT are prevalent.

The field capacity of VMP was 0.07 ha/hr for strip planting which was 34 % higher than for conventional tillage due to the reduced number of operations. Land preparation cost by VMP was decreased by up to 75 % for single pass compared to conventional tillage. The VMP was capable of sowing many crops from small jute seed (2 g/1000 seeds) up to maize (160 g/1000 seed). The VMP weighs 152 kg and ex-factory price is US$900-1,000. Significant variation was observed on field capacity when operated for conventional tillage, SPST, SP, ZT and shallow BP: 0.03, 0.07, 0.07, 0.06 and 0.05 ha hr^{-1}, respectively. Fuel consumption was highest for conventional tillage (33.1 l ha^{-1}) and lowest in strip planting (5.83 l hr^{-1}) by VMP. The SPST, SP, ZT and BP by VMP saved 38, 82, 50 and 13 % diesel fuel over CT. The maximum cost (US$ 41.47 ha^{-1}) of land preparation and seeding was incurred in case of conventional tillage system and the lowest (US$ 10.27 ha^{-1}) for SP.

Local Service Providers

Local service providers are widely spread in rural Bangladesh providing a diverse range of mechanization services (ploughing, transportation, pumping, threshing, shelling). The development of LSP for CA planting has been a priority of the Project, as the LSP are expected to have a key role in making CA accessible to farmers, in driving the development of the technology and improvements in the VMP and other planters.

Since 2010, a total of 243 units of different models of VMP have been manufactured and sold (143 by HC) locally and 44 units exported to 9 countries (Mexico - 15, India - 14, Ethiopia - 6, Vietnam 2, Zimbabwe 2, Kenya 1, Myanmar 1, Tanzania 1, and Uganda 1).

During 2012 to 2017, a total of up to 50 VMPs were monitored closely to collect performance data. The adoption of VMP by farmers to grow various crops has been increasing over the period. On average, each VMP covered 6.5 ha during 2012-2013; average planting area increased to 11.7, 12.5, 13.7, and 18.9 ha and served 31, 87, 93, 56, and 75 farmers during 2012-13, 2013-14, 2014-15, 2015-16, and 2016-17,

respectively. In 2017, 18 LSP were purposely selected from Rajshahi, Thakurgaon, Mymensingh, and Rajbari districts for a study of their business model. The study revealed that LSPs effectively utilized the VMP and 2WT for 4-6 months. They received A$2,191 (65Tk = A$)(with subsidy on VMP) and A$2,094 (without subsidy) per year as net income. The average payback periods were 0.72 and 0.98 years with and without subsidy, respectively. The annual break-even use of VMP is 7.8 ha. The business model appears to be profitable and attractive option for small business operators. With the income earned, the new LSP invested in home improvements, additional land and livestock. They reported increased consumption of meat and fish in their family diet.

Commercialization models tested

The commercialisation approach being pursued involves the creation of both supply and demand. Over emphasis on either demand or on supply is unlikely to trigger a breakthrough in commercialisation of the VMP or related planters. Manufacturers are reluctant to invest without evidence of demand. Where manufacturers supply only to bulk orders there is little feedback from users on how to improve design and performance and often poor-quality products are supplied. Low quality planters hampered initial efforts to develop farmer confidence in planters and create demand. To create demand, the Project trained 318 LSP, technicians from the National Agricultural Research and Extension System (NARES), NGOs, the private sector; and 43 mechanics of VMP/VSSD and manufacturing factory/repairing workshops. A total of 6,611 farmers hired/used VMP/VSSD to sow lentil, mustard, mungbean, sesame, jute, wheat, maize, rice, chickpea, etc. and covered more than 1,500 ha. This illustrates the level of demand already created in the six project working hubs.

Of the five manufactures provided with designs for the VMP, only Hoque Corporation has taken the initiative to develop the market for VMPs by setting up distribution and sales networks and developing a supply chain to manufacture or import component parts, maintain quality control of component parts and the VMP, seek orders and deliver on time, continuously upgrade designs for user satisfaction and provide after sales service. In 2016, Hoque Corporation sold 98 VMP. An important component of the commercialisation model developed with Hoque Corporation is the training of LSP in the operation of the VMP and related services such as weed control. New LSP are provided with repeated training sessions during the first 1-2 years after purchasing the VMP. Experienced operators are engaged to provide training and to mentor the new LSP. In addition to the Project supported sales (21 in 2015, and 36 in 2016), the National Bank in 2016 provided a 3-year loan package for 62 new LSP in Nagoan Upazilla, Rajshahi to each buy a new 2-wheel tractor and VMP. Apart from the training provided by the project to the selected LSP, no other project support or incentives were provided for the National Bank clients. The sales programme with the National Bank was entirely handled by Hoque Corporation. The National Bank has again offerred this loan package to LSP in 2017 (40 have signed up so far). The LSP is eligible for an unsecured loan worth 80 % of the total cost and must pay a 20 % deposit.

Market intelligence suggests that once annual sales exceed 200 VMP, the private sector will be able to fully absorb the costs of further commercialisation of the VMP market. Another 1-2 years of support with demand creation and training of new LSP would ensure this target is secured.

Policy

The project has organized CA related seminars, workshops (including annual and mid-term review), symposia, conferences and continuously interacted with the leaders of researcher institutes and agricultural universities. They together with policy planners were invited to the above events.

The project also led the development of CA briefing notes on “CA and mechanisation” and on Minimum Tillage Unpuddled Transplanting of Rice” and circulated them to policy

makers including the Minister of Agriculture, Secretary, Ministry of Agriculture, Government of Bangladesh (GOB); DG and Directors of NARS institutions and Department of Agricultural Extension; Executive Chairman and Member Directors of BARC, Governor and Senior officials of Bangladesh Bank; Managing Director and Senior Officers of BASIC Bank; Vice-Chancellors and Faculty Deans of Agricultural Universities, etc. Briefing meetings were held with the the Minister of Agriculture, Secretary, Ministry of Agriculture, Government of Bangladesh (GOB); DG and Directors of NARS institutions and DAE; Executive Chairman and Member Directors of BARC, Governor and Senior officials of Bangladesh Bank.

At the CASH-II conference, delegates endorsed the Mymensingh Declaration, a 2-page statement of the principles and benefits of CA in Bangladesh, and recommendations for further development, promotion and commercialisation of the CA technology.

9.2 Recommendations

For the Government of Bangladesh and the national research community, we recommend that:

The Government of Bangladesh adopts a Conservation Agriculture policy for implementation by its agricultural extension, research and university sectors;

The Government of Bangladesh engages with the private sector and farmers' organisations to establish a Bangladesh Centre for Conservation Agriculture Research & Development to represent, coordinate and guide the CA programmes of research, development and extension (R, D & E) agencies, agricultural universities and research funding agencies.

Through its Department of Agricultural Extension, the Government of Bangladesh should develop a programme on mass promotional activities including publicity and awareness building on CA.

The Government of Bangladesh and the private sector work with and strengthen CA farmers' associations to promote adoption and local adaptation of CA.

The Government of Bangladesh and other fund providers and investors allocate funding to conduct R, D & E on CA, to adapt it to the conditions and requirements of Bangladesh agriculture;

The use of CA practice is promoted by donor programmes in the crop production sector;

Laws, regulations and policies be reviewed to identify and amend those that hamper the profitable adoption of CA by farmers;

The Government of Bangladesh removes bottlenecks for profitable engagement by the private sector in promoting CA;

Stakeholders in CA commit to holding biennial Conservation Agriculture conferences to report on, review and plan for the widespread adoption of CA in Bangladesh;

Protagonists work with finance institutions to establish accessible, interest-free or low interest finance for CA-related machinery manufacturers, LSP, users, and to apply incentives to LSP and farmers to take up CA practices;

CA be included in the text books of the national educational curriculum from primary level to universities, and;

The Government of Bangladesh and universities develop more human resources/scientific capacity providing MS, PhD scholarships and short-term training in aspects of CA.

These recommendations coincide substantially with those adopted by delegates at the CASH-II conference (the Mymensingh Declaration).

For research, extension and education in Bangladesh on CA, we recommend the priorities are:

Set up and maintain long term CA experiments in key soils and regions to assess system productivity, improvement in soil properties and identify emerging trends that affect weed control and pest and disease control.

While most of the long-term experiments to date on CA were conducted on farmers' fields, there are still no farmer-managed fields where continuous CA practice has occurred for 3 years of more. Targeting the early adopters of CA to assess the benefits accrued by farmers after 3-5 years is therefore a priority for future research.

Continue to improve non-puddled rice establishment, including defining the domain of rice production in the country where it is best suited.

Continue to improve zero tillage/ strip tillage direct seeding of rice for reliable crop establishment and weed control in different field types, hydrological regimes and seasons with the aim of defining the domain where this technology is reliable for farmers to adopt.

Where adoption occurs over a significant proportion of the landscape, undertake landscape-scale water balance studies to define the real effects of CA practice on ground water levels and recharge rates.

Develop a national programme of on-farm adaptive experiments to design improved local and regional variations on best practice for CA.

Develop recommendations on row spacing, seed rate, seedling depth etc for CA practice of major crops involving strip planting or zero tillage and different levels of crop residue retention.

Determine fertiliser management requirements for crops under CA management (This will be investigated by LWR/2016/136).

Develop and promote to farmers integrated weed management approaches to reduce reliance on herbicides for weed control and minimise the development of herbicide resistance in weed species.

Routine screening of cultivars of major crops for vigour and yield in CA planting (strip planting and retained crop residues). In addition, for the major crops grown under CA, identify key traits required for CA planting and develop selection programmes to identify and release better-adapted cultivars.

Routine screening of new cultivars of major crops (rice, wheat, maize, jute, mung bean, lentil, mustard, sunflower) for phytotoxicity and residual effects by herbicides. Since herbicides are rapidly becoming the weed control practice of choice by farmers, this recommendation is not specific to CA, but applies to conventional tillage as well. There may well be differences in phytotoxicity though between CA with minimum soil disturbance and residue retention and conventional tillage.

Second generation testing of planters used by LSP to identify faults, their limitations and to improve design and performance.

Pilot studies on 4-wheel tractor-led niches for CA in Bangladesh. This will involve initial studies on best bet planters for 20-30 and 40-60 horsepower tractors.

Adding benefits of CA in the text books of national educational curriculum starting from primary level.

Develop program on mass promotional activities including publicity and awareness building on CA

Develop more human resources/scientific capacity for CA development and implementation by providing MS, PhD and short-term training.

Ensuring access to low interest financing for CA related machinery manufacturers, LSP, users, etc.

Provide price support or incentives to LSP and CA farmers until there is evidence of adoption take-off.

Strengthening CASPA and other farmers' associations to ensure the farmers have a voice in setting the CA research agenda and the capacity to represent farmers' needs to the private sector suppliers of machinery and inputs.

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MS THESIS

Abdullah- Al- Musabbir. Performance study of Versatile Multi Crop Planter with Different Types of Blade. Department of Farm Power and Machinery, Bangladesh Agricultural University. June 2014

Azit Kumar Dass. Adoption of conservation agriculture practices in Bangladesh. Department of Agricultural Extension Education. Bangladesh Agricultural University, Mymensingh. June 2013

Juthi, Z. Yield response of mungbean to different tillage options under different soil moisture levels in southwestern Bangladesh. Agrotechnology Discipline, Khulna University, Khulna. 2016.

M. Mortuba Ali. Requirement of Nitrogen for the Wheat-Mungbean Cropping Sequence under Strip Tillage System. MS Thesis, Dept of Soil Science, BAU. 2014.

M. Ripon Hossain. Nitrogen Requirment of Crops Under Strip Tillage System at Two Residue Levels in the Rice–Wheat-Mungbean Pattern. MS Thesis, Dept of Soil Science, BAU. 2016.

M. Shamsuzzaman Shameem. Response of jute, mungbean and sunflower to the residual toxicity of herbicides used in wheat under strip tillage system. Department of Agronomy, Bangladesh Agricultural University, December 2014.

M. Sultan Ali. Effect of seed rate on yield performance of three mungbean varieties under strip tillage system. Department of Agronomy, Bangladesh Agricultural University, Mymensingh, May 2014.

Md Sanowar Hossen. Performance evaluation of Compressor and Lever Operated Type Sprayer for Weed Control. Department of Farm Power and Machinery, Bangladesh Agricultural University. June 2014.

Md. Asif Iqbal. Yield performance of four aman rice varieties under minimum tillage unpuddled rice transplanting system. Department of Agronomy. Bangladesh Agricultural University, Mymensingh. 2015

Md. Riaz Hasan. Effect seed rate on the yield performance of wheat under strip tillage system. Department of Agronomy, Bangladesh Agricultural University, Mymensingh.

Md. Sabbir Hossain. Modification of VMP for better residue handling capacity. Department of Farm Power and Machinery, Bangladesh Agricultural University, Mymensingh. 2016.

Ms. Nahida Sharmin. Assessment of soil weeds seedbank status in long-term trials of conservation agriculture. Department of Agronomy, Bangladesh Agricultural University, Mymensingh. 2017.

Ms. Priyanka Chakrobarti. Performance of T.Aman rice varieties under unpuddled transplanting systems. Department of Soil Science, Bangladesh Agricultural University, Mymensingh. 2014.

Ms. Sultana Razia. Study on weed seed distribution in different depth of soil under long-term conservation agricultural system. Department of Agronomy, Bangladesh Agricultural University, Mymensingh. 2017.

Muhammad Shahinur Islam. Utilization of Crop Residues and Crop-Livestock Interaction in Rural Household in Bangladesh. Department of Animal Science. Bangladesh Agricultural University, Mymensingh. June 2013.

Prokash Chandra Biswas. Grain yield of mungbean under different tillage by Versatile Multi-crop Planter in southwestern Bangladesh. Agrotechnology Discipline, Khulna University, Khulna. 2016.

Rafia Akhter. An Economic Study on Conservation Agriculture in Rural Areas of Bangladesh. Department of Agricultural Economics. Bangladesh Agricultural University, Mymensingh. December 2013

Sabab Farhan. Effects of Conservation Agriculture and Nitrogen Fertilization on Carbon Footprint in the Wheat-Mungbean-Rice Cropping System. MS Thesis, Dept of Soil Science, BAU. MS Thesis, Dept. of Soil Science, BAU. 2016.

Sahed Hasan. Crop Response to Nitrogen Fertilizer under Strip Tillage and Residue Retention in the Wheat-Mungbean-T. Aman Pattern. MS Thesis, Dept of Soil Science, BAU. 2015.

Sarmin Shahanaz. Requirement of Nitrogen for T. Aman Rice under Strip Tillage. System. MS Thesis, Dept of Soil Science, BAU. 2013.

Sutapa Karmaker. Nitrogen Requirement for T. Aman rice under Strip Tillage System at Two Residue Retention Levels. June 2014. MS Thesis, Dept of Soil Science, BAU. 2014.

Trisha Paul. Influence of Conservation Agriculture and Nitrogen Fertilization on Soil Properties in Rice Based Cropping System. MS Thesis, Dept. of Soil Science, BAU. 2016.

PhD Thesis

Zahan T (2017) A PhD Thesis on Effect of herbicides on weed and crop in rice-wheat-mungbean cropping pattern under conservation agriculture systems. Submitted to Department of Agronomy, Bangladesh Agricultural University. Submitted September 2017.

Alam, K.M. 2017. The Carbon Footprint of Conservation Agriculture in Rice-based Cropping Systems.

Hossain, M.M. 2017. The Weed seedbank un Conservation Agriculure in Rice-based Cropping Systems.

Hossen, M.A. 2017. Development of rice transplanter for unpuddled condition. Department of Farm Power and Engineering. Bangladesh Agricultural University, Mymensingh.

Islam, M.A. 2016. Conservation Agriculture: Its effects on crop and soil in rice-based cropping systems in Bangladesh, PhD thesis. School of Veterinary and Life Sciences, Murdoch University, Australia. Accepted subject to revisions January 2017.

Nazmus Salahin. 2017 Influence of Minimum Tillage and Crop Residue Retention on Soil Organic Matter, Nutrient Content and Crop Productivity in the Rice-Jute System. Department of Soil Science, Bangladesh Agricultural University, Mymensingh. Accepted 2017.

Nurul Hassan Mahmud 2018. Water balance under conservation agriculture in rice-based cropping systems

Training, Seminar, etc.

Hashem, A (2011) Intensive 5-day training on herbicide mode of cation, safe use ad handling, weed identification and weed research project planning at RDRS, Rangpur. 20 scientists (government/private, University teachers, government extension officers/chemists, company agronomists. January, Rangpur.

Hashem A (2014) trained three scientists (Nur Nobi Mia, Selima Zahan and Taslima Zahan-PhD student) in Western Australia in weed science, herbicide application procedures, data recording, field day, and data analysis.

Hashem A. Presented 2 seminars at SAU, 1 at IUBAT, 2 at BAU on the need on weed management in CA and safe use and handling of herbicides.

Hashem A, provided One training on sprayer calibration at BAU for teachers and post-graduate students.

Hashem presented one seminar at Ishurdi BARI centre for scientists on weed management and herbicides in 2010.

Hashem as Adjunct professor at the Agronomy Department is supervising two PhD students in weed management, helping with research, thesis and manuscripts of the students via emails, face to face meeting, and telephone.

Hashem presented ONE paper on weed control in rice on behalf of Taslima Zahan at the International Weeds congress in June 2016 in Prague, Czech Republic.

Brennan reviewed SIX manuscripts for PhD students enrolled at BAU or Murdoch University.

Brennan provided specialist advice on plant nutrition to students and scientists.

Hashem and Brennan provided one on one advice to students and researchers 4-6 occasions.

Hashem A and Brennan R served on the Editorial Committee of CASH I/CASH II.

Zahan T (2014) A training on weed science, herbicide application procedures, data recording, field day, and data analysis in Western Australia.

Field Days

Hashem A (2012) Field walk at wheat-lupin-canola or lupin-wheat-canola rotation trial at Western Australian No-till Farmers' Association (WANTFA) Cunderdin site (about 100 farmers and agronomists). 19 July Cunderdin WA.

Hashem A and Bell R (2012) Spring Field Day presentation on weed control in wheat and lupin of wheat-lupin-canola or lupin-wheat-canola rotation trial at Western Australian No-till Farmers' Association (WANTFA) Cunderdin site. 4 September (about 75 farmers and agronomists).

A Hashem (M Amjad filled on 3 March 2015). Weed control in wheat and lupin of wheat-lupin-canola or lupin-wheat-canola rotation trial. WNTFA update at Cunderdin, WA.

Invited lectures and session chairing (Bell, R.W.)

Keynote address "Conservation Agriculture for Smallholders- A Win-Win for Agriculture and the Environment", at 2nd Conference on Conservation Agriculture for Smallholder, 14-16 February 2017, Mymensingh

Keynote address "Minimum Tillage Non-Puddled Rice Establishment: an Overview", at 2nd Conference on Conservation Agriculture for Smallholder, 14-16 February 2017, Mymensingh

Invited lecture Conservation agriculture and mechanization for smallholder farms presented at BSMR Agricultural University, Gazipur, Bangladesh 24 August 2016

Australia-India Education Council Eminent Researchers Lecture Program 27 June-1 July 2016; Conservation Agriculture And Mechanisation For Smallholder Agriculture: A Win-Win For Agriculture And The Environment. Lectures at: Indian Agriculture Research Institute, Delhi; Professor Jayashankar Agricultural University, National Institute of Plant Health Management and ICRISAT, Hyderabad; Bidhan Chandra Kishi Vishwavidyalaya Kalyani; Indian Institute of Technology, Kharagpur.

Keynote Address RW Bell and ME Haque On Conservation Agriculture And Mechanisation For Smallholder Agriculture: A Win-Win For Agriculture And The Environment. International Conference on Agriculture and Environment: Food, Water, Soil, Air. 25-26 May 2016, Kuala Lumpur

International Workshop on Mechanization- Crop Establishment. 6 November 2015 at National Agriculture and Forestry Research Institute, Laos. Invited speaker on Commercialisation of planters for 2-wheel tractors: developing supply chains and farmer demand for adoption of planting services

Conference on Minimum Tillage Unpuddled Transplanting for Rice Establishment, 16-17 September 2015, Gazipur. Presented key note paper on Minimum Tillage Unpuddled Transplanting of Rice: An Overview.

Bell, R.W. Chair's Opening and Concluding Remarks at Conference on Conservation Agriculture for Smallholders in Asia and Africa. 7-11 December 2014, Mymensingh, Bangladesh.

Bell, R.W., Haque, M.E. and Amin, Md. Nurul (2014). Entrepreneurship and the adoption of conservation agriculture by smallholder farmers - key learning from Bangladesh. Oral paper presented at 6th World Congress of Conservation Agriculture. 22-26 June 2014, Winnipeg, Canada

Invited paper on Conservation Agriculture in Australia: Learning and Lessons for the Development of Policy for Promoting Conservation Agriculture in Asia. Paper presented at Expert Consultation Workshop on Conservation Agriculture (CA) for Formulation of CA Policy and Strategy for Asia 19-22 November, 2013, Beijing.

TECHNICAL REPORTS

Miah, M.A.M.; Rashid, M. A.; Haque, M. E. and Bell Richard (2017). Impact of versatile multi-crop planter (VMP) on service providers' livelihood in some selected areas of Bangladesh. In: Annual Research Report 2016-17, Agricultural Economics Division, BARI, Joydebpur, Gazipur.

Miah, M.A.M.; Rashid, M. A.; Haque, M. E. and Bell Richard (2017). Adoption impacts of conservation agriculture technology at farm level in Bangladesh. In: Annual Research Report 2016-17, Agricultural Economics Division, BARI, Joydebpur, Gazipur.

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MEDIA REPORTS, NEWSLETTERS, PAMPHLETS AND VIDEOS

No.	Contents
1	ACIAR project video on Conservation and VMP Machine on 20 September, 2012
2	ACIAR project video on Conservation Agriculture and VMP Machine 23 September, 2012
3	ACIAR project power point report on Conservation Agriculture and Farm Mechanization in Bangladesh on 29 November, 2017
4	The Daily Inqilab Newspaper published on Conservation Agriculture on 15 February, 2017
5	The Daily Ittefaq Newspaper published on Conservation Agriculture on 15 February, 2017
6	The Daily Kaler Kontho Newspaper published on Conservation Agriculture on 15 February, 2017
7	The Daily Noyadiganta Newspaper published online portal on Conservation Agriculture on 15 February, 2017
8	The Daily Prothom Alo Newspaper published on Conservation Agriculture 15 February, 2017

9	The Daily Samakal Newspaper published on Conservation Agriculture on 15 February 2017
10	The Daily Observer published on Conservation Agriculture on 15 February, 2017
11	The Daily Inqilab Newspaper published on Conservation Agriculture and VMP Machine on 15 February, 2017
12	Leaflet on Minimum Tillage Unpuddled Transplanting of Rice Seedlings
13	Abstracts/Proceedings of Minimum Tillage Unpuddled Transplanting of Rice Seedlings on 16 – 17 September, 2015
14	Project Newsletter Vol 1 on Conservation Agriculture Project on October – December, 2015
15	Project Newsletter Vol 2 on Conservation Agriculture Project on January – March, 2016
16	Project Newsletter Vol 3 on Conservation Agriculture Project on April – June, 2016
17	Project Newsletter Vol 4 on Conservation Agriculture Project on July – September, 2016
18	Barind Research Porikroma published Agriculture-water-climate-disaster-ICT newsletter on Feb, 2017
19	The Jai Jai Din Newspaper published on Conservation Agriculture in Rajshahi on 02 February, 2014
20	Newspaper article The National Bank has been awarded by Conservation Agriculture for small holders for VMP distribution
21	Newspaper published photo of The National Bank has been awarded by CASH-II for VMP Machine distribution
22	The Daily Somokal Newspaper published news on weed training on 24 January, 2011
23	The Channel I broadcasted TV news on Field Days at Rajshahi on Conservation Agriculture and VMP Machine on 16 October, 2012
24	The Channel I broadcasted TV News on Unpuddled Rice (adoption) in Rajshahi
25	The Chennel I broadcasted TV News on Conservation Agriculture and VMP Machine on 15 February, 2017
26	Barendra Gobesona Porikroma published Agriculture-water-climate-disaster-ICT research letter on Feb, 2017
27	Leaflet (Bengali) on Conservation Agriculture Project and VMP Machine Operation and Maintenance
28	Bangladesh Television broadcasted TV news on VMP Machine
29	VMP Operation Repair and Maintenance Training Video 42 min duration
30	VMP Introductory Video for demonstration 27 min duration

11 Appendixes

11.1 Appendix 1:

Publications provided on CD