MANUAL FOR SMALLHOLDERS' CONSERVATION AGRICULTURE IN RICE-BASED SYSTEMS

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Australian Government
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The purpose of this document is to describe the current practices that comprise conservation agriculture (CA) and support effective extension, adoption and practice change on CA in Bangladesh.

Launching Ceremony of the "Manual for Smallholders' Conservation Agriculture in Rice-based Systems"

Launched by

Begum Matia Chowdhury, MP, Honorable Minister, Ministry of Agriculture, Government of Bangladesh (4th from right); H.E. Ms. Julia Niblett, Australian High Commissioner to Bangladesh (3rd from right); Mr. Mohammad Moinuddin Abdullah, Senior Secretary, Ministry of Agriculture, Government of Bangladesh (5th from right); Dr. Md. Ikramul Haque, Executive Chairman, Bangladesh Agricultural Research Council (2nd from right); Professor Andrew Campbell, Chief Executive Officer, Australian Centre for International Agricultural Research (1st from right); and Dr. Wais Kabir, Executive Director, Krishi Gobeshona Foundation (6th from right).

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AUTHORS

Dr Md. Enamul Haque, Adjunct Associate Professor Murdoch University, Australia and Project Coordinator - Conservation Agriculture Project has over 26 years practical experience in the field of Conservation Agriculture (CA), farm mechanization, technology dissemination, and commercialization of agricultural equipment. He has contributed significantly to the development of new technologies on CA-system based crop management and machinery development e.g., 2-wheel tractor operated seed drills, zero tillage planter, bed planter, potato planter, Versatile Multi-crop Planter (VMP), Versatile Strip Seed Drill, rice-wheat reaper, mobile fodder and straw chopper, pulses de-husking mill, etc. He has established research and extension platforms (hub) with agricultural scientists, extensionists, farmers and private entrepreneurs to work together for rice, wheat, maize, pulses, triticale, CA-based technology development etc. mass promotion and commercialization. He served as a Cropping System Agronomist for International Maize and Wheat Improvement Centre (CIMMYT) from 1994 to 2011. Dr Haque has been a member of the International Conservation Agriculture Advisory Panel for Africa (ICAAP-Africa) since 2015. He was the Organizing Secretary for 1st and 2nd International Conferences on Conservation Agriculture for Smallholders (CASH-1 and CASH-2) held in Mymensingh, Bangladesh during 2014 and 2017. He has served on the Board of Expert Committee and Scientific Review Committee for the 7th World Congress of Conservation Agriculture, Rosario, Argentina. He participated in many research projects and published 33 journal papers; 107 conference proceedings papers; 12 books and chapters; 8 technical and training video and documentaries.

Dr Richard W. Bell, Professor of Sustainable Land Management, Murdoch University, Australia. He is specialist in Soil Fertility and Land Management with lecturing and research experience in Australia, Bangladesh, Brazil, Cambodia, China, Indonesia, India, Fiji, Laos, Sri Lanka, Thailand, Turkey and Vietnam. His interests are in plant nutrition on problem soils, soil management, management of sandy soils, diagnosis and correction of mineral disorders of plants, plant adaption to mineral stress, nutrient cycling, rehabilitation of degraded land, conservation agriculture, dryland salinity, catchment hydrology and management and sustainable land use. He has authored 159 refereed journal papers, edited 12 books, written 91 refereed articles in book and proceedings. He has been the Project Leader of international cooperative research projects with China on boron and zinc nutrition of oilseed crops (1992-97), land suitability for upland crops in Cambodia (2004-2007); increasing rabi season legume crops production in north-west Bangladesh (2006-2009); reducing water pollution from aquaculture fishponds in Vietnam (2007-2009), developing soil and crop management for sandy soils of coastal south central Vietnam (2009-2012), developing conservation agriculture for smallholder farms in Bangladesh (2012-2017) and soil, nutrient and water management on sands in south-central coastal Vietnam (2014-2018). Supervisor of 12 current and 52 completed post graduate students.

Dr M. Jahiruddin, Professor of Soil Science and Dean of the Faculty of Agriculture, Bangladesh Agricultural University (BAU). His teaching and research area covers soil fertility, soil chemistry, micronutrients, heavy metal pollution, organic matter management and Conservation Agriculture. He has 187 journal papers, 74 proceedings papers and 7 book chapters. Meanwhile he has supervised 12 PhD and 70 Master's students, and currently he is a supervisor of 5 PhD and 5 Master's students at BAU. He has led a number of research projects such as adptation of Conservation Agriculture at farm level (2015-18), biofortification of zinc & iron on rice & wheat (2015-18), community based adaptive research in coastal zones (2014-16), strengthening post-graduate research (2011-13), Conservation Agriculture effect on soil (2012-16), soil fertility management in monga areas (2009-12), screening of boron efficient wheat genotypes (2006-11), and arsenic contamination of soils and crop sustainability (2001-15). He is a member of many professional societies across the world. He has presented papers in many national and international forums. He has completed a number of professional assignments. He worked as a Team Leader for Research Priority Setting in Agriculture and Development of Vision Document-2030 and Beyond: Land and Soil Resource Management.

Dr Md. Mosharraf Hossain, Professor, Department of Farm Power and Machinery, Bangladesh Agricultural University, Mymensingh has 40 years of teaching and research experience in the field of agricultural machinery and management, farm mechanization, Conservation Agriculture and renewable energy. He supervised 6 PhD students and more than 40 MS students. He published 48 research articles in national and international journals. He developed a self-propelled reaper for rice and wheat harvesting and a power tiller axle power measurement device.

Dr Md. Moshiur Rahman, Professor, Department of Agronomy, Bangladesh Agricultural University has 30 years of teaching and research experience in the field of Agronomy. He has successfully completed 14 research projects funded by national and international agencies and developed some agricultural technologies such as water-efficient rice culture through dry direct seeding, weed management for strip planted non-puddled transplanted and dry direct seeded rice, seed storage technology for soybean, groundnut, jute, wheat and rice, planting practices for many field crops etc. He has supervised 80 MSc/MS and 12 PhD students and published 118 journal papers. His research is mainly focused on the development of low cost climate-smart technologies for sustaining crop productivity under present changed climate scenario.

Dr Mahfuza Begum, Professor, Department of Agronomy, Bangladesh Agricultural University (BAU), Mymensingh, Bangladesh. Conducted research and supervised PhD study on weed dynamics in two cropping patterns as influenced by weed management practices under Conservation Agriculture (CA) system. She has 23 years of teaching and research experience on agronomic crop production, crop and weed management, weed biology, weed biodiversity, soil weed seed bank: in-situ and ex-situ, weed seed distribution pattern and weed management in CA system. She earned an "International OWSD Award" for Young Women Scientists in Biology for the Asia and Pacific region for 2011 sponsored by the Elsevier Foundation and TWAS, "John Dillon Memorial Fellowship Award" for further developing leadership skills in the area of agricultural research management, research extension and/or policy making by ACIAR, Australia in 2012 and "Weed Science Award 2012" for her contribution in Weed Research, Management and Education offered by Weed Science Society of Bangladesh (WSSB). She served as head of the Department of Agronomy, Associate Director and Director of BAURES, Executive Editor of the Journal of Bangladesh Agricultural University. She also served as Program Coordinator of MS in Food Security, Interdisciplinary Centre for Food Security, BAU. She has published 68 articles in national and international peer reviewed journals and attended many national and international conferences. Supervisor of 7 current and 55 completed post graduate students. She is the co-author of a book entitled "Weed Science" published by University Grants Commission of Bangladesh.

Dr Anwar Hossen, Senior Scientific Officer, Farm Machinery and Post-Harvest Technology Division, Bangladesh Rice Research Institute. Conducted PhD research on mechanized transplanting of rice in non-puddled soil. He is a specialist in rice-based machinery design, development and dissemination to the end users. His interests are in deep placement of fertilizer application, non-puddled rice establishment, power tiller operated transplanter, combine harvester development as well as multipurpose use of existing agricultural machinery. He published 50 scientific papers in national and international journals and attended more than 25 training programmes, conferences and workshops in country and abroad. He also authored one book and 5 booklets. He successfully implemented the NATP-1 funded project as Principal Investigator on USG applicator and rice transplanter design, development and validation (2010-2013), Co-principal Investigator of KOICA funded project on capacity building of BRRI (2011-2013) and Principal Investigator of the Govt. special funded project on incorporation of prilled urea deep placement mechanism in the walk-behind type rice transplanter (2018). He is now implementing PBRG, NATP-2 funded project on design and development of fertilizer deep placement mechanism for the walking and riding type rice transplanter as Principal Investigator (2018-2021). He is an expert member (rice transplanter) of the Technical Working Group (TWGs) of Asia and Specific Network for Testing of Agricultural Machinery (ANTAM) under Centre for Sustainable Agricultural Mechanization (CSAM) of United Nations Economic and Social Commission for Asia and the Pacific (ESCAP). He is an approved supervisor of Bangladesh Agricultural University, Mymensingh and Sylhet Agricultural University, Sylhet (supervisor of 4 current and 4 completed post graduate students). Dr Hossen is a member of the Bangladesh Society of Agricultural Engineers (BSAE), JICA Alumni Association and the Institute of Engineers (IEB), Bangladesh.

Dr Nazmus Salahin joined Soil Science Division of Bangladesh Agricultural Research Institute as a Scientific Officer in 2007. Since then he has been involved in research on developing Conservation Agricultural (CA) technologies (minimum tillage and crop residue retention) for diversified cropping systems in Bangladesh. Beside these, he conducts experiments on crop establishment practices for successful production of crops in rice-based cropping systems under changing climatic conditions in the Eastern Indo-Gangetic plains. He has comprehensive expertise on physical aspects of soil management. In addition, his major research interests lie with soil organic matter, nutrient management, problem soils management, saline and hill soil management and soil fertility improvement. In line with these, he was awarded Doctoral Research Scholarship from ACIAR in 2012 and conducted his PhD research on the medium-term effects of CA on soil organic matter, nutrient content and cropping system productivity in the rice-jute cropping system. He participated in many seminars, workshops and training programmes at home. He achieved the 'Award in recognition of outstanding contribution for Research on Conservation Agriculture for Soil Health Improvement' by Conservation Agriculture (CASH-II) Conference Organizing Committee, 2017. He has published 26 full research papers, one short communication in well-recognized national and international journals, two book chapters and six proceedings in national and international conferences related to increasing yield and soil health improvement under different tillage methods, residue management, green manuring, hill soil management, problem soils management and soil organic matter improvement.

Dr Taslima Zahan, Scientific Officer, On-Farm Research Division, Bangladesh Agricultural Research Institute. Conducted PhD research on effect of herbicides on weed and crop in rice-wheat-mungbean cropping pattern under Conservation Agriculture (CA) systems. She also studied herbicide tolerance of rice and wheat varieties under CA systems and the residual effects of herbicides on the succeeding crops and on soil micro-organisms. She is highly engaged with research related to weed management in CA systems since 2012. She has published 13 research articles in national and international journals; 18 conference proceedings papers and abstracts and 4 booklets. She attended many national and international conferences and workshops. She trained farmers, scientists and extension workers on weed management especially under CA systems. She has received a recognition award for outstanding research in weed management under CA systems in the 2nd International Conference on Conservation Agriculture for Smallholders (CASH-1 and CASH-2) held in Mymensingh, Bangladesh during 2017.

Mohammad Mobarak Hossain, Scientist-Water Science, International Rice Research Institute (IRRI). He conducted on-farm PhD research on weed seed bank dynamics and crop productivity in Conservation Agriculture (CA) during the CA project in Bangladesh. He graduated with a Bachelor of Science in Agriculture Honors' from Bangladesh Agricultural University (BAU) in 2010 and Master of Science in Agronomy from the same University in 2012. He was awarded University Gold Medal Award for the outstanding academic and research performances during his post-graduate studies. He was selected for a PhD fellowship supported by the Australian Centre for International Agricultural Research (ACIAR) project, for in-country doctoral research at BAU during 2013. He is specialized in crop production under CA principles, weed control in CA utilizing strip planting, cropping pattern, crop residue retention, and safe use and handling of herbicides. He has published more than 30 research articles in different peer-reviewed journals, proceedings and manuals related weed control and weed seed bank dynamics in CA for sustainable crop production. He presented research papers and posters in different national and international conferences, workshops, and seminars and was awarded best research paper presenter several times including the Conference of Conservation Agriculture, Bangladesh Society of Agronomy (BSA), and Bangladesh Weed Science Society (BWSS). During his professional career, he gained skills on the modern water management technique for profitable crop production through on-farm research and advanced training courses. His future research interest is in the QTL deployment in rice for increasing resistance against biotic stresses. The author is a life member of BSA, BWSS and Krishibid Institution Bangladesh (KIB).

Dr Abul Hashem, who gained a PhD from Oregon State University, USA, is currently the Principal Research Scientist (Weed Science) of the Western Australian Government Department of Primary Industries and Regional Development (DPIRD) and has 37 years of experience in agronomy and weed science. He was awarded USAID Scholarship for PhD in USA (1987-1991); outstanding research and extension award in Western Australia (2006); Australian Fulbright Scholar to USA (2009-2010); and Outstanding reviewer of Elsevier Publisher (Journal of Crop Protection). He has published 44 papers in refereed scientific journals; presented 216 national and international conference papers, and abstracts in proceedings; 50 Newsletter and popular articles; 20 Press/Media Releases (all Australian national outlets); and contributed to 15 state radio interviews. He is an external examiner of MS and PhD theses of Australian and overseas Universities, and reviewer of seven international weed science and crop science journals. In the CA project, he conducted research on weed control utilising crop competition and herbicides in CA; supervised PhD students; trained scientists and extension workers on safe use and handling of pesticides.

Dr Md. Ariful Islam is a Scientific Officer at Pulses Research Centre of Bangladesh Agricultural Research Institute. He did his PhD on crop and soil management with Conservation Agriculture (CA) in rice-based cropping systems from Murdoch University, Australia. His current research interests are in sustainable crop production system with a particular emphasis on soil and crop management with legumes and CA in intensive and diversified rice-based systems. His interests also include soil nutrient dynamics in CA, biological nitrogen fixation, weeds and herbicides. In 2017, Dr Islam was honoured with an Award by the 2nd Conference on Conservation Agriculture for Smallholders for his outstanding contribution to research on CA for soil health improvement. Dr Islam has published several scientific papers in national and international journals. He presented his scientific papers in a number of national and international conferences.

Dr Wendy H. Vance, Research Fellow in the School of Veterinary and Life Sciences, Murdoch University. Her research has covered areas of land capability assessment, soil physical constraints to crop production, crop agronomy, crop simulation modelling and cropping systems whilst participating in ACIAR projects in Bangladesh (2006-2015) and Cambodia (2002-2006). Much of her PhD research (completed in 2013) was undertaken in the field in Bangladesh. Her PhD research documented the dynamics of soil water in the root zone under strip planting of chickpea relative to conventional crop establishment methods.

Dr Md. Israil Hossain is an Agricultural Engineer. He acquired an academic bachelor degree from Bangladesh Agricultural University (BAU), Mymensingh in 1984. He joined Bangladesh Agricultural Research Institute (BARI) in 1989 as a Scientific Officer and currently holds the position of Chief Scientific Officer & Head of Farm Machinery & Postharvest Process Engineering Division of BARI, Gazipur. He is strongly involved in Conservation Agriculture (CA) based machinery and mechanization research work since 1996. He has been published more than 85 research articles in different national and international journals, proceedings related to farm machinery and mechanization, especially on zero till, strip planting, raised bed planting, minimum till technology, and two wheel tractor attached appropriate small machinery for the farmers. He presented research papers in different national and international workshops, seminars, and conferences as an invited guest speaker on his subject specialization. He is an experienced machinery researcher who gained knowledge from: higher farm mechanization training course, JICA, Japan; CA training from CIMMYT, Mexico; plant protection machinery training from China. He successfully implemented and completed small machinery and mechanization related donor funded projects in the farmers' fields as a technical researcher with ACIAR, Cornell University (USA) and FAO. He received Food for Progress Award from Cornell University, USA; Two wheel tractor expert certificate from ACIAR, Australia. He also awarded as the best paper presenter in the seminar of Bangladesh Agronomy Society 2014. Currently, he is an active member of Technical Working Group of the Centre for Sustainable Agricultural Mechanization (CSAM) of UN ESCAP.

Mr. R Jeff Esdaile is an Australian grain grower and agronomist, with wide experience in Conservation Agriculture (CA). He has been associated with practical CA since the late 1960's and grew the first cereal crop in Northern NSW using zero tillage in 1977. Since that time, with others he has promoted this system, as well as actively developing reduced and zero tillage farming. From 2004 to 2016 Jeff has been involved in research, development and promotion of CA farming in South Asia and East Africa, with special emphasis on small farm mechanisation. With others he has developed CA farming implements to suit small area farmers of the developing world. Jeff was awarded the Donald medal by the Australian Society of Agronomy in the year 2000 for his service to the profession. He was also made a member of the Order of Australia in 2006 for his contribution to Australian agriculture.

Dr Md. Enamul Kabir, Professor of Agrotechnology Discipline, Khulna University, Bangladesh. He completed his PhD from Murdoch University, Australia on Plant Nutrition. His teaching and research area covers plant nutrition, plant physiology, soil fertility, Conservation Agriculture (CA), plant adaptation to mineral, salt, drought and excess water stresses and nutrient management under these abiotic stresses and CA. Over the years he has been engaged in research in smallholder farms on cropping intensification especially in the marginal lands. His research projects are aligned with the "Agricultural Research Priority: Vision-2030 and beyond" of the Government of Bangladesh. He has been engaged with several collaborative research projects with different Australian and domestic organizations such as cropping system intensification in the coastal zones of Bangladesh and India (2016-2019), nutrient management for diversified cropping in Bangladesh (2018-2021). Recently he started a project on silicon, salinity and wheat. He has 25 peer reviewed articles and 8 proceedings papers. He is a supervisor of 5 PhD and 8 Master's students. Earlier he supervised 10 Master's and 25 undergraduate research students.

FOREWORD

Bangladesh Agricultural Research Council
Farmgate, Dhaka, Bangladesh

Bangladesh as a nation has made great strides forward in achieving food security. Farmers and the agriculture service sector can be proud of the achievements of crop intensification that have boosted the food production of Bangladesh. But more needs to be done to sustainably maintain and strengthen food security in the face of rising population, variable and changing climate, declining groundwater levels, scarcity of farm labour and rising cost of production.

The Government of Bangladesh supports initiatives to address these challenges. I understand that research over the last decade in Bangladesh has demonstrated that Conservation Agriculture-based crop and production system management practices could have a major role in adapting cropping to variable and changing climate, to reversing the declines in groundwater levels, and overcoming scarcity of farm labour and rising costs of production. The Government of Bangladesh is also very pleased to note that conservation agriculture (CA) has water saving benefits as well as cost savings.

Researchers and university professors have to learn from their own firsthand practice to grow crops under CA systems. This will give them a high degree of self-confidence if they gain the experience themselves and know that CA works. This can make them good communicators if they are humble and use appropriate language. Universities should include under graduate and post-graduate courses on the CA. Extension people can be good communicators if well-trained and if they have practical experience with CA systems and practices themselves, which is not always the case. Being the link between researchers and farmers they sometimes do not have the facilities to be able to practice growing crops under CA. Therefore, demonstration plots on farmer's fields are the opportunity for them to gain experience with CA and show farmers how the system works. Farmer to farmer extension has been the most effective way of transferring knowledge and experience about CA to other farmers. A farmer with experience in CA is much more credible in front of his/her peers than anybody else.

While CA covers about 180 million ha globally it has mostly been adopted on large mechanized farms. Although only a small percentage of CA area in Asia and Africa is managed under CA systems, globally more small farms practice CA than large farms. While researchers in Bangladesh have been developing CA systems, including rice-based systems, for small farms for the past 20 years, adoption on farms has begun only recently. We are grateful to Murdoch University Australia for leading the Conservation Agriculture Project funded by ACIAR and in partnership with the Bangladesh Agricultural Research Council, Bangladesh Agricultural Research Institute, Bangladesh Rice Research Institute, Bangladesh Agricultural University, and the Conservation Agriculture Service Providers Association which created ample opportunities for research and development on CA systems in Bangladesh. I am encouraged that most of the research has been carried out in this country by the Bangladeshi NARS scientists and university professors in partnerships with farmers and private sector organizations. I have learned that CA works well for cropping systems involving crops such as rice, jute, oil seed, maize, wheat and legumes.

Conservation Agriculture is knowledge and management intensive and it is a complete paradigm change in the way agricultural land use and production is managed which requires greater engagement with land, crops and ecosystem management planning, as well as acquiring adequate management skills and the willingness to learn and innovate constantly. The Manual for Smallholders' Conservation Agriculture in Rice-based Systems has been developed by the scientists mostly from Bangladesh who have led the CA initiative during the last decade or so. The purpose of this Manual is to assemble information from research and extension activities in Bangladesh under the Conservation Agriculture Project to support effective extension, adoption and practice of CA in Bangladesh. It is encouraging that there are plans to publish this Manual in English for non-Bengali peoples, in Bangla for Bengali peoples, and a shorter pictorial Bangla version for Bangladeshi farmers.

I am thankful to Murdoch University for leading the initiatives to prepare this Manual, and confident that it will be an excellent resource for policy makers, researchers, university teachers, students, extensionists, service providers and farmers.

Dr Md. Kabir Ikramul Haque
Executive Chairman

FOREWORD

Bangladesh Agricultural Research Institute
Joydebpur, Gazipur, Bangladesh

Conservation Agriculture (CA) is based on three principles - minimum soil disturbance, covering of soil surface with crop stubble or cover crops, and crop diversification. The shift of cropping practices from conventional multiple full tillage operations and crop stubble removal to minimum soil disturbance, crop stubble retention and diversified cropping is likely to alter nutrient forms and availability in soils and fertilizer responses of crops, change weed dynamics, require adjustment of agronomic practices, water management etc. The concept of CA is fairly new in Bangladesh, while it has been practiced globally since the 1960s. Currently CA is being applied on about 180 million ha globally. Although most of the CA area is being managed by large mechanized farmers, there are more small farmers practicing CA globally than large farmers. CA has greater potential in developing regions and during the past two decades, CA systems have begun to spread in Asia and Africa. With funding support from the Australian Centre for International Agricultural Research, Bangladesh has been developing the elements of Conservation Agriculture since the mid-2000s through the involvement of Bangladesh Agricultural Research Council, Bangladesh Agricultural Research Institute, Bangladesh Rice Research Institute, Bangladesh Agricultural University, Murdoch University and the Department of Primary Industry and Regional Development - Australia, etc. The adoption of full CA on small farms is just beginning to take off in Bangladesh.

Three basic elements, along with complementary crop and production management practices, are necessary to implement good quality CA on a farm: a specialized seeding/planting machine adequate to seed into untilled soil, cover crops/chemicals to control weeds and knowledge about how to manage these new cropping practices and systems. Planter selection for implementation of CA depends on various factors - (i) farm size; (ii) agro-ecology; (iii) type of crops; (iv) farmers' socio-economic condition; (v) level of stubble retention; etc. While in Conventional Agriculture a farmer does not need to know too much about weeds because in general tillage implements kill most weeds, in CA the farmer needs to be able to identify each weed individually and know which herbicide, cover crop or management practices can be used to control it. Weed management in crop fields is a major challenge. I understand that herbicides are widely used in Bangladeshi agriculture. It is timely to learn about principles for the development of effective weed control in smallholder farms including those practicing CA. Farmers need guidelines on safe and effective use of herbicides and they also need advice on effective non-herbicide approaches to weed control.

It is really encouraging that the planters made in Bangladesh are now being commercialized to allow owners of power tillers (2-wheel tractor) to plant crops with minimum soil disturbance and crop stubble retention. With lower costs of crop production, and the capacity to establish 2-3 times greater area of crops in the same time period, increased profits can be achieved with mechanized crop establishment. It is estimated that practicing CA can bring an extra Taka 43,500 ha^{-1} per year for smallholder farmers.

The ACIAR-funded Conservation Agriculture Project led by Murdoch University, Australia in partnership with BARC, BARI, BRRI and BAU helped to conduct many research projects of CA and farm mechanization and developed sustainable and environment friendly CA technologies. Research over the last decade in Bangladesh has demonstrated that CA practices could have a major role in overcoming scarcity of farm labour and rising costs of production through mechanization.

I am happy to know with the leadership of Murdoch University; the Manual for Smallholders' Conservation Agriculture in Rice-based Systems has been developed where the authors have compiled all research results of the Conservation Agriculture Project outcomes related to crop production in CA systems. I am very proud to know that significant contributions have been made by several BARI scientists to this Manual from their research on farm mechanization; agronomy including weed management and safe use of herbicides; soil health improvement; carbon sequestration, etc.

Although, this Manual is written in English, I am pleased that a translation will be published in Bengali language. This Manual will help the new researchers, teachers, students, extensionists and farmers to implement CA practices in smallholder's farming communities.

Dr Abul Kalam Azad
Director General

FOREWORD

Bangladesh Rice Research Institute
Joydebpur, Gazipur, Bangladesh

While Conservation Agriculture (CA) systems and practices are now well-developed and tested for non-rice crops, the adoption of CA in transplanted-rice-based systems remains a challenge. Rice is the staple food in Bangladesh and rice area occupies about 80 % of the total cropped area of Bangladesh. The Boro and Aman rice occupy about 4.7 and 5.05 million ha, respectively. Soil puddling is the common field preparation practice for rice seedling transplanting but it is time consuming, capital intensive, and degrades the soil physical condition. Conservation Agriculture refers to a wide array of specific technologies that are based on applying three interlinked principles - (i) minimal soil disturbance); (ii) covering the soil surface adequately; (iii) diversified cropping. Conservation Agriculture is a win-win approach that reduces operational costs, including machinery, labour, and fuel, while increasing yields and better utilizing natural resources. Conservation Agriculture helps farmers to reduce production costs while maintaining or increasing crop yields, and improving soil health, crop diversity and timeliness of cultivation. Thus, systematic work is needed on the adoption of CA in rice-based systems.

A group of professors, scientists, and students from Bangladesh Agricultural Research Council, Bangladesh Agricultural Research Institute, Bangladesh Rice Research Institute, Bangladesh Agricultural University, Murdoch University - Australia, Department of Primary Industry and Regional Development of Western Australia have studied the various elements of CA in rice-based systems of Bangladesh through the funding support from the Australian Centre for International Agricultural Research (ACIAR). The research elements include - (i) development of minimum soil disturbing farm machinery including non-rice and rice crops; (ii) developing 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; (iii) soil health improvement; (iv) carbon footprint; (v) non-puddled rice transplanting, etc.

The research and extension work clearly demonstrated that the CA works well in many adapted crops in Bangladesh including rice, wheat, maize, jute, oil seed, etc. Development of non-puddled transplanting of rice technology is of great interest to BRRI and I congratulate the research team for the development of non-puddled rice transplanting systems.

I am happy to know that the BRRI scientists led the non-puddled rice transplanter development research, water balance in CA, etc. and few of the BRRI scientists contributed to this Manual for Smallholders' Conservation Agriculture in Rice-based Systems based on their research under the Conservation Agriculture Project. This Manual is basically the compilation of the research works that have been carried out mostly by the Bangladeshi NARES scientists under the CA project. I am pleased to know along with this English version, the Manual will be translated into Bengali and produced in a pictorial form. These Manuals will be helpful for the policy makers, researchers, teachers, students, extensionists, and farmers for further research and development of Conservation Agriculture.

Dr Md. Shahjahan Kabir
Director General

FOREWORD

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The development and evolution of Conservation Agriculture (CA) has been one of the major success stories of Australian agriculture over the last forty years. Ploughed fallow and stubble burning is very rare in Australia today in the cereal belt, in rice and even in sugar cane, and the retention of organic matter and incorporation of legumes into cropping rotations is seen as standard good farming practice. This reflects decades of fruitful collaboration between Australian agricultural scientists in the public and private sectors, innovative farmers, extension services and agribusiness. Complementing progress within Australia, ACIAR has been a major investor in research and development in CA in our partner countries, because it has great potential to benefit farmers, food security and sustainability. Research in the rice-based intensive agriculture of Bangladesh has demonstrated multiple benefits from CA, including labour saving, decreased costs of production, improved soil health and decreased greenhouse gas emissions, while maintaining or improving yields. ACIAR sees research as the beginning of transformations in agriculture, not the end, and this Manual is intended to make findings from CA research more accessible to a range of stakeholders, to support practical application. ACIAR places high value on technologies that are safe for the environment and for farmers. We are pleased to see that safe use of herbicides is given due emphasis in the Manual. These principles and guidelines will be equally useful for conventional agriculture in Bangladesh.

The Manual is the collective effort of many partners, demonstrating the value of ACIAR's collaborative approach to research funding. It draws on long-term research from a number of sources, including ACIAR Project LWR-2010-080 Overcoming Agronomic and Mechanization Constraints to Development and

Adoption of Conservation Agriculture in Diversified Rice-based Cropping in Bangladesh. That project trained 7 PhD and 18 MSc students from National Agricultural and Educational Research Systems in Bangladesh and underpinned two international conferences on conservation agriculture for smallholders.

In addition to this English version of the Manual, which summarises the main science underpinning CA in Bangladesh, ACIAR is funding the publication of a Bangla version to make the information more accessible to a wider range of stakeholders and practitioners. We are also supporting production of a pictorial version that will communicate directly with farmers in Bangladesh.

I am delighted to see that these very useful manuals will be accessible to a much wider global audience via a web-based repository.

Professor Andrew Campbell
Chief Executive Officer

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PREFACE

Conservation Agriculture (CA) is widely practiced worldwide. Predominantly, CA is a practice that has developed for large mechanized farms, but increasingly adoption of CA is occurring on small farms in Africa and Asia, where institutional support is available, as has been the case in South America in countries such as Paraguay and Brazil.

Adoption of CA in Bangladesh is limited. Rahman et al. (2017) reported that in 2013-14, about 440 hectares of crop was planted with strip tillage or zero tillage. Haque (unpublished data) reported that Rabi season planting by CA principles using the Versatile Multi-crop Planter (VMP) (which can be operated by a two-wheel tractor (2WT) to place seed and fertilizer in soil for crop establishment) in the 2016-17 season was 1,500 hectares. In Durgapur Upazilla, where a concentration of effort on VMP promotion and extension has occurred in the last 5 years, 2016-17 Rabi season planting was 4.5 % of the total crop area. In three blocks, the CA planting reached 10-16 % of all Rabi season crops. Hence there is evidence of early adoption by farmers where there have been programmes to build farmer awareness, practical skills and confidence in the technology and the availability of the planters and local service providers (LSP) to offer planting services to farmers on a custom hiring basis.

There is now a substantial body of research on CA systems and components of CA, and on their performance in farmers' fields and from long-term experiments. Based on these findings, many of which were reported at the first and second Conferences on Conservation Agriculture for Small Holders (CASH), it is timely to outline the technologies and management practices that comprise current best management practice (BMP) in CA for small holders in Bangladesh. The practices of CA will evolve over time based on adaptations of the technology by farmers and LSP, accumulated experience by farmers, release of new machinery and equipment into the market, and further research and innovation.

This is the first version of the CA Manual. It is designed to describe the current state of knowledge about the practices that represent CA systems for smallholders in rice-based cropping in Bangladesh. Given the evidence that adoption of CA has begun, this Manual aims to accelerate learning about CA by farmers, extension officers, researchers, local service providers, and other stakeholders. CA management should be a process of continuous improvement and this can occur through learning, reflection and continuous dialogue among practitioners and stakeholders. Further versions will be necessary as the BMPs for CA systems evolve. To make the results more accessible, a Bangla translation of this Manual will be published as well as a pictorial form of the Manual for farmers with Bangla text.

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There are so many people to thank for helping us during the last 10 years while conducting research and farmer engagement and supporting businesses in the development of Conservation Agriculture (CA) systems for Bangladesh.

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LIST OF ABBREVIATIONS

%	Percentage
2WT	Two-wheel tractor
a.i.	Active ingredient
ACIAR	Australian Centre for International Agricultural Research
AWD	Alternate wetting and drying
BARI	Bangladesh Agricultural Research Institute
BRRI	Bangladesh Rice Research Institute
BARC	Bangladesh Agricultural Research Council
BAU	Bangladesh Agricultural University
BHT	Bangladesh Hand Tractor
BMDA	Barind Multi-purpose Development Authority
BP	Bed planting
BRAC	Bangladesh Rural Advancement Committee
BMP	Best management practice
CA	Conservation Agriculture
CASH	Conference on Conservation Agriculture for Small Holders
CHT	Chinese Hand Tractor
CIMMYT	International Maize and Wheat Improvement Center
cm	Centimetre(s)
CT	Conventional tillage
DAE	Department of Agricultural Extension
DAS	Days after sowing
DAT	Days after transplanting
DBS	Days before sowing
DSR	Direct seeded rice
EU	European Union
EWRS	European Weed Research Society
EPA	Environmental Protection Authority
FAO	Food and Agriculture Organization of the United Nations
ha	Hectare(s)

HC	Hoque Corporation
hp	Horsepower
hr	Hours
IAS	Immediates after sowing
IWM	Integrated weed management
kg	Kilogram(s)
Knockdown	Non-selective herbicide
L	Litre
LSP	Local service provider(s)
mm	Millimetre(s)
MOA	Mode of action
MU	Murdoch University
MSDS	Material safety data sheet
NGO	Non-government organization
NARS	National Agricultural Research System
NARES	National Agricultural Research and Education System
NPT	Non-puddled transplanting
P	Phosphorus fertilizer
PIO	Project Implementation Office
PPE	Personal protective equipment
PTOS	Power Tiller Operated Seeder
Rabi	Cool and dry season
rpm	Revolutions per minute
S	Sulphur fertilizer
SE	South-east
SP	Strip planting
SPST	Single pass shallow tillage
SWC	Soil water content
SOC	Soil Organic Carbon
t	Tonne
T. Aman	Transplanted Aman (monsoon season) rice
Upazilla	Sub-district
USA	United States of America
VMP	Versatile Multi-crop Planter
VSSD	Versatile Strip Seed Drill
WA	Western Australia
ZT	Zero tillage

CONSERVATION AGRICULTURE IN RICE-BASED SYSTEMS

INTRODUCTION

Conservation Agriculture (CA) is widely practiced worldwide but is still new to Bangladesh agriculture. Recent estimates put the area of CA globally at 180 million ha (Kassam et al. 2018). Some 80 % of the global practice of CA is in five countries: USA, Brazil, Argentina, Australia and Canada. In South America, adoption of CA is about 60 % of crop land. In some regions, such as West Australia (WA), adoption is over 90 % (Rochecouste and Crabtree 2014). Predominantly, CA is a practice that has developed for large mechanized farms. There is also development of CA for small farms in Brazil at the same time as CA was expanding on large farms, and most of the farmers in Paraguay are small and nearly all of them practice CA. More recently, adoption of CA has been occurring on small farms in Africa and Asia. In fact, nearly 8 % of the global CA area is in Asia including in countries such as Kazakhstan, India, Pakistan, China and Iran.

Conservation Agriculture is an approach to managing agro-ecosystems for improved and sustained productivity, increased profits and food security while preserving and enhancing the resource base and the environment.

On-farm practice of CA in Bangladesh has begun in recent years. Rahman et al. (2017) reported that in 2013-14, about 440 hectares of crop was planted with zero tillage or strip planting. Haque at el 2018 (unpublished data) reported that Rabi season planting by CA principles using the Versatile Multi-crop Planter (VMP) (which can be operated by a two-wheel tractor (2WT) to place seed and fertilizer in soil for crop establishment) in 2016-17 season was 1,500 hectares. In Durgapur Upazilla, where a concentration of effort on VMP promotion and extension has occurred in the last 5 years, CA planting covered 4.5 % of the total crop area in the Rabi season of 2016-17. In three blocks, the CA planting reached 10-16 % of all Rabi season crops. Hence there is evidence of adoption and uptake by farmers where there are programmes to build farmer knowledge and confidence in CA systems and the availability of the planters and local service providers (LSP) to provide planting services for farmers on a custom hiring basis.

There is a growing body of research on CA and its components in Bangladesh, on its performance in farmers' fields and from long-term experiments. Based on these findings, many of which were reported at the first[1] and second[2] Conferences on Conservation Agriculture for Small Holders (CASH), it is timely to outline the system that comprise current best management practices (BMP) in CA for small holders in Bangladesh. The CA systems will evolve over time based on modifications of the technology by farmers and LSP, release of new machinery into the market, and further research.

[1] Vance, W.H., Bell, R.W. and Haque, M.E. (2014). Proceedings of the 1st Conference on Conservation Agriculture for Smallholders in Asia and Africa. 7-11 December 2014, Mymensingh, Bangladesh. Published as an E-book. p 213. http://researchrepository.murdoch.edu.au/26081/

[2] Haque, M.E., Bell, R.W. and Vance, W.H. (2017). Proceedings of the 2nd Conference on Conservation Agriculture for Smallholders in Asia and Africa. 14-16 February 2017, Mymensingh, Bangladesh. Published as an E-book. p 201. http://researchrepository.murdoch.edu.au/id/eprint/36818/

WHAT IS CONSERVATION AGRICULTURE?

Conservation Agriculture is "a set of soil-crop-nutrient-water-landscape system management practices" (Kassam et al. 2015). More specifically, CA is an approach to managing agro-ecosystems for improved and sustained productivity, increased profits and food security while preserving and enhancing the resource base and the environment. CA is characterized by three linked principles (FAO, 2014), namely:

1. Continuous no- or minimal mechanical soil disturbance i.e., no-tillage and sowing or broadcasting of crop seeds, and direct placing of planting material in the soil; no-till weeding; minimum soil disturbance from farm operations, harvest operation or farm traffic; in special cases limited strip or band seeding disturbing less than 25 % of the soil surface;

2. Maintenance of a permanent organic soil mulch cover, especially by crop stubble, mulches and cover crops; and

3. Diversification of crop species grown in rotations, sequences or associations involving annual and perennial crops, including a balanced mix of legume and non-legume crops.

To date in Bangladesh, the long-term experiments suggest that both minimum soil disturbance and increased stubble retention produce independent benefits for crop yield, soil organic carbon and decreased weed seed banks and infestation.

WHY CONSERVATION AGRICULTURE?

Multiple benefits are produced by applying the CA approach for crop production. The relative value of the benefits may vary among crop species, soil types and agro-climatic zone. The value of the various benefits to farmers may also vary from farm to farm. For a cash-poor farmer, the reduced cost of production may be the key benefit, while for a farmer with adequate farm labour, the labour savings may not be influential in the decision to adopt CA.

THE KEY BENEFITS OF CA SHOWN BY RESEARCH IN BANGLADESH

- Save labour.
- Save costs.
- Save time.
- Improve soil health.
- Save water.
- Decrease weed seed bank.
- Improve yield and yield stability.

Elsewhere in the world, CA is also beneficial because it decreases soil erosion. On the flat lowlands of Bangladesh, soil erosion is not a consideration for farmers, but the spread of CA to the hill tracts of SE Bangladesh will elevate the importance of erosion control.

Water savings are a key benefit for CA particularly in rainfed cropping in semi-arid and arid environments. Water savings are achieved by minimum soil disturbance that slows the loss of soil water by evaporation. In addition, soil cover by standing or prostrate crop stubble slows the rate of soil water evaporation. The cooler temperatures under retained stubble also contribute to slower evaporation loss of soil water. To date, only limited research has been done on the water savings under CA, and most of this has been under irrigated crops where less irrigation water has been reported to be adequate for wheat and rice.

FACTORS AFFECTING ADOPTION OF CONSERVATION AGRICULTURE?

INVESTMENT IN LEARNING

Conservation Agriculture is a complex innovation on farms requiring a substantial learning investment by farmers and LSP before and during adoption. In Australia, farm consultants were often critical to enabling farmers to learn enough about the system to implement CA. Farmer groups also provided a learning network where farmers could meet to discuss constraints with all aspects of CA adoption and to share their learning. In Bangladesh also, the complexity of the CA innovation needs to be recognized. It is not equivalent to the adoption of a new cultivar, where essentially every part of the crop production process remains the same, except for the change of the variety of seed. In the case of CA, there are many changes to incorporate and each needs a few years of experience to fully learn how to optimize the technology on a particular farm. For example, farmers and LSP have to select the correct soil water content for seeding using minimum soil disturbance, new planters and with retained crop stubble. The planting of seed and placement of basal fertilizers in rows rather than by broadcasting is a new practice for many farmers. Weed control practices have to change, in particular the critical need to control weeds before sowing in CA.

BARRIERS TO ADOPTION OF CA

From global studies, the main impediments to adoption of CA are (Friedrich and Kassam, 2009; Jat et al., 2014; Farooq and Siddique, 2014):

- knowledge on how to do it (know how);
- mindset (tradition, pre-judgment about likely success or failure);
- unsupportive policies, for example, subsidies for ploughs and tillage machinery;

- unavailability of appropriate equipment and machines (many countries of the world), and of suitable herbicides and alternative management strategies to facilitate weed and vegetation management (especially for larger farms in developing countries).

Additional factors limiting adoption of CA in Queensland, Australia (Thomas et al. (2007) were:

- investment cost of machinery conversion or replacement;
- buildup of soil- and stubble-borne plant disease;
- concern that inclusion of residual herbicides may limit crop options;
- integration of livestock with cropping may require tillage to remove forage or pasture phases;
- herbicide resistance and buildup of hard-to-kill weed species; soil disturbance may be needed in some situations in future; and
- environmental and health concerns about the effects of herbicides on and off site.

In semi-arid environments, the supply of crop stubble is low due to low yield, and in farming systems that run cattle or sheep residue is used to feed livestock. The lack of stubble is perceived to be a barrier to CA adoption. In addition, where herbicides are not available, the immediate crops after adopting CA have a higher weed burden than where tillage has suppressed weeds. This too is a large disincentive for farmers to adopt CA and is especially burdensome for women who generally do the manual weeding (Giller et al., 2009).

DRIVERS OF CA ADOPTION

The main drivers behind the adoption of CA in Australia were the desire to control excessive erosion, the need to save soil moisture at sowing and the merits of earlier sowing for crop yields (Thomas et al. 2007). In Southern Brazil, farmers' initial motivation to adopt CA was erosion control. Later, farmers in Brazil were given incentives by the government to adopt CA as an erosion control measure in order to reduce sediment loading of water in reservoirs. In WA and South Australia (SA), episodic wind erosion events on sand-surfaced soils were a trigger to find methods for protecting sandy soils.

In both cases, the reduction of tillage and retention of crop stubbles were identified as practices that protected soils and greatly reduced the frequency of wind erosion events. In both Australia and Brazil, Government programmes provided incentives for farmers to adopt CA to control soil erosion.

In areas where fastest adoption occurred in WA, low profit margin was a driver behind the need to save costs of crop establishment and low rainfall was an incentive to save soil water for crop establishment. Early sowing, afforded by one-pass, minimum soil disturbance planting, was an additional goal for adoption of CA. There are now no significant areas not using CA in WA.

In Queensland, excessive water erosion was the major imperative for reduced tillage and crop stubble retention. Research demonstrated the efficacy of soil cover in reducing erosion rates. However, significant adoption only followed the widespread availability of cheap glyphosate herbicide for weed control.

Many of the above factors affecting CA adoption were reinforced in the survey of 1,170 Australian grain growers by Llewellyn et al. (2012) who found that 84 % were using minimum soil disturbance planting on some portion of their land. Currently concerns about soil erosion play no role in whether a farmer would adopt CA. By contrast, weed control effectiveness and reliable early sowing were important considerations. Greater soil water retention and the ability to establish crops reliably with lower rainfall are currently the important benefits perceived by Australia farmers for adopting CA.

CONSERVATION AGRICULTURE ADOPTION IN BANGLADESH

The factors limiting adoption in Bangladesh have not been studied in detail. From group discussions and informal discussions with key informants, the main factors affecting the adoption of the practice of non-puddled transplanting seem to be:

- farmer's belief in the necessity of ploughing and leveling, based on conventional practices;
- peer pressure from neighbours to continue ploughing and leveling so that fields look "well prepared";
- concern that machine planting may not produce satisfactory plant populations;
- concern about lower yield;
- investment cost for machinery purchase;
- inclusion of potato in the cropping rotation requires tillage to plant and harvest (if done conventionally);
- perceived difficulty of controlling hard-to-kill weeds without soil disturbance; and
- mindset;
- environmental and health concerns about the effects of herbicides on and off site.

As with any innovation in agriculture, there will be early adopters who quickly assess the potential benefits of the technology and are willing to test it on their farm when the practice is still new. This is evident in Bangladesh. In Durgapur, for example, after seven years of experiments on CA, a concerted effort was made to promote VMP sales to LSP. By 2016, 32 VMP were available in the Upazilla that covers 1,650 ha. Those 32 LSP planted 900 hectares in 2016-17 Rabi season, comprising 4.5 % of all plantings. These are the early adopters of the technology. Based on the benefits observed, other farmers are likely to try in coming years.

EVOLUTION AND CONTINUOUS IMPROVEMENT OF CA

To facilitate the continued adoption of CA, results from elsewhere suggest the following factors should be considered:

- ongoing machinery modifications to achieve greater flexibility in the cropping systems;
- refinement of controlled traffic (CT) farming and precision agriculture;
- development of resistance or greater tolerance by crop cultivars to plant diseases associated with stubble retention;
- availability of more crop options and rotations;
- development of a broader spectrum of effective herbicides for use in fallow weed control;
- genetic modification technologies increasing the efficiency of the system and the options available (e.g. herbicide-resistant crops); and
- improved understanding of the evaporation component of the water balance with regard to factors such as stubble.

Most of the above factors are also important for on-going adoption of CA in Bangladesh.

SITE SELECTION

Soil type, soil water content, stubble level, stubble type, weed density, slope of the land, drainage facility, etc. are the success factors for the performance of any seeder/planter. Thus, site selection is criticaly important for CA.

WHERE CA CAN BE PRACTICED?

Loamy soil textures, 22 to 34 % soil water content, 20-30 cm standing rice/wheat stubble, absence of weeds, and 0-10 degrees slope are the most suitable conditions for CA planting of crops. The Versatile Multi-crop Planter (VMP) was used on most of the soil types in Bangladesh (Figure 1) and crop performance indicates that the CA practice is suitable to adopt widely in Bangladesh.

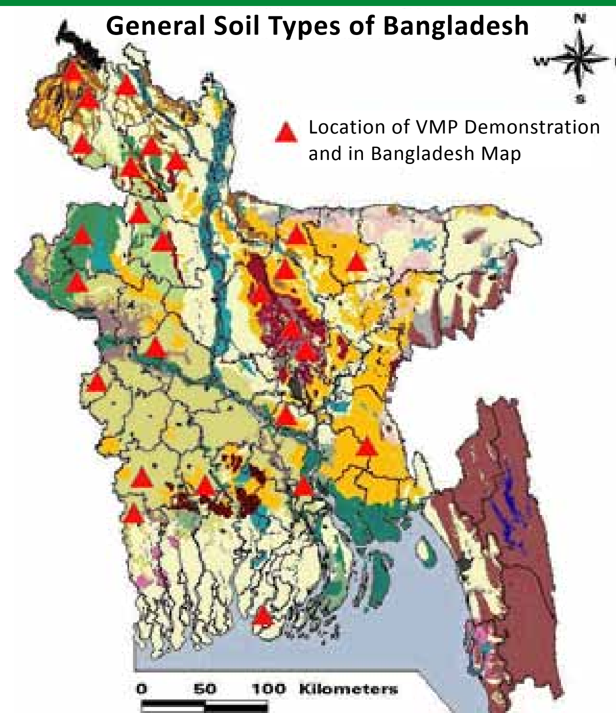

Figure 1: Map of Bangladesh showing CA and VMP demonstration locations.

LAND SURFACE CONDITIONS

Levelled land is preferred for operating the 2WT and planter. Due to their relatively small wheel diameter and narrow wheel base, uneven surfaces cause lack of depth control for seed placement. This results in uneven depth of seeding and dropping of seed on the soil surface, both of which may decrease plant emergence and increase weed population density.

AVOID STONE OR GRAVEL SOILS FOR STRIP PLANTING

The rotary-type strip planters such as the VMP (Figure 2), Versatile Strip Seed Drill (VSSD), power-tiller-operated seeder (PTOS), BARI bed planter and BARI strip till planter cannot operate safely in soils with stones or rocks. Stone and rocks will blunt and damage blades that they contact. Importantly, the high-speed blades will cause stones and rocks to fly from under the planter and can cause serious injury to the operator and people standing nearby. However, the zero tillage planters or the VMP with the zero-tillage setting are able to operate in stony or gravelly fields.

Figure 2: Alluvial soil, having 20-30% of moisture and 20 cm height of rice stubble is most preferable land type to operate the 2WT-based planter.

AVOID PLANTING ON WET SOILS

It is not a good idea to use planters for strip planting when it would be too wet (Figure 3) for conventional planting. However, after a light to moderate rain, plots may be ready for strip planting several hours or even a day before the conventionally tilled area. Soil water content and the planter capability ultimately determine whether planting can proceed.

Figure 3: VMP operating in wet field to show seed. This should be avoided.

Soil disturbance of any type including conventional tillage should be done within a narrow range of soil water: not too dry nor too wet. When pressure from tynes, blades, roller, press wheels or tractor wheels press on wet soil, they compress it and damage aggregates. To alleviate this damage, additional tillage is required. Strip planting and zero tilage in wet soils results in smearing of the side and bottom walls of the disturbed slot which turn very hard and impenetrable to roots when dry. In addition, the wet soil disturbed by the rotating blades in strip planting will form large clods that do not provide good seed-soil contact for germination. Finally, there is poor backfilling of soil into the disturbed slot so that seed cover is often absent on wet soils following strip planting and zero tillage.

MANAGE PRE-PLANTING WEED INFESTATION

Heavy weed infestation needs vigorous weed control before minimum soil disturbance planting. Since there is limited mechanical control of weeds due to minimum soil disturbance, fields with heavy weed infestation generally need thorough and sometimes repeated application of knockdown herbicides such as glyphosate (Roundup) to achieve effective control for crop establishment.

Immediately after harvesting of Aman rice, Boro rice, jute, wheat, mustard, maize, lentil, etc. the lands may be relatively free from weeds. In the situation of few weeds, establishment of the next crop should be done as quickly as possible after harvesting the previous crops. This allows the crop to become established before weeds and to out-compete the weeds.

Heavely weed infested fields generally need thorough and sometimes repeated application of knockdown herbicides such as Glyphosate (Round up) to achieve effective control for crop establishment.

PLAN STUBBLE HEIGHT DURING HARVESTING OF THE PREVIOUS CROP

Stubble height should be less than 40-50 cm. The planters and seeders[3] for 2WT can work well with stubble < 30 cm height if standing. With skillful operators and correct setting of the blades, the VMP can operate in up to 50 cm height of rice/wheat stubble. Hence the harvest height of the preceding crops needs to be set at a level that will be suitable for planting of a crop, based on the type of planter, the crop type and the skill of the planter operator.

ADJUST SEED RATE AND DEPTH ACCORDING TO SITE CONDITIONS

In fields which create stress or variable conditions for seed germination, high seed quality is a must. If you know that seed depth or seed-to-soil contact will be less than ideal, you may improve stands by increasing the seeding rate, e.g. by 10 percent.

[3] As per Wikipedia, the term seeder is used for continuous seeding, i.e. in-line broadcasting of smaller seed by any equipment; however, equipment that can handle larger seeds with precision-spaced sowing tends to be called a planter.

SEED QUALITY

CHOOSE HIGH QUALITY SEED

The best results with crop establishment under CA will be obtained by the use of good quality seeds. Seed should be genetically pure, free from admixture, viable, free from disease and pest infection, bold and uniform without breakage or damage, contain 8-12 % moisture, have high germination percentage (more than 80 %), and high vigour to allow it to germinate uniformly and rapidly when sown. When the soil is not as soft as in conventional tillage, seedling vigour is even more important in CA for rapid and even establishment. Apart from choosing high seed quality, seed size, uniformity, shape, and weight play critical roles in the calibration and performance of the planter/seeder to obtain the target plant population. If there is doubt about seed quality, it is best to conduct a germination test of the seed and adjust the seed rate according to the germination rate. Early seedling vigour to establish a strong root system and rapid leaf cover helps with weed suppression. Selection of bold, disease-free seed with high germination percent is the best insurance for seedling vigour. This is particularly important for CA planting.

The good quality seed should be genetically pure, free from admixture, viable, free from disease and pest infection, not broken or damaged, contain 8-12% moisture, have high germination percentage (more than 80%), and germinate uniformly and rapidly when sown.

SEED TREATMENT AND PRIMING

Seed treatment may be needed to supress seed-borne and soil-borne diseases of seedlings. Seed priming may be recommended for accelerating the emergence and crop establishment success. The use of primed seed in planters such as the VMP has been well tested. Such seed should be well dried. In addition, priming should avoid softening of the seed as this may cause excessive seed damage during seed metering through fluted type seed meters and delivery to the soil. Chickpea in the High Barind Tract is established from primed seed.

Rhizobium inoculum will improve crop growth on soils that have not previously grown legumes such as chickpea, and molybdenum fertilizer treatment of the primed legume seed is recommended in acid soils.

Pulse crops inoculated with the proper rhizobium strain have the potential to secure up to 80 % of their nitrogen requirement through nitrogen-fixation. Proper care should be taken to ensure maximum rhizobia survivability. Rhizobium strains are susceptible to temperature stress, drying out, and damage from direct sunlight. Inoculant must be stored in a cool dark environment prior to use, and expiry dates must be observed. Inoculated seed should be planted as soon as possible. Inoculants are sensitive to granular fertilizer therefore, banding fertilizer to the side and/or below the seed is recommended. Inoculants are also sensitive to some seed-applied fungicides. When using a combination of fungicide and rhizobia inoculant, apply the fungicide to the seed first, allow it to dry, and then apply the inoculant immediately prior to seeding.

TYPE OF PLANTERS

Compared to planters available in the market for CA planting with four-wheel tractors, the development and commercialisation of planters for 2WT is recent and still quite limited. Initial research and development of planting implements/seed drill/seeders for 2WT in Bangladesh started in 1995 through the introduction of the Chinese-made 2BG-6A seed drills (which was named variously as the Chinese Hand Tractor [CHT] seeder; Bangladesh Hand Tractor [BHT] seeder; PTOS, etc.). Since then, several types of single-pass planters/seeders were tested or developed to establish crops in Bangladesh including PTOS, bed planter, strip planters (sometimes called strip tillage planters), zero tillage planters.

Not all of these planters are suitable for CA planting. The PTOS seeder accomplishes three operations i.e. shallow tillage (up to 60 mm), placement of seed in a furrow and levelling which can be done in single pass. Although this planter is often called a CA planter or minimum tillage planter, research results confirmed high levels of soil disturbance with the PTOS as well as with a Bed Planter. Hence neither qualifies as a minimum soil disturbance planter (Haque et al., 2017). Only planters suitable for CA planting in Bangladesh are examined in the following sections. However, a brief outline of the PTOS is included, since this is the most widespread planter for 2WT in Bangladesh at this stage.

There are a number of criteria and challenges that would need to be satisfied by potential purchasers of a planter including low purchase price; sufficient earning capacity; flexible set up in the field with capability to be modified quickly for different seed rate, fertilizer rate, row spacing, seed size, planting depth; durable and reliable in operation, and; light weight with minimal vibrations.

STRIP PLANTING SYSTEM

Figure 4. A Versatile Multi-crop Planter in use for strip planting.

Strip-planting is a mode of CA involving seed sowing in 4-5 cm width strips, leaving the no-till zone with at least 30 % crop stubble retention. According to Food and Agriculture Organization (2016), strip planting by VMP qualifies as a form of CA as the disturbed area is less than 25 % of the cropped area. The seedbed is divided into a seedling zone and a soil management zone (Figure 4). The seedling zone (which can vary in seeding depth and width but is usually 4-5 cm width and 5-7 cm depth) is mechanically tilled to optimize the soil and micro-climate for germination and seedling establishment. The inter-row or soil management zone (more than 75 %) is left undisturbed and protected by standing crop stubble or mulch. This planting system has the potential of combining the benefits of conventional and no-tillage system by disturbing the seeding row and leaving the inter-row with complete stubble cover.

The 12-16 hp 2WTs have insufficient power and traction to drag even one furrow opener in hard silty clay soil of the High Barind Tract in the case of zero tillage planter. However, the same 2WT can comfortably sow in 4 rows in the same soil when operating as a strip planter. The rotary blades of strip planter provide positive propulsion force and better wheel traction during strip planting.

Strip planting refers to the practice of opening a narrow strip of soil ahead of the furrow openers, so the seed and fertilizers can be placed into the strips.

The strip planter covers the seeds with loose soil in the strip. Strip planting helps soil pulverization in strip to improve back filling and soil seed contact for better germination.

Surface stubble handling by planters with low-height clearance such as zero tillage planters is challenging. The furrow openers of the zero tillage planters accumulate surface residue around the tyne shank which hampers reliable and uniform seed dropping or placement. On the other hand, inclusion of disk openers with the zero-tillage planter to cut surface stubble adds cost and performance may be hampered by the light weight of the 2WTs. The high-speed rotary blades of the strip planter and VMP, aligned in front of the furrow openers, chop the stubble and clean the path ahead of the furrow openers. The strip planting systems helps in fields where stubble levels are too high for the simple inverted-T shanks/opener.

STRIP SEEDER

Two-wheel tractor-based strip seeder development commenced in 2001 using the Chinese 2BG-6A seeder (PTOS) to plant seed on new beds and permanent beds. By removing every alternative pair of blades and reconfiguring them, the PTOS can be reformed as a strip seeder (Justice et al., 2004; Roy et al., 2004 and 2009). In this system, three operations can be done in a single-pass operation, however, that strip tillage system disturbed up to 50 % of the land leaving the rest untilled (Justice et al., 2004).

In the strip seeding system, the rotary blades are set up in front of the furrow openers, to till a 100-mm wide strip for each row into which seed is placed in a furrow. The rotating blades clean the stubble in front of the furrow openers. However, in this configuration, strip tillage planters such as the PTOS are not operating as a CA planter.

To minimize the width of the strip seeding slit, so that it conforms to CA definitions, the angle of the rotary blades and furrow openers can be reduced. With funding support from the Australian Centre for International Agricultural Research (ACIAR) through project LWR-2005-001, intensive research and demonstration was carried out to promote the 2WT-based strip seeders and planters in Bangladesh. However, it did not gain popularity until 2009. Initial strip seeders used fluted type seed meters; however, at later stages the inclined plate seed meter and fluted type fertilizer meters were tested for strip planters such as VMP and VSSD.

TOOLBAR FRAME MOUNTED NO-TILL SEEDER

Hossain et al. (2009) reported the development of a no till seeder in Bangladesh with the funding support of ACIAR (Figure 5). The improvement of the seeder was mainly on the furrow opener, adjustable press wheel, and dual bi-compartment seed and fertilizer boxes that were fixed above the 2WT handle. The seeder could pull a maximum of 4 tines in case of soft soils, however in clay soils when the top soils was dry and the layer of the moist soils was at 8-10 cm, the 12 hp 2WT was unable to pull even three tynes and there were excessive wheel slippage and variations were observed (Hossain et al., 2009). The effective field capacity of the planter is 0.15 ha hr^{-1}. Using of press wheels with this seeder increased plant stand by 22, 17, and 25 %, respectively in the case of wheat, maize and mungbean crops (Hossain et al., 2009).

Figure 5: The toolbar mounted Zero Tillage Planter developed in Bangladesh with the funding support of ACIAR.

Rationale for design and capabilities

Figure 6: The VMP attached to 2-wheel tractor in operation.

In South Asia where cropping intensity is high, due to changing profitability of crops, smallholders cultivate 4-6 crops over a 2-3 years cycle with diverse seed sizes, seed rate, row spacing, fertilizer rates, seeding depth etc. A planter for such diverse cropping systems needs to have multi-functional capabilities. Small contractors providing planting services (e.g., LSP) need to be able to hire out their planter for business all-year-round to justify the investment (Miah et al. 2017). There are a number of other criteria and challenges that would need to be satisfied by potential purchasers of a planter including low purchase price; sufficient earning capacity; flexible set up in the field with capability to be modified quickly for different seed rate, fertilizer rate, row spacing, seed size, planting depth; durable; reliable in seed and fertilizer placement, and; light weight with minimal vibrations. To date, most of the seeders and planters developed in Bangladesh cannot satisfy the minimum soil disturbance criteria of CA; and none of the present planters for 2WT are capable of planting or seeding in all crop establishment modes. Hence the LSP and farmers are reluctant to purchase a planter and seeder that can only be used for a narrow selection of crops at a particular time of the year. The challenge was to design a multi-function planter capable of handling many crop species and planting methods, with reliable field performance and durability, at a price that allows ready adoption in the target market. The VMP (Figure 6) meets the above criteria and has successfully established a diverse range of crops in Bangladesh (Haque et al., 2017a; Bell et al., 2017).

Design features of VMP

The research and development of the 2WT-based VMP was carried out under ACIAR funding (Project LWR-2010-080). The main functional parts of the VMP are: rotary shaft with attached blades; vertical disk-type seed meter fitted in a seed box, fluted-type fertilizer meter fitted in a fertilizer box; a toolbar frame; depth controller-cum-press roller; driving seat for transportation; furrow opener, etc. (Figure 7). Haque et al. (2017a) reported the detailed fabrication of the VMP. The VMP is powered by 8.95 to 11.9 kW Dongfeng (Figure 7), Sifang 2WT, or could be used with any other 2WT with similar power rating and hitching arrangement. The Dongfeng or Sifang 2WT have different but suitable hitching points to attach with the VMP.

Planting capabilities of VMP

The VMP was designed with capability for seeding and fertilizing in lines for: 1) single-pass shallow-tillage (SPST); 2) strip planting (SP); 3) zero tillage (ZT); 4) bed planting (BP) (for single-pass new bed-making or re-shaping of permanent beds together with simultaneous planting and fertilizer application); and 5) conventional tillage (CT) using full rotary tillage following broadcast seeding and fertilizer spreading. On-station and on-farm replicated trials were conducted with different tillage options and seed calibration to assess its field capacity, fuel consumption, crop establishment and yield. Details of performance evaluations of VMP with major crops are elaborated in Bell et al. (2017) and Haque et al. (2017a).

Versatile Multi-crop Planter designed to achieve improved flexibility for multi-crop planting and capacity for rapid adjustment of row spacing, seed rate and seed depth on a field-by-field basis.

Planters such as VMP could be used to develop conservation agriculture practices across a wide range of cropping systems used by smallholder farmers in Asia, Africa and other regions.

Calibration of the VMP for different planting methods and crops

The planter needs to be calibrated based on planting type (e.g., strip planting, zero tillage, bed planting, etc.), seeding type (i.e., continuous seeding vs. spaced planting), crop type (small seeded crop or larger seeded crops), crop recommended row distance (narrow [20 cm in the case of rice, wheat, etc. or wider 40 or 60 cm in the case of chickpea or maize]). The Table 1 below provides guidance to calibrate the VMP for different crops in strip planting or zero tillage or single pass shallow tillage mode:

Table 1: Calibration of the VMP for different planting methods and crops.

Name of the crops	Seed rate	Seeding/ planting type	Row distance	Seed to seed distance	Sprocket number*	No. of lines per VMP pass
Rice (direct seeded)	14-16 kg ha^{-1}	Spaced planting	20 cm	20 cm	13 teeth	4
Wheat	100-120 kg ha^{-1}	semi-spaced seeding	20 cm	2-4 cm	18 teeth	4
Maize	83,300 plants ha^{-1}	Spaced planting	60 cm	20 cm	13 teeth	2
Maize**	~150000 plants ha^{-1}	Spaced planting	50 cm	20 cm	18 teeth	2
Chickpea	34-40 kg ha^{-1}	Semi-spaced seeding	35 cm	3-5 cm	18 teeth	2
Mungbean or Black gram	30-40 kg ha^{-1}	Semi spaced seeding	30 cm	2-4 cm	18 teeth	3
Mustard***	4-5 kg ha^{-1}	Semi spaced	25 cm	1-4 cm	18 teeth	3
Jute***	3-4 kg ha^{-1}	Semi spaced	25 cm	1-4 cm	18 teeth	3
Chilli***	15 kg ha^{-1}	Semi spaced seeding		3-5 cm	18 teeth	
Lentil	30-35 kg ha^{-1}	Semi spaced	25 cm	2-4 cm	18 teeth	3
Peanut		semi spaced seeding	20 cm	8-10 cm	18 teeth	4

*should be attached with the seed box; ** for high density maize (e.g., baby corn or fodder maize); *** 1:2 volumetric ratio of seed : rice husks should be mixed to put in seed box.

The rotary shaft of a VMP is shown in Figure 7. Rotary blade arrangement with the shaft of a VMP depends on tillage type and spacing between two rows of the crops (Figure 8).

Figure 7: Re-designed rotary shaft of VMP that is suitable to sow varied row spacing of crops in different tillage mode.

The configuration of the VMP for four different planting types relative to the conventional tillage

Strip planting (SP):

In each line, 2-4 cm wide and 4-8 cm deep tilled strips are made (that preserved about 80 % of untilled soil) in untilled flat land to place seed and fertilizers at the base of the strips by a tyne/furrow opener in single pass operation. However, if needed (for higher moisture and slow drying soil) the width of strips can be increased by increasing the curvature of the blades.

Single pass shallow tillage (SPST):

Up to 6 cm depth of surface soil is fully disturbed by rotary blades operated by the VMP while seed and fertilizers are placed in line by tyne/furrow opener in single pass operation. Thes is not a CA planting operation.

Zero tillage (ZT):

Up to 10 cm deep and 6 cm wide slits could be made (about 80 % undisturbed soil) by tyne/furrow openers in untilled flat land by VMP. Seed and fertilizers are placed simultaneously behind tyne/furrow opener in a single pass operation.

In case of lentil, jute and wheat seed sowing, zero tillage planting was accomplished by one pass with the VMP using a narrow furrow opener that opened a 2-6 cm wide slot at 20 cm row spacing. Seed and fertilizers were dropped in the furrow behind the opener and the following roller pressed soil down to ensure adequate seed/soil contact.

Bed planting (BP)

About 60 cm base width and 18-20 cm height of the bed can be made by VMP and seed and fertilizers can be placed in rows near the two edges of the beds in a single pass operation or in a single row (e.g., maize) in the middle of the bed. Bed planting is not a CA oparation.

BLADE ARRANGEMENTS ON THE ROTARY SHAFT OF A VMP

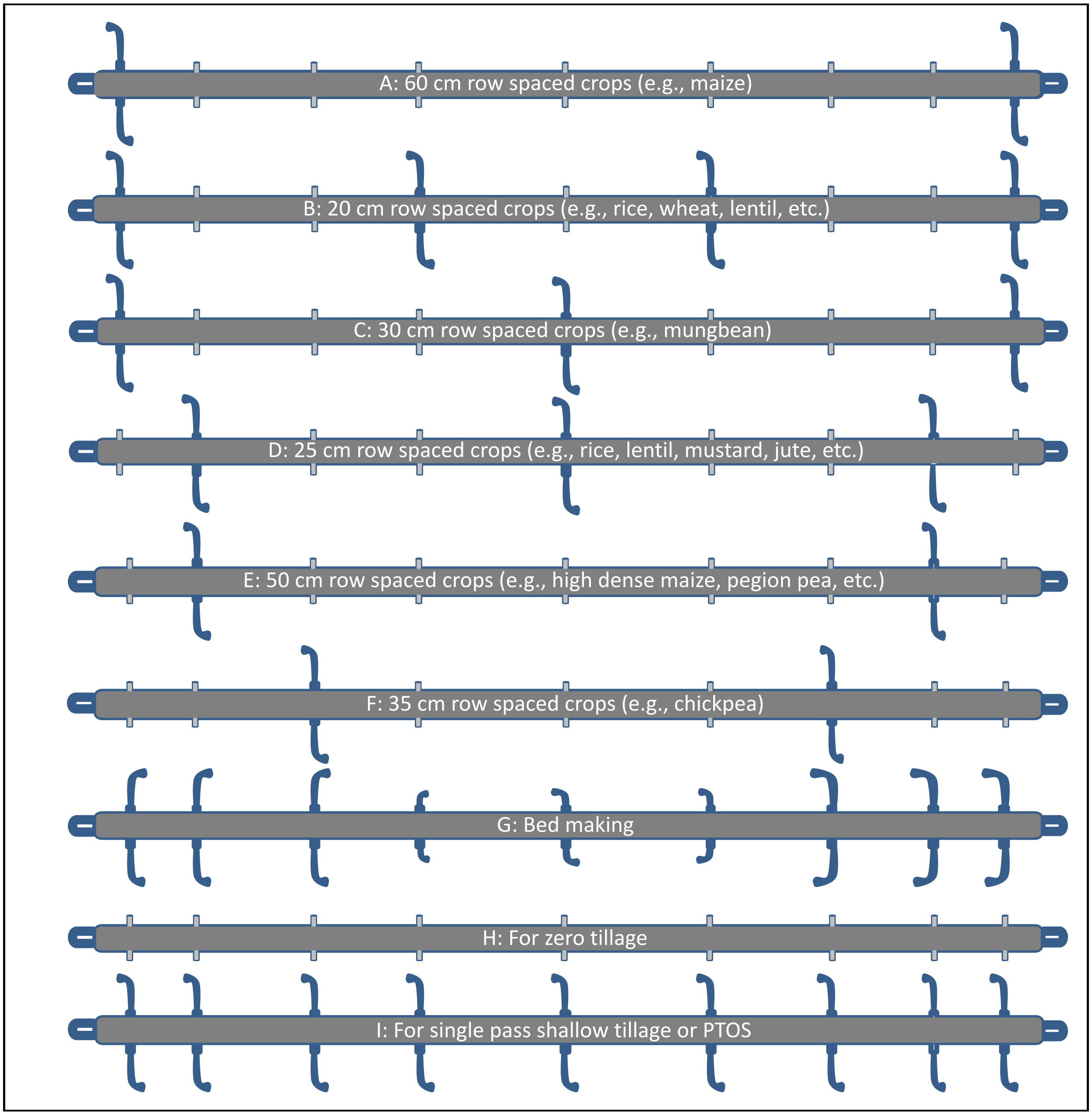

Figure 8: Tyne/rotary blade arrangement with shaft of VMP for varied tillage opening mode and different crop establishment.

SEED AND FERTILIZER CALIBRATION

A set of vertical disk seed meters each with different aperture diameter are used in the VMP. The aperture sizes of vertical disk meters are selected based on the recommended seed rate and seed size of the crops. By contrast, the fluted roller type meters are used with the VMP as fertilizer meters. Granular and less hygroscopic fertilizers can be regulated through the fluted roller type meters. Also, the fluted roller type meters could be used as a seed meters for continuous seeding. Calibration of basal fertilizer or seed rates are essential prior to establishment of any crops. There are many ways to calibrate a planter fitted with fluted roller type fertilizer/seed meters; some of them are complex and need mathematical knowledge. Based on experience, it is difficult for most operators/farmers to learn the fertilizer/seed calibration process. Before going to field with a planter the operators must know how much seed or fertilizers he/she needs to dispatch in a unit area. Thus, the steps below could be followed to calibrate seed and fertilizer delivery.

Let us consider a crop that has to be planted with 20 cm row spacing.

1) Mark 20 m distance on a flat surface.
2) Fill-up the fertilizer/seed box of the VMP.
3) Hang a poly bag underneath each fertilizer seed dispatching tubes.
4) Turn on fertilizer/seed meter using the off/on lever.
5) Run the planter at normal operating speed over the 20 m marked distance.
6) Collect seed/fertilizers from each poly bag.
7) Weigh individual poly bag seed/fertilizer contents.
8) Calculate seed rate using following equation.

Fertilizer/seed rate (kg) ha^{-1} * distance (cm) between two rows * 0.0202 (constant)

Suppose a farmer wants to apply 120 kg ha^{-1} of DAP fertilizer in a wheat field with 20 cm row spacing. Thus, the equation would be:

= 120 kg * 20 cm * 0.0202 (constant)
= 120*20*0.0202
= 48.48 g

If each of the poly bags accumulates 48 g (+/- 5 %) of fertilizer after 20 m operation, the planter is perfectly calibrated to dispatch 120 kg of DAP fertilizer ha^{-1}. If it is less or more, you need to adjust the fertilizer meters using the fertilizer meter adjustment handle.

VERSATILE STRIP SEED DRILL

Figure 9: The Versatile Strip Seed Drill (VSSD developed in Bangladesh under the funding support of ACIAR.

As a variation of the VMP, the Versatile Strip Seed Drill (VSSD) was designed with the capacity to form 40 mm wide and 60 mm deep strips in untilled land along with seed and basal fertilizer application in a single-pass operation, while powered by the 2WT (Figure 9). The VSSD is the modified and upgraded version of VMP. An important innovation of the VSSD was to fit the seed box with both fluted roller-type and vertical disk-type seed meters. The former seed meters are used for delivery of small-sized seeds to achieve adequate plant density per unit row length; and vertical disk-type seed meters are used for precision and spaced row planting of larger seeds. Both continuous seed dropping by fluted roller seed meters and spaced planting by vertical disk seed meters provided optimum plant populations that were generally higher than in conventional, full-tillage plots with the same rate of hand-broadcasted seed and fertilizers. The capacity of sowing by VSSD ranged from 0.13 to 0.18 ha^{-1}. When the VSSD was attached to the 2WT for planting, the diesel fuel consumption varied from 4.4 to 6.1 L ha^{-1}, which was lower than for most 2WT-based planters previously used in Bangladesh. In on-farm multi-locations trials, wheat crops established with the VSSD had statistically similar grain yield compared to conventional tillage; however, significantly higher grain yield was obtained from mustard and lentil, by 14 % and 19 %, respectively. Detailed construction design and performance information on the VSSD are elaborated in Haque et al. (2016a).

STRIP-BASED NON-PUDDLED RICE SEEDLING TRANSPLANT

The adoption of CA is challenging in puddled rice-based cropping systems. Transplanting rice seedlings into non-puddled soils with minimum soil disturbance is an opportunity to expand the adoption of the CA in rice-based cropping systems (Haque et al., 2016b). Two approaches can be used. Firstly, prepare strips by VMP in non-saturated soil. Then flood the field for 18-24 hrs so that the soil in the strip softens, followed by transplanting of rice seedlings into the strip manually or by a walk-behind type of transplanter. Secondly, an experimental rice transplanter (Hossen 2017), incorporating a narrow strip tillage mechanism, was also suitable for non-puddled transplanting. Under LWR-2010-080, the non-puddled rice transplanter was developed with a strip tillage mechanism that aligned ahead of and in the same line as the rotary picker. Detailed performance and construction design of strip-based non-puddled rice transplanter is described in Hossen (2017) (Figure 10).

Photo: Developed riding type rice transplanter

Figure 10: Photograph of the riding type rice transplanter with non-puddled transplanting mechanism.

POWER TILLER OPERATED SEEDER (PTOS)

Figure 11: The PTOS pulverizes soils more than conventional tillage.

The PTOS carries out shallow full tillage (up to 60 mm), placement of seed in a furrow and levelling in a single pass. However, it is not a CA planter. The net weight of the PTOS 167 kg (Figure 11). It covers 1200 mm width allowing it to plant a maximum of six lines of crops at 200 mm row spacing and the field capacity is 0.14 ha hr^{-1}. PTOS uses a fluted-roller type seed metering system which is unable to maintain even seed distribution, and it is not capable of placing uniformly-spaced seeds (e.g., maize, rice, etc.). The standard imported PTOS has no fertilizer application system. In addition, the depth of tillage by PTOS is generally shallow, which results in shallow seed placement.

Although the PTOS is commonly referred to as a minimum tillage planter and CA planter in Bangladesh, about 95 % of the PTOS are being used as high-speed rotary tillers for soil pulverization for transplanting of onion seedlings and garlic bulbs. Establishing onion and garlic needs a fine soil tilth that required 8-12 passes of conventional 2WT: by contrast, fine tilth land preparation could be accomplished by PTOS in 1-2 tillage passes. The PTOS are widely used in the onion and garlic growing areas including Rajbari, Faridpur, Madaripur, Sharioutpur, etc.

The International Maize and Wheat Improvement Center (CIMMYT) during 1995 to 2003 attempted to commercialize the locally-made PTOS, including project-led procurement and sale to farmers, involvement of research, extension, local manufacturing, and non-government organizations (Haque et al., 2013). However, the adoption of PTOS planters started in 2003 when a private importer (Green Machinery Store) took responsibility for sales and distribution process. Until the end of 2012, more than 5,200 PTOS were imported and a few were locally fabricated. Since 2012, more than five importers have imported and sold about 1500 units per year of PTOS from China in Bangladesh. The vast majority of these are used as high-speed rotary tillers, not as planters. At present, the Green Machinery Store, Chittagong Builders, ACI Motors, Janata Engineering, and Alim Industries are the main importers of PTOS in Bangladesh.

CROP MANAGEMENT GUIDELINES FOR CONSERVATION AGRICULTURE

The land selection, crop choice, crop rotation, timing of sowing/transplanting, seed and fertilizer rates, post-planting weed control, pest control, irrigation, harvesting and post-harvest management of CA crops are similar to the recommendations for conventional planting by the research institutes and by the local farmers' practices. The major changes proposed for crop management in CA are as follows:

CROP ESTABLISHMENT

Do not till fields. Tillage is unnecessary, takes time and money, and robs soil of moisture, organic matter, and structure. Plant crops with minimum soil disturbance techniques (e.g., strip planting) using VMP to line sow seed and to place basal fertilizers in a single-pass operation; there are now proven alternatives to multiple tillage and leveling with 2WTs and hand-broadcasting of seed and fertilizers or manual transplanting (in the case of rice seedling transplanting) that are the common practices for conventional tillage systems. In conventional systems, most of the farmers prepare puddled fields to transplant rice seedling. However, in CA systems, strip based non-puddled transplanting or direct seeded rice is recommended.

PRE-PLANTING WEED CONTROL

If required, kill the pre-planting weeds with a non-selective herbicide (e.g., glyphosate) before planting. This may not be necessary where there is little weed growth after harvest of previous crops. In conventional tillage systems, farmers generally use repeated tillage and/or standing water (in the case of irrigated rice) to control pre-sowing/pre-transplanting weeds; however, in CA systems, crop rotation, stubble retention, reducing turn-around-time and/or application of knockdown herbicides are recommended.

CROP ROTATION

In conventional tillage systems, the crop rotation is not highly practiced; however, in CA systems, the crop rotation is one of the key principles. It is always advisable to grow at least one leguminous, oilseed or other non-rice (e.g. jute) crop in each annual crop cycle.

CROP STUBBLE RETENTION

In conventional tillage systems, the rice/wheat/maize stubble is a burden to establish next crops. In many places (e.g., Haryana, Punjab in India), farmers burn huge amounts of stubble. However, in CA systems, rice/wheat/maize stubble is considered as a valuable resource. The retention of crop stubble on the soil surface could improve soil structure and health, reduce soil temperature, reduce CO_2 emission, minimize weed infestation and conserve soil water. Thus, in CA systems, the stubble retention in the field is highly recommended.

REDUCE TURN-AROUND-TIME

In CA systems, the next crop can be planted immediately after harvesting of the previous crop, which will minimize the weed infestation, and loss of stored soil water. In conventional tillage systems, longer time is required for multiple tillage to prepare land and broadcast the seeds.

Based on different field studies in Bangladesh that established crops for CA, the seed rates, line-to-line and plant-to-plant spacings are shown in Table 2.

Table 2: Seed rate, row spacing and seeding methods for strip planting using VMP.

SL	Name of the crops	Seed rate (kg ha^{-1})	Row spacing (cm)	Plant to plant distance (cm)
1	Rice (DSR)	16-18	20	20
2	Wheat	110-120	20	Continuous
3	Maize (Hybrid)	83,333 plant ha^{-1}	60	20
4	Mungbean	28-30	30	3 to 4
5	Lentil	30-34	20	Continuous
6	Sesame	4-5	20	Continuous
7	Mustard	3.5-4.5	20	Continuous
8	Chickpea	40-45	30	3 to 4
9	Jute	3-4	20	Continuous

DSR=Direct seeded rice.

FERTILIZER RATES USED FOR DIFFERENT CA TRIALS IN BANGLADESH

The NARS recommended fartilizer doses were used to maintain adequate crop nutrition for CA crops in Bangladesh (Table 3).

Table 3: Dose and time of applications of fertilizers for different crops in Bangladesh.

SL	Name of the crops	Fertilizer for basal application (kg ha^{-1})						Fertilizer (urea) for top dressing (kg ha^{-1}) and time of application	
		Urea	TSP*	MOP*	Gypsum	Zinc Sulphate	Boron	1st	2nd
1	Rice (DSR)*	100	98	165	113	11	-	100 (20-25 DAT*)	100 (5-7 PI*)
2	Wheat	120-147	140-180	40-50	110-120	-	-	60-73 (20 DAS*)	-
3	Maize (hybrid)	167	240-260	180-220	240-260	10-15	5-7	167 (25-30 DAS)	166 (40-50 DAS)
4	Mungbean	40-50	80-85	30-35	-	-	-	-	-
5	Lentil	40-50	80-90	30-40	-	-	-	-	-
6	Seasame	50-63	130-150	40-50	100-110	5 (IN)	8-10 (IN*)	50-62 (25-30 DAS)	-
7	Mustard	125-150	170-180	85-100	150-180	5-7	10	125-150 (BF*)	-
8	Chickpea	40-50	80-90	30-40	-	-	10-12	-	-
9	Jute	83	25	30	45	11	-	83	-

*DSR = Direct seeded rice; TSP = Triple super phosphate; MOP = Murate of Potash; DAT = Days after transplanting; DAS = Days after sowing; PI = Panicle initiation; BF = Before flowering; IN = If needed.

IRRIGATION WATER

The long-term experiments with CA for Aman rice-wheat-mungbean and Aman rice-lentil-Boro rice crop rotations on silty clay loam soils of Rajshahi were used to estimate irrigated water use. Over three years, strip planting saved 11-33 % of water compared to conventional tillage. Water productivity of wheat was higher in strip planting compared to conventional tillage in three years. In 2015, water productivity of wheat was 2.06 and 1.25 g grain kg^{-1} water for strip planting and conventional tillage, respectively. Similarly, water productivity of wheat in 2016 and 2017 was the highest (2.32 and 1.95 g grain kg^{-1} water respectively) in strip planting (Mahmud et al., 2017).

DISEASE

So far there has been no clear evidence that the type of disease or severity of infection in CA crops is different from conventionally planted crops. There is a risk that the retention of crop stubble may increase the prevalence of diseases that are spread on crop stubbles. This has been the case with CA crops elsewhere in the world. As the coverage of CA cropping increases and the area of retained stubble increases, the diseases that spread on crop stubble may become more prominent. However, the observation of a varied crop rotation is an important factor to avoid disease build up.

INSECTS

So far there has been no clear evidence that the type of insects or their prevalence in CA crops is different from conventionally planted crops. There is a risk that the retention of crop stubble may increase the prevalence of insects that are feed on crop stubble or use it as habitat. This has been the case with CA crops elsewhere in the world. As the coverage of CA cropping increases and the area of retained stubble increases, the insect pests that spread on crop stubble may become more prominent. On the other side with the maturation of CA systems the natural control of pests improves and natural enemies of pests become part of the cropping ecosystem.

PLAN FOR STUBBLE RETENTION

The level of crop stubble retention should be planned based on the crops grown, stubble handling capacity of the planter and type of the planter, type of planting (e.g., zero tillage, strip planting, bed planting or conventional tillage), planting season, stubble type (stubble/anchored or loose), moisture level in the stubble, freshness of the stubble, etc.

More detail on these CA management practices are presented below together with case studies for management of specific crops.

WEED MANAGEMENT IN CONSERVATION AGRICULTURE

Weeds are a major constraint for both conventional and CA crop cultivation. However, in conventional agriculture, weed control is assisted by repeated tillage operations prior to planting. Very often farmers use soil-applied pre-emergent herbicides having residual efficacy to further reduce the weed germination. In addition, the use of selective herbicide application over the top of the crop at a later date reduces the weed pressure until the end of the season. However, successful weed control requires farmer's attention throughout the season in order to achieve an optimal harvest even in the conventional full tillage cultivation system. Thus, the weed control in conventional system is not a small task. However, weed control poses even a greater challenge to achieve comparable results in the CA system as many weed species are able to flourish when intense tillage operations of conventional full tillage are minimized. Therefore, during initial adoption, CA may experience greater weed densities than conventionally tilled crop production practices. Over time, as the weed seedbank reduces, the prevalence of weeds commonly declines in CA.

Weed control is essential for both conventional and Conservation Agriculture.

In CA cropping, farmers lose the weed control offered from seed burial by tillage and options to incorporate soil applied pre-emergent herbicides. Moreover, the soil applied pre-emergence herbicides may have reduced persistence and efficacy in the presence of plant stubbles that intercept and bind the chemical before it reaches the soil surface. However, CA farmers do not experience the appearance of weed seeds from the soil-seed bank brought up for germination by tillage. Furthermore, farmers willing to adopt CA initially face shifts in weed population dynamics due to altered distribution of weed seed within the soil. Perennial weed species thrive in the reduced tillage settings particularly if mulch covers are not complete and thick enough and can be difficult to control with the available post-emergent herbicide options. The weed seedbank or viable weed seed within the soil declines over time with the use of CA. The weed control becomes easier to manage with chemical control due to selection of appropriate herbicides though the initial weed control strategies are a challenge when farmers first switch to CA.

Haque and Bell (2017) conducted a study in 11 districts involving 287 farmers to assess the herbicide use in Bangladesh for conventional agriculture. This study reported that the hand weeding increased weed control costs over herbicide uses by 108 to 597 % for the main cultivated crops: Aman (grown in monsoon) and Boro rice (grown in winter), wheat, maize, potato, onion, garlic, lentil, chickpea, mustard, jute,

Manual and mechanical methods were traditional means of weed control in Bangladesh but in the past few years farmers have switched to using of herbicides intensively in conventional full-tillage-based agriculture due to labour crisis, and the easy, effective and economic means of weed control achieved.

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 % of these farmers bought the herbicides from local dealers. The crop-wise herbicide use in their localities was 75, 78, 55, 56, 60, 48, 76, 51, 48, and 45 % for Aman and Boro rice, wheat, maize, jute, mustard, potato, lentil, chickpea, and mungbean, respectively (Haque and Bell, 2017).

Over-use and dependency on herbicides creates environmental hazards and accelerates the development of herbicide resistance in weed species making weed control more difficult. Therefore, integrated use of different weed control strategies to reduce herbicide use is recommended for long-term control of weeds and for environment-friendly weed control. Various approaches, including the use of preventive measures, crop stubbles as mulches, intercropping, competitive crop cultivars, herbicide tolerant cultivars, and herbicides, are needed to manage weeds in a CA system.

Even in conventional agricultural system, about 85 % of respondents used herbicides and only 14% used hand weeding to control weeds in their crop fields in 2015-16; whereas, five years back it was only 19% by herbicide, and 81% was sole hand weeding.

INTEGRATED WEED MANAGEMENT

The concept of integrated weed management (IWM) has been around for a long time but has not been taken seriously. Traditionally, tillage and other control operations have been integrated with herbicide use in conventional agriculture but farmers adopting CA can no longer depend upon these systems. Therefore, the IWM approach should be employed in CA for sustainable weed control by integrating different approaches. The goals of an IWM system should be to reduce the movement of weed seeds and propagating units into the soil and to reduce the impact of weeds on crops to an economically acceptable level. The IWM system emphasizes the management of weeds rather than eradication employing the two major approaches: (i) preventive methods, and (ii) pre-and post-crop planting control strategies.

The initial weed control could be challenging when the farmers practicing conventional agricultural first switch to CA.

ADVANTAGES OF IWM

1. Shifts in crop-weed competition in favour of crops.
2. Prevents weed shifts towards perennial nature.
3. Prevents development of weed species resistance to herbicides.
4. Minimize the danger of herbicide residue in soil or plant.
5. Minimum environmental pollution.
6. Contribute to economic crop production.

PREVENTIVE METHODS

Prevention and sanitation are very important components of an IWM system. Preventing invasive and alien weeds from establishing in fields is usually easier and less costly than controlling them after severe infestation. Some weed-preventive measures are: use of clean crop seeds, use of clean agricultural implements, and managing weeds on bunds or levees and roads, etc. Minimizing disturbance of soil by vehicles, machinery, wildlife and livestock also could help to prevent noxious weed establishment. The weeds seeds deposited in the soil seed bank need to be reduced and any action taken to reduce it will undoubtedly result in less weed interference and better crop growth.

CONTROL STRATEGIES

The main weed control methods applied before and during the crop cycle are:

1. Cultural methods (crop rotation, good crop stands and row-spacing, intercropping, cover crops, mulches and others).
2. Physical control (mechanical and manual non-soil engaging weeding).
3. Chemical control through the use of herbicides.

CULTURAL WEED CONTROL

Crop rotation

Rotation of crops is a key method for controlling weeds. Continuous cultivation of a single crop or crops having similar management practices allows certain weed species to become hard to control. Therefore, it is very important to rotate crops having different growing periods. According to Karlen et al. (1997), different crops require different management practices, which may help in disturbing the growing cycle of weeds and, may prevent selection of the weed flora toward increased abundance of problem species. Moreover, rotating to another crop may prevent one particular weed species from becoming unmanageable (Locke et al., 2002). Intensive cropping systems with shorter turnaround periods between crops in CA can increase the competitive ability of crops, thereby reducing weed pressure.

With the introduction of herbicides, it was thought that crop rotation could be avoided, but experience has demonstrated the opposite. Well-managed preceding crops are important in the reduction of weed infestation and help crops to compete better with weeds. Normally certain weeds are better adapted to the environment created by a particular crop. Mono-cropping tends to increase population of those weeds well adapted to the crop. Crop rotations that include crops morphologically and physiologically different, serve to break the cycle and adaptation of several weed species.

CROP STAND AND ROW SPACING

An extremely important measure for weed control is to have a good crop stand based on suitable row spacing. Any space left in the field will be normally occupied by weeds, and their reproduction may produce a reservoir of seeds and a factor for their further spread. Good crop stand is also a guarantee of crop competition with weeds that emerge early in the crop cycle. Crops with high early seedling vigour would give the advantage of early canopy coverage and help weed suppression. Higher seeding rate and narrow spacing help preventing weed development and therefore, could be used as a possible means for preventing weed development.

Retention of 50% stubble soil cover can reduce the weed pressure by 25-40% in T. Aman and boro rice, wheat, and mustard and mungbean.

Hence, the application of different herbicides with the combination of 50% crop stubble soil cover could be an effective tool for the controlling weeds in these crops under CA systems.

CROP STUBBLE COVER AND NATURAL MULCHES

Retention of crop stubble cover in CA systems improves soil health and conserves soil moisture (Locke and Bryson, 1997). In addition, stubble soil cover can influence weed seed germination and seedling emergence. The germination response of weeds to stubble cover depends on the quantity, position (vertical or flat and below or above weed seeds), and allelopathic potential of the stubble and the weed biology (Chauhan et al., 2006). In CA, the dead mulch of the cover crop on the soil surface suppresses weed germination by exhibiting allelopathic effects and decreasing light transmittance to the soil surface. A number of cover crops, including legumes (sesbania, sunhemp, soybeans, and cowpeas) and non-legumes (sunflower, rapeseed, rye, buckwheat and Sudan grass), have been found to suppress and smother various weeds by crop competition or allelopathic interaction. This weed control effect by suppression and shading is of particular importance for weeds propagating with roots or shoots.

PRACTICING STALE SEEDBED

In CA systems, stale seedbed practice can be a valuable way of reducing weed pressure. In this practice, a light irrigation or shower encourages weed seeds to germinate and emerged seedlings are killed by the use of non-selective herbicides. As most of the weed seeds remain in the topsoil layer in CA and weed seeds mostly germinate and emerge from the top 3 cm of the soil layer, a flush of weed seedlings can be destroyed with non-selective herbicides glyphosate or paraquat.

TIME OF CROP SOWING

In CA, time of crop sowing can be manipulated in such a way that ecological conditions for the germination of weed seeds are not met. Earlier seeding of Rabi crops can improve their ability to compete with weeds. In such situations, only post emergence herbicide application may be needed for the weeds emerging after an early seeding.

INTERCROPPING

Intercropping means growing two or more crops of different growth habits simultaneously on the same piece of land, which offers early canopy cover and seedbed use resulting in reduced weed growth due to competition for resources among component crops. For example, Maize-legume intercropping led to a higher soil canopy cover and decreased light availability for weeds, which resulted in a reduction in weed density and dry matter compared with sole crops (Kumar et al., 2010).

PHYSICAL WEED CONTROL

Although CA implies less use of machinery and implements for tillage, some manual weed control is still a useful approach, particularly in small farms. Farmers use several tools, among them the hand-hoe and weeder. More recently some other more productive tools have been developed like the motorized hand mower, which can be used to control weeds in between crop rows. Different weeders can be used to kill weeds in inter rows in case of row crops. Farmers also use a roller with cutting blades to flatten and/or eliminate a cover crop. In some areas overseas area where CA has been established more than five years ago, the use of chemical products is not anymore required and manual weeding using these tools is an economically feasible option. Important for long-term weed management is, also for mechanical weeding operations to minimize soil disturbance.

HERBICIDAL WEED CONTROL

Weed management using herbicides has become an integral part of modern agriculture. Herbicides offer great flexibility of operation, are effective, and are often more cost effective than any other method of weed management. Control of weeds using herbicides is becoming popular mainly because herbicide application requires less human effort, makes weed control easy and allows flexibility in weed management. Nevertheless, injudicious and continuous use of a single herbicide over a long period of time may result in the development of resistant biotypes, shifts in weed flora, and negative effects on the succeeding crop and environment. In CA systems, choosing an appropriate herbicide and appropriate timing is very critical (Buhler, 1995; Chauhan et al., 2006). In this system, existing weeds need to be controlled with a non-selective herbicide such as glyphosate, paraquat, or glufosinate prior to crop emergence (Hartzler and Owen, 1997). Since these herbicides lack residual activity, application should be scheduled as close as possible to crop planting in order to minimize further weed emergence prior to crop emergence.

Whether herbicide is poison?

Herbicides are chemicals just like fertilisers, fungicides and insecticides. All these agro-chemicals are required to be used following the instructions on the specific label and a Materials Safety Data Sheet (MSDS) that must accompany the specific product at all times (handling, transport, storage, application, etc.). No pesticide is to be used if the label and MSDS are missing. A label will provide information on where, how much, when, how, and why to use the specific herbicides while the MSDS will provide information related to physical and chemical characteristics, environmental risks, persistence, risks of poisoning including LD50, disposal procedures, etc.

Herbicides are harmful to plants but are generally not poisons if they are used following the instructions on the label. However, some of the herbicides (e.g., Paraquat) are lethal if inhaled. The LD50 of most herbicides is way less than for most insecticides. However, the level of risks to plants is greater with herbicide than fungicides or insecticides. A wrong dose or wrong selection of fungicide is unlikely to kill the crop plants. However, a wrong selection of an herbicide or application of higher rate may kill the crop plants. This is why a greater depth of knowledge is required to handle herbicides than other pesticides. When herbicides are applied following the protocols on the label and MSDS, they would control weeds effectively and should not hurt any off-target species or environment. The life time of most herbicides is less than six weeks. Most chemicals will be lost via different degradation processes (chemical breakdown, microbial breakdown, solar degradation, removal by plants, volatilization etc.) As such, a certain period of waiting time is to be followed before grazing, harvesting or picking. At the end of the prescribed waiting period, there should not be any risks from any herbicides or concerns in eating or feeding the crop products under circumstances when it has been applied following label instructions.

In CA systems, crop stubbles are present at the time of pre-emergence herbicide application and may decrease the herbicide's effectiveness as the stubble intercepts the herbicide, thus resulting in reduced amount of herbicide reaching the soil surface with less control of germinating weed seeds (Hartzler and Owen, 1997). Crop stubbles can intercept 15 to 80 % of the applied herbicides resulting in their reduced efficacy in CA systems. Herbicides intercepted by crop stubbles are prone to volatilization, photo-degradation, chemical degradation, microbial degradation, absorption and deactivation by crop plants, and other losses. To obtain the maximum efficacy they need to be incorporated with soil. Such high losses of herbicides under CA systems could have serious implications to weed control as insufficient herbicide remains to control late-emerging weeds. As the amount of soil disturbance decreases, the efficacy of pre-emergence herbicides, having high vapor pressure, can be expected to decrease. The efficacy of herbicides also depends on the herbicide formulations under CA systems. For example, granular pre-emergence herbicides (alachlor, cyanazine and metolachlor) provided better weed control than liquid-formations (pendimethalin). The granules are assumed to reach the soil surface through the stubble more effectively than a liquid applied. The effectiveness of post-emergence herbicides may also be reduced by the presence of weeds and crop stubbles. It is suggested that farmers should wait until weeds become established and then control them with post-emergence herbicides since the timing of weed emergence is less uniform in CA systems than in conventional systems. In general, herbicides requiring incorporation into the soil cannot be used in CA systems as they lead to considerable soil disturbance.

Herbicides are used pre-sowing, pre-emergence or post-emergence, depending on the selectivity of the herbicide to be used. Soil-acting herbicides are mainly used in pre-sowing or pre-emergence treatments while post-emergence one's lack long residual effect in soils.

Early herbicide application to eliminate weed competition in any system is a guarantee for vigorous early crop growth. Rational use of herbicides increases the productivity of the whole cropping process. Herbicides used correctly and at the right rates normally do not pose any problem to the environment. Soil-acting herbicides regularly decompose in soil in a period of 4-6 weeks after their application while most post-emergence ones are quickly dissipated in soil.

TYPES OF HERBICIDE

Herbicides can be classified based on their mode of action, mobility, method of application, time of application, and structural similarity.

Based on mode of action or mobility of herbicides

Systemic or translocated herbicide:

Translocated (systemic) herbicides move from the treated parts of plants to untreated areas through the xylem or phloem depending on the nature of molecule. Systemic herbicides may be applied to stems and leaves or to the soil. These herbicides are best for controlling perennial weeds. Glyphosate is a systemic herbicide when applied to stems and leaves, but it has no activity when applied to the soil. Translocated herbicides may be selective or nonselective. Example: 2,4-D (amine or ester), 2,4-DB, MCPB, MCPA.

Non-systemic or contact herbicide:

A contact herbicide kills those plant parts with which it comes in direct contact. They are normally applied to leaves and stems. Because they affect only the plant parts that they contact, they are less effective on perennial weeds than on annual weeds. Thorough coverage of the plant is essential for contact herbicides to be effective. A contact herbicide may be selective and nonselective too. Example: Propanil, paraquat, diquat, and Basalin (Fluchloralin). Some herbicides show both contact and translocated actions.

Based on selectivity

Selective herbicide:

Herbicide selectivity is very important in crop production. An herbicide is considered as selective when in a mixed growth of plant species, it kills some species without injuring the others. Through selectivity, it is possible to kill a grassy weed like Echinocloa crus-galli, by using herbicide in a grassy crop such as rice.

Non-selective herbicide:

Nonselective herbicides kill all types of plant species that means weeds as well as crops. Example: glyphosate, paraquat, etc.

Based on site of action

Soil applied herbicide:

Pre-planting herbicide:

A pre-planting herbicide application is made before the crop is sown. This application helps in crop establishment in a minimum soil disturbance cropping system. Translocated foliar herbicides (like glyphosate) kill perennial broadleaf weeds and grasses found in the fallow vegetation and application of paraquat is more judicious where annual weeds predominate. Volatile pre-planting herbicides such as trifluralin need to incorporated into the soil before planting, to avoid damage to the crop and are therefore not suitable for CA systems.

Pre-emergence herbicide:

Pre-emergence herbicides are applied to the soil surface after planting but before crop and weed emergence (for direct seeding system), and before weed emergence (for transplanted crops). These herbicides are known as residual herbicides. Selective systemic herbicides are normally used this way. Moisture is necessary to carry these herbicides to weeds germinating below the soil surface. Residual herbicides for dry seeded rice cultures should be applied to moist soil or during light rain, or irrigation should be provided a few days after herbicide spraying.

Foliage-applied herbicide:

Post-emergence herbicide:

Post-emergence herbicides are applied after crop and weed have germinated or after the seedling has been transplanted. The herbicide must, therefore, be selective otherwise crop seedlings will be killed. If the herbicide is selective, it can be applied over the foliage to kill the weeds without harming the crop. Examples are 2,4-D, chlorsulfuron, pyrasulfotole, etc.

Based on time of application

Pre-plant application:

Pre-plant herbicides should be foliar applied before sowing or along with sowing. Glyphosate is sprayed on the standing vegetation before land preparation or sowing as a knockdown treatment to clean the land for sowing. By contrast, trifluralin is incorporated into soil before sowing.

Pre-emergence:

Herbicides are applied to the soil soon after sowing a crop but before emergence of weeds. Example: atrazine, butachlor, pretilachlor, etc.

Post-emergence non-selective:

Herbicide is applied to kill the young weeds standing in the crops or applied after the emergence of both weed and crop. Example: glyphosate, paraquat (interrow with spray shield to protect the crop), etc.

Post-emergence selective:

Post-emergence herbicides can selectively kill the weeds without killing the crops. For example, 2,4-D amine or chlorsulfuron will kill most broadleaf weeds in wheat crop without killing the wheat plants.

Early post emergence:

Herbicide is applied in the crop to kill very young or emerging weeds in the early stage of crops. Example: Ethoxysulfuran, Cyhalop-butyl, Carfentrazone ethy, Pyrazosulfuran ethyl, etc.

Late post emergence:

Under very late conditions, a few herbicides are applied to control seed set of weeds by crop topping or desiccating the crop for ease of harvest. For example, triasulfuron, 2,4-D ester (low volatile) can be used to control late emerging broadleaf weeds in wheat crops. Paraquat can be sprayed at the physiological maturity of a pulse crop to control weed set. Glyphosate is used in crops to hay off (synchronized maturity) crops for ease of harvest.

WEED MANAGEMENT FOR AMAN RICE

Before transplanting of seedling or direct seeding of rice in non-puddled condition by CA practices, assess the pre-plant weed density and whether use of knockdown herbicide is needed. Usually the seedling of Aman rice is transplanted in kharif II season and at that time Aman rice fields are highly weed infested with various types of weed species especially grass and sedge species. Therefore, prior to transplanting of rice seedlings in non-puddled fields, application of pre-plant non-selective herbicide (e.g. glyphosate) is a pre-requisite. Several products of glyphosate are available in the market but Roundup® at the rate of 75 ml per 10 L of water is more effective than any other products. After knockdown herbicide application, weeds become dry within 5 to 7 days and finally die within 10 to 15 days. However, it is preferable to start land preparation (strip making, irrigation and basal fertilizer application, soaking the field, and transplanting) 24 hr after application of glyphosate.

PRE-EMERGENCE HERBICIDES

In a transplanted Aman rice field, the presence of standing water will help to suppress weed emergence at the early stage of crop growth but certain grass weeds re-establish especially from stems. Therefore, a suitable and effective pre-emergence herbicide needs to be applied within 3 to 5 days after transplanting if there is a likelihood of grassy weeds such as Cynodon dactylon re-establishing quickly. In Table 4 some effective rice herbicides are listed with their rate and method of application.

POST-EMERGENCE HERBICIDES

Different types of weeds start to emerge at later stages of crop growth and compete with rice plants for light, space, nutrients, etc. Therefore, post-emergence herbicide needs to be applied within 7-10 days or 15-20 days after transplanting. Some late post-emergence herbicide also can be applied at 20-25 days after transplanting to kill broadleaf weeds (see list of registered herbicides in Bangladesh in Table 4 and 5).

ROLE OF STUBBLE SOIL COVER FOR WEED MANAGEMENT

In CA systems, a certain amount of previous crop stubble is retained in the field as soil cover; however, stubble rots over time in the standing water. Several studies reported that retained stubble may restrict soil applied herbicide to spread through the soil and therefore herbicide has limited contact with emerging weed seeds. In this situation, liquid herbicides are more effective for weed control than the dry-applied powdery herbicides. In non-puddled field, standing water remains less muddy or more transparent above the soil surface in the absence of suspended soil particles that may retard powdery herbicide from mixing with soil sediments properly.

MANUAL WEEDING TO AVOID SEED SET

Often weed species escape from herbicide spray due to uneven application. In such situations, weed seed setting must be disrupted to avoid mixing weed seeds with rice seeds at the time of harvest. To avoid weed seed setting there is nothing so helpful as manual weeding or manual removal of the weed inflorescence. But this action should be taken before completion of seed or fruit setting of weeds.

Table 4: Dose, time of application and required field conditions to apply different herbicides for selected crops in Bangladesh (based on the recommendations on the product labels).

Herbicides			Dose (rate ha^{-1})					
Group	**Name**	**Trade name**	**Aman and Boro rice**	**Wheat**	**Mustard**	**Mung bean**	**Time of application**	**Field condition**
Pre-plant	Glyphosate	Roundup® 41SL	3.7 L	-	-	-	1 DBS	Free of water
Pre-emergence	Pendimethalin	Panida® 33 EC	2.5 L	-	2.5 L	-	DAT *(IAS for mustard)	Free of water
Post-emergence	Ethoxysulfuron	SunRice® 15 WDG	100 g	-	-	-	25 DAT	3-5 cm Standing water
	Carfentrazon-Ethyl	Affinity® 50.75 WP	-	1.25 Kg	-	-	25 DAT	Free of water
	Oxadiazon	Ronstar® 25EC	-	-	2.5 L	-	15 DAS	Free of water
	Fenoxyprop-p-Ethyl	Whip Super 9 EC	-	-	-	650 ml	25 DAS	Free of water

*IAS= Immediately after sowing,

WEED MANAGEMENT FOR WHEAT

Wheat grows during the Rabi season and most annual weeds also emerge at that time. Therefore, wheat fields commonly have heavy weed infestation. To kill the existing weeds before sowing wheat seeds, pre-planting knockdown herbicide (glyphosate) needs to be applied on the field. Application of Roundup® at the rate of 4 to 5 L ha^{-1}/500 L of water ha^{-1} is effective to kill the standing weeds of the field. If infestation is high then a second time of application is suggested.

PRE-EMERGENCE HERBICIDES

Wheat seedlings emerging under CA may encounter high weed infestation. That's why it is wise to use pre-emergence herbicide at 0 to 3 days after sowing. Pre-emergence herbicides will help to control grass and sedge types of weeds. However, while there are a very limited number of pre-emergence herbicides registered for wheat, pendimethalin, pretilachlor or triasulfuron can be used as effective pre-emergence herbicides under CA.

POST-EMERGENCE HERBICIDES

Broadleaf weed infestation is considered one of the major threats for quality deterioration of wheat seeds. Moreover, broadleaf weed species are dominant in wheat, as for example Chenopodium album, Polygonum spp., etc. Post-emergence application of herbicide is effective to control broadleaf weeds. Early post-emergence herbicides are applied at 10 to 15 days after sowing and late post-emergence herbicides are at 20 to 25 days after sowing. However, to control Physalis heterophylla late post-emergence herbicide can be sprayed at 30 days after sowing. Suitable herbicides can be chosen from the list of herbicides as given in Tables 4 and 5.

ROLE OF CROP STUBBLE FOR WEED MANAGEMENT

In dry field condition, crop stubble cover helps to restrict weed seedling emergence by preventing sunlight penetration. As a result, germinating weed seeds exhaust their energy reserves and become etiolated, weak and more susceptible to herbicides. Manual weeding should be practiced to avoid seed set of weeds. To avoid weed seed setting in wheat fields manual weeding of a whole weed plant or reproductive part of weed should be done. The plant can be left as mulch in the field and need not be removed or burnt.

WEED MANAGEMENT FOR LENTIL AND CHICKPEA

After Aman rice or jute harvest, weed infestation at the time Rabi crop sowing of lentil or chickpea is often limited (Figure 2). Hence, pre-plant weed control strategies for lentil and chickpea after rice or jute harvest have not been assessed. However, application of Roundup® herbicide @ 150 ml per 15 L with water applied 1-2 days (24-48 hours) before seed sowing of lentil resulted in effective suppression of regrowth rice (ratoon rice) and newly emerged weeds.

PRE-EMERGENCE HERBICIDES

There are no registered pre-emergence herbicides for controlling weeds in lentil and chickpea crops. However, application of Roundup before sowing should suppress weed growth and ratoon rice during emergence and early growth. Also, limited application of fertilizer and irrigation for lentil and chickpea at sowing further suppresses weed infestation and growth compared to the situation in irrigated cereal crops.

POST-EMERGENCE WEED CONTROL

There are still no registered post-emergence herbicides for lentil and chickpea. As a result, no herbicides are recommended at this stage for post-emergence weed control in lentil and chickpea crops. Use of unregistered herbicides may cause crop damage.

Retaining surface stubble in the inter-row with strip planting resulted in good suppression of weed infestation and growth in lentil and chickpea fields.

Weeds in lentil and chickpea fields should be controlled by manual hand weeding at 25-30 days after seed sowing. One-time hand weeding was effective for controlling weeds of lentil and chickpea.

HERBICIDE RESISTANCE

Herbicide resistance is defined as the inherited ability of a weed population to survive an herbicide application that is normally lethal to the vast majority of individuals of that species. Herbicides are applied to kill the target weeds but they fail to control these weeds when resistance develops against the herbicides. The appearance of herbicide resistance is a serious threat for weed management. Resistance of Senecio vulgaris to the triazine group of herbicides was noticed during 1970. Worldwide, there are currently 487 unique cases (species x site of action) of herbicide resistant weeds, in 253 species (147 dicots and 106 monocots). Weeds have evolved resistance to 23 of the 26 known herbicide sites of action and to 163 different herbicides. Herbicide resistant weeds have been reported in 92 crops in 70 countries (Heap 2018).

Herbicide resistance in weeds may develop due to variation in time, dose and method of application of herbicide, variation in phenotypes of a population and also due to genetic variation by mutation or activation of pre-existing genes. Development of herbicide resistance is favoured by the repeated use of the same herbicide or use of herbicides with the same mode of action due to the practice of monoculture. It is usually found in areas where minimum soil disturbance or zero tillage is practiced due to high degree or level of weed control by herbicides and in non-crop situations like road side vegetation, railway tracks etc. where herbicides are repeatedly used at higher doses.

Factors affecting speed of selection for herbicide resistance include (1) Level of cultural practices, (2) Frequency of herbicide use, (3) Herbicide mechanism of action, (4) Biology of weed species and (5) Frequency of resistant biotypes.

MANAGEMENT OF HERBICIDE RESISTANCE

Generally, the best approach to resistance management is to follow Integrated Weed Management (IWM) practices.

The most important principle of weed resistance management is to prevent the survival and spread of resistant populations. The following approaches should be practiced to avoid herbicide resistance development in weeds.

1. Use an effective alternate mode of action (MOA) herbicide to control known herbicide-resistant weeds.

2. Include effective alternate MOA at least every-other year for "at-risk" weeds.

3. Scout fields to monitor effectiveness of the herbicide program.

The following additional considerations should be incorporated into the farming practices to manage weed resistance:

1. Use multiple MOA herbicides on target weeds, including those with residual effects, prior to glyphosate applications and/or tank-mix another herbicide with glyphosate to get better efficacy.

2. Utilize cultural practices such as non-soil engaging mechanical weed management practices, mulch covers or crop rotation.

3. Apply herbicides at rates and at the recommended stage of weed growth as stated on the label.

4. Crop variety should be selected based on agronomics, desired traits and yield potential as well as tolerance to certain herbicides.

5. Growers utilizing herbicide programs with herbicide tolerant crops can do so on an annual basis with wide enough crop rotations provided the technology is managed effectively.

6. Fields should be scouted before and after herbicide applications.
7. Equipment clean out is essential to reduce the spread of resistant weed seed.

POINTS TO BE CONSIDERED DURING PLANNING WEED CONTROL MEASURES

1. Survey regularly your areas to record major weed species in the field.
2. Keep in mind that crop rotation is the key for good weed management.
3. Grow cover crops and select the cover crop varieties considering the weed infestation history of the plot for the management/control of weed infestation.
4. Do not leave non-cropped spaces in the field and use correct seed densities as well as row-spacing.
5. Most post-emergence herbicides should be used at early weed emergence, although some systemic compounds such as glyphosate are most effective a couple of weeks after weed emergence.
6. Pre-emergence and/or pre-sowing soil-acting herbicides are best used with appropriate soil moisture.
7. To prevent problems of resistance it is important to avoid the use of the same herbicide repeatedly and year after year.
8. The main objective of weed management should be sustainable reduction of the weed seedbank and not only the control of weeds interfering during the critical periods of competition.
9. Perennial weed species may require the integration of various control methods to get the required reduction of their stand.
10. Preventive methods such as field hygiene at field level should not be neglected.

Table 5: Lists of available registered herbicides used for different crops under conventional agriculture systems in Bangladesh. The available herbicides with their common name, trade name, target weeds, mode of action, time of application and doses are based on the product label rate.

Chemical name	Commonly used trade names	Crop	Recommended dose (ha^{-1})	Application method and time	Target weed
1. Pendimethalin	Panida 33EC	Rice & Wheat	2.5 L & 3.0 L	Mix with water and spray in rice at 3-5 days after transplanting and in wheat at 1-3 days after sowing	Grass & sedge
	Pendulum 330EC	Rice	2.0 L	Mix with water and spray at 3-5 days after transplanting	
	Fist 33EC	Wheat	3.0 L	Mix with water and spray at 1-3 days after sowing	Chenopodium album
2. Pyrazosulfuron-ethyl	Manage 10WP	Rice & Wheat	150 g	Mix with water and spray in rice at 3-5 days or 10-15 days after transplanting and in wheat at 15-20 days after sowing	Grass, sedge & few Broadleaf (Ludwigia decurrens, Commelina beghalensis, Cynotis auxillaris, Vicia sativa)
	Porisker 10WP		125 g		
	Super Power 10WP	Rice	150 g	Mix with water and spray at 3-5 days or 10-15 days after transplanting	Echinochloa crusgalli, Cyperus difformis, M. gaginallis, E. fluctuans, S. juncoides
3. Pretilachlor	Rifit 500EC	Rice	1.0 L	Mix with water and spray at 3-5 days after transplanting	Echinochloa crusgalli, Cyperus difformis
	Commit 500EC				All weeds
	Prechlor 500EC				

Chemical name	Commonly used Crop trade names	Crop	Recommended dose (ha^{-1})	Application method and time	Target weed
4. Acetochlor	Offer 50EC	Rice	250 *g*	Mix with water and spray at 3-5 days after transplanting	Echinochloa crusgalli, S. maritimus, Cyperus difformis
5. Acetochlor (14%) + bensulfuron methyl (4%)	Changer 18WP	Rice	350-400 *g*	Mix with sand or nitrogen fertilizer and broadcast on 2-3 leaved weeds in the field having 2-3" standing water	Grass, sedge and broadleaf
	Sunchance 18WP	Rice & Tea	750 *g* & 3 kg	After emergence of 2-3 leaves of weed	Grass, sedge and broadleaf
6. Bensulfuron methyl (18%) + Pretilachlor	Londax Powder	Rice	9 kg	After emergence of 2-3 leaves of weed	Grass, sedge and broadleaf
7. 2,4-D	Fielder	Rice & Tea	2.24 L & 2.80 L	After emergence of 2-3 leaves of weed	Broadleaf
	2,4-D amine	Rice, Tea & Rubber	2.24 L & 2.80 L	After emergence of 2-3 leaves of weed	Broadleaf
	Salix	Rice	1.15 L	After emergence of 2-3 leaves of weed	Monochoria vaginalis, Ludwigia spp., Sphenoclea zeylanica
	2,4-D Weeder	Tea	2.24 L	After emergence of 2-3 leaves of weed	Broadleaf
8. 2,4-D Butyl Ester	Rampitox 45WP	Rice	125 *g*	After emergence of 2-3 leaves of weed	Broadleaf
9. Bensulfuron methyl (3%) + Mefenacet (50%)	Super clean 53WP Famous 53wp	Rice	450 *g*	After emergence of 2-3 leaves of weed	Sedge & broadleaf

Chemical name	Commonly used trade names	Crop	Recommended dose (ha^{-1})	Application method and time	Target weed
10. Bensulfuron methyl (18%) + Bispyribac sodium (12%)	Sirius Plus 300WP	Rice	120 g	20-25 days after transplanting	Cyperus difformis, Cynodon dactylon, Echinochloa crusgalli, M. vaginalis
11. Bispyribac sodium	Xtra Power 20WP	Rice	150 L	10-15 days after transplanting	Echinochloa crusgalli, M. vaginalis, C. difformis
12. Butachlor	Golteer 5G	Rice	25 kg	Apply on 2-3" standing water in the field at 3-5 days after rice transplanting	Monochoria vaginalis, Cyperus difformis, C. iria, Scirpus matrimu
	M-chlor 5G				
	Vitachete 5G				
	Supershine 5G				
13. Butachlor (35%) + propanil (35%)	Prepona 700EC	Rice	1 L	Mix with water and spray at 20-15 days after transpalnting	Echinochloa crusgalli, Fimbristylis miliaceae, M. vaginalis, Cyperus difformis, M. minuta
	Gang 700EC				Broadleaf
	Butacrop 70EC		1.5 L		Broadleaf
14. Carfentrazone-ethyl (50%) + isoproturon (0.75%)	Affinity 50.75WP	Wheat	1.5 kg	Mix with water and Spray at the emergence of 2-3 leaves of weeds	Grass, sedge & broadleaf
15. Carfentrazone-ethyl	Hammer 24EC	Wheat, rice & Potato	104 ml, 100 ml & 104 ml	Mix with water and Spray at the emergence of 2-3 leaves of weeds	Sedge & broadleaf
	Aim 40DF	Rice & Potato	62.5 kg		

Chemical name ethyl	Commonly used trade names	Crop	Recommended dose (ha^{-1})	Application method and time	Target weed
16. Ethoxysulfuron	Sunrise 150WP	Rice, Wheat & Jute	100 g, 100 g & 200 g	Mix with water and then Spray at 10-15 days after transplanting or sowing	Sedge & broadleaf
17. Fenoxaprop-p-ethyl	Whip Super 9EC	Jute, Brinjal, Onion & Mungbean	650 ml, 0.75 L, 0.75 L & 650 ml	Mix with water and then Spray at 7-10 days after sowing	Echinochloa colonum, E. crusgalli, Eleusine indica, Digitaria sanguinalis
18. Cyhalofop-butyl (5%) + Fenoxaprop-p-ethyl (5%)	Depon 10EC	Maize	100 ml	Mix with water and then Spray at 15-20 days after sowing	Echinochloa crusgalli, Cynodon dactylon, Cyperus rotundus, Amaranthus spp.
19. Metamifop	Pyzero 10EC	Jute & Rice	750 ml	Jute: Spray at 12-16 days after seeding of jute on 2-6 leaved weeds. At the time of spray enough moisture should be ensured. Rice: 10-15 days after seeding or transplanting herbicide needs to spray on 2-6 leaved weeds. At that time excess water should be drained out from the field and irrigation should be provided after 3 days of herbicide spraying.	Grass
20. Metribuzin	Neon 70WG	Potato, Maize & Sugarcane	750 g, 750 g & 1.5 kg	Mix with water and then Spray at 15-20 days after sowing	Broadleaf
	Sencor 70WP	Potato	375 g	Mix 0.75 gL^{-1} water and spray at 2-3 leaved weeds	E. colonum, Ludwigia anagali, G. affinal

Chemical name	Commonly used trade names	Crop	Recommended dose (ha^{-1})	Application method and time	Target weed
21. Oxadiazon	Ronstar 25EC	Rice, Potato & Onion	2 L, 1L & 1L	Mix with water and then Spray at 7-10 daysafter transplanting or sowing	All weeds, especially Chenopodium album
	Miracle 25EC	Rice	2 L		All weeds
	Weeder 25EC		1 L		Chenopodium album, S. maritimus, M. vaginalis
22. Quizalofop-p-ethyl	Quilop 5EC	Jute &Kanaf	650 ml	Mix with water and spray at 0-2 days after sowing of jute and 0-1 day after sowing of kanaf	Echinochloa colonum, Digitaria sanguinalis
23. Pyrazo-sulfuron-ethyl (0.6%) + Pretilachlor (34.4%)	Escape 35WP	Rice	800 g	Mix with water and spray at 5-10 days after transplanting	E. crusgalli, C. difformis, M. maritimus
24. Pyrazosulfuron-ethyl (34.4%) + Pretilachlor (0.6%)	Tiptop 35WP	Rice	800 g	Mix with water and spray at 7-10 days aftertransplanting	E. crusgalli, C. difformis, M. maritimus
25. Orthosulfam-uron	Kelion 50WP	Rice	150 g	Mix with water and spray at 10-15 days after transplanting	All weeds
26. Atrazine	Simazine 50SC	Maize	2.5 L	Mix with water and spray before maize emergence	Cynodon dactylon, E. crusgalli, Cyperus rotundus, Amarathus spp.
27. Triasulfuron	Logran 75WG	Rice & wheat	10 g	Rice: mix with nitrogen fertilizer and broadcast in the rice having 1-2 standing water at 3-7 days after rice transplanting Wheat: Mix with water and spray before emergence of wheat	Sedge & broadleaf
28. Sulfentrazone	Authority 48SC	Rice	200 ml		C. difformis, S. maritimus, E. crusgalli, M. vaginalis
		Soybean	550 ml		C. rotundus, C. dactylon, E. crusgalli, P. distichum, E. fluctuans
		Sugarcane	1.04 L		Sedge & broadleaf

HERBICIDE RESIDUES

Soil-applied herbicides need to persist long enough in the soil to give an acceptable weed control. The length of time that an herbicide remains active in the soil is called persistence or soil residual life. The quantity of herbicide that remains in soil after its mission is accomplished is referred to as residue. Sometimes herbicides are carried over from one crop season to another. Sensitive crops that follow in rotation can be damaged completely by herbicide residue. For example, application of trifluralin in a sunflower crop exerted toxic effects on a succeeding wheat crop; and atrazine in maize could damage a succeeding wheat crop. However, application of pendimethalin, pyrazosulfuron-ethyl, pretilachlor, butachlor, orthosulfamuron and 2,4-D amine in non-puddled transplanted Aman rice did not show any toxic effect on the succeeding wheat, lentil and sunflower. Furthermore, pendimethalin, pretilachlor, triasulfuron, ethoxysulfuron, and carfentrazone-ethyl applied in a strip planted wheat crop did not have any toxic effect on the following jute, mungbean and sunflower.

It is reported that longer persistence of residues poses hazards to the subsequent crops. Therefore, the persistence of herbicides in soil is designed to be long enough to control weeds, but short enough that the subsequent crops are not affected.

Soil-applied herbicides are deactivated in the soils by a range of factors. Crop plants can absorb and deactivate the herbicide molecules while weed plants absorb herbicide and get killed and consequently, herbicide concentrations are reduced. Some herbicides such as trifluralin have high vapor pressure and are lost by volatilization if not incorporated in the soil immediately after application. Some soil-applied herbicides are degraded by solar radiation. Some herbicides such as chlorsulfuron break down by chemical reaction in the soil or by microbial degradation. Some plants such as maize can chemically breakdown the herbicides (such as triazine) inside the plant rendering the herbicides safe to crop plant but the target weed plants do not have this ability. However, stubbles can absorb soil-applied herbicides leading to longer persistence of herbicides. On the other hand, high stubble is likely to contribute to high organic matter in the soil and high soil microbial activity that can breakdown the herbicide molecules faster by using herbicides as a source of energy.

Various management practices are used to minimize residue hazards in soil as follows:

1. Application of herbicides at the lowest effective dosages at which desired weed control is achieved (usually the label rate) would reduce the hazards from residue. Application of herbicide in bands rather than broadcasting would reduce total amount of herbicides to be applied.

2. Maintenance of soil organic matter levels.

3. Application of farm yard manure (FYM) reduces the residual toxicity of herbicides by increasing the absorption of herbicide molecules in the colloidal fraction of soil. In addition, increased FYM increased microbial activity that in turn degrades the herbicides at a faster rate.

4. Tillage mixes the herbicides with a large volume of soil that dilutes the herbicide. Deep tillage helps burying the herbicides into deeper soil layers and thus residual toxicity of herbicides is reduced.

5. Application of activated carbon (charcoal) reduces the residual toxicity of herbicides because of its high adsorptive capacity. In addition, mixing of some adjuvant with the herbicide formulation or added to the spray tank can increase the weed control potency while reducing the residual hazards.

6. Safeners and antidotes are used to protect the crops from possible damage by herbicides. Napthalic acid (NA, 1,8-napthalic anhydride) has been used as a seed dressing on rice to protect the crop against molinate and alachlor. Another herbicide safener, cyometrinil, is used along with metolachlor in grain sorghum and other crop species.

7. With frequent irrigation, water-soluble herbicide (e.g., 2,4-D amine, MCPA, Dalapon, etc.) can be leached out by irrigation to reduce their residual toxicities (although the risk of leaching into groundwater also needs to be considered).

HERBICIDE PHYTOTOXICITY

Herbicides are designed to kill weeds but when not used correctly may harm or kill the crop (this is called phytotoxicity). Herbicides bring about various physiological and biochemical effects on the growth and development of emerging seedlings as well as established plants of weed and crops, either after coming into contact with the plant surface or after reaching the site (s) of action within the plant tissue. The net result is damage to tissue or death of the plant. Phytotoxic-physiological and biochemical effects are followed by various types of visual injury symptoms on susceptible plants. These include chlorosis, defoliation, stunting, necrosis, stand reduction, epinasty, morphological aberrations, growth stimulation, cupping of leaves, marginal leaf burn, desiccation, delayed emergency, germination failure, etc. These injury symptoms may appear on any part of the plant including roots, flowers, fruits, foliage etc.

The rate of appearance of these phytotoxic effects varies with the characteristic actions of the herbicide and depends on the degree of tolerance or susceptibility of the plant species. After reaching the site of action, the herbicide affects the biochemical processes of the plant and these effects are immediately reflected in the growth morphology and physiology of the plant.

The phytotoxicity of a particular herbicide can be assessed by taking observations on seed germination (in case of pre-emergence herbicides), plant height, number of tillers (in tillering crops), dry matter production and final grain and straw yield. Phytotoxicity may also be assessed by visual observations, particularly for post-emergence herbicides.

Crop injury rating could be done at 7 and 14 days after herbicide application based on visual observation using the scales developed by European weed research Society (EWRS), where, 1 = total control, 9= no effect on weeds (in case of weed control rating) and in case of crop tolerance rating, 1= healthy plant, 9 = crop killed.

Phytotoxicity of herbicides on rice plants (leaf yellowing, burning of leaf tip, stunting growth, etc.) can also be visually assessed by recording the degree of toxicity on rice plants following 1-5 scale used by IRRI as (a) No toxicity, (b) Slightly toxicity, (c) Moderate toxicity, (d) Severe toxicity, (e) Toxic (plant kill) where no toxicity =1 and toxic (total killed) =5

SCREENING OF CROP TOLERANCE FOR HERBICIDE

A crop may tolerate a range of herbicides but tolerance levels of one cultivar may be different from another cultivar of the same crop species. Similarly, a cultivar may be tolerant to one herbicide when applied at specific stage of the crop but the same herbicide may be toxic to another cultivar of the same crop when applied at the same stage. As described above, some cultivars may not be affected with visible symptoms of injury but the ultimate grain yield may be reduced significantly, leading to a loss in the profit of growers.

All new crop cultivars must be screened for their tolerance to various herbicides recommended for each crop, before the release of the cultivar. The screening for herbicide tolerance needs to be reported as part of the production guidelines of each variety. The tolerance of the new cultivars should be performed via a range of screening trials by experienced weed scientists by applying label rate (1X) and twice the label rate (2X) at different growth stages of the crop cultivar. Some of the current cultivars with known phytotoxicity may be added as controls. On the other hand, if new herbicide molecules are about to come in market, these also should be subject to screening with current species and cultivars.

SAFETY WITH HERBICIDES AND OTHER PESTICIDES

Bangladesh has achieved food security by the benefits of pesticides that protect crops from pests (weeds, insects and diseases). Insecticides were introduced in the late 1950s and fungicides in the 1970s. The first herbicide glyphosate was introduced in the 1960s to control Mikania vine (Mikania micrantha) in the tea gardens. Herbicides to control weeds in field crops were introduced on a small scale in the 1980s but farmers started adoption of herbicides on a wide scale after 2010 due to labour shortages for manual weed control.

Recent farmer focus group discussions suggest that almost all farmers in Bangladesh are now aware that herbicides can effectively control weeds before and after planting crops and save labour costs. However, safety during storage, handling, transport, application, grazing, harvesting, and consumption are less well known and emphasized. The only way to achieve safety of pesticides at all these levels is to ensure regulatory compliance via training and education of users including farmers, and of pesticide suppliers and traders.

National training should be introduced, and to raise awareness on personal safety and safe food production systems. There should be enforcement of pesticide license requirements for growers, dealers, contractors and supervisors to emphasize the need for:

- Proper sprayer calibration.
- Use of safe sprayers (complying to international standards for safety of agricultural pesticide sprayers such as FAO, ISO or corresponding national standards)
- Use suitable of personal protective equipment (PPE).
- Labelling, safe storage and transport of chemicals based on toxicity.

- Operator training by professional trainers to apply best practices:
    - Avoidance of spray drift and risks to off target organisms.
    - Understanding label and material safety data (MSDS).
    - Avoidance of spraying when conditions are not suitable.
    - Lockup storage facilities for herbicides.
    - Washout and follow waste management procedures to keep equipment clean and avoid contamination of soil and water with residues.
    - Procedures for disposal of outdated chemicals and used containers.

For the safety of the operator, PPE must be used to prevent the person from exposure to pesticides. Pesticides can enter into the human body via skin, absorption by eyes, inhalation and ingestion. Suitable PPE adapted to climatic conditions must be used as standard practice to protect the operator but they cannot make up for unsafe and leaking sprayers.

STUBBLE RETENTION

Crop stubble retention on the soil surface is one of the core principles of CA. Enormous benefit has been identified from stubble retention in CA systems for soil quality improvement, natural resource conservation, decreased weed pressure, and increased productivity, etc. However, the level of stubble retention and handling characteristics depend on household use of stubble, crop type, stubble type (loose or anchored), freshness (or weathering status), water content in stubble, soil type, soil water content in the field, type of implements used to sow the next crop, disease of previous crops, depth of stubble soil cover, etc.

HOW MUCH STUBBLE COVER TO LEAVE FOR THE NEXT CROP

Crop stubble has many farm household uses including feed for cattle and sheep, fuel for cooking, thatching material for the roofs of houses, filler to package agricultural commodities, etc. Crop stubble should not be burnt. The level of stubble available for retention should be estimated based on household level stubble requirements for other purposes, the type of stubble, the stubble handling capacity of the planter, etc. In rice-based systems, particularly in Bangladesh where cropping intensity is high, and there is short turn-around time between crops, the retention of rice stubble has been increasing in recent years. Most of the farmers in the intense rice-based systems of Bangladesh retained about 20 cm high, anchored Aman rice stubble in the field (Fig 12). The level of stubble retention is higher in the case of Boro rice, wheat, mungbean, etc. Research results show that 50 cm high rice and wheat stubble retention is more beneficial, whereas, retention of 20 cm high stubble from each rice crop (Aman and Boro) along with minimum soil disturbance systems helps to maintain soil health and increase crop yields.

TYPE OF STUBBLE (STANDING AND ANCHORED VS LOOSE)

Dry, soft, short, stubble (standing and anchored), and non-fresh (old) stubble is most suitable for planters to plant into. For planters with furrow openers (e.g. VMP), if the stubble cover is reasonably thick with tall stubble it will accumulate on the shank of the furrow opener rather than be pushed aside that causing opener blockages of the planter. If the soils have high moisture and

Figure12: Optimum stubble height/level suitable to operate planter.

Figure 13: Lentil planted in rice stubble by VMP.

stubble is damp, there is greater accumulation of loose stubble around the furrow openers. It is therefore essential to consider the capabilities of planters for handling the surface stubble. Chopping of straw into relatively shorter lengths is beneficial to prevent clumping around the furrow openers. However, chopping straw will enhance the decomposition of the stubble which is not recommended for CA.

STUBBLE HANDLING CAPACITY OF VMP

Each tillage type available with the VMP has varying capacity to cope with the volume and height of stubble retained from the previous crop.

Strip planting

In the strip planting setting of the VMP, with sharp and straight rotary blades aligned with furrow openers, minimal stubble accumulation of rice and wheat straw occurred on the rotary shaft and furrow openers provided the height of anchored residue was <60 cm (equivalent to 5.5 t ha^{-1}) (Figure 13). If loose, and >40 cm (up to 4.5 t ha^{-1}), the rice or wheat straw accumulation in strip planting was substantial especially if the stubble was fresh and wet.

Bed planting

In Bed planting system, 20 cm or more of any type of crop stubble accumulated on furrow openers and needed to be cleaned by an operator quite often. Higher amounts of stubble retention and multiple tillage passes enhanced the stubble accumulation on the rotary shaft and furrow openers, which was severe if loose and fresh stubble was retained in the field.

Zero tillage

Stubble accumulation on furrow openers was observed if the height of stubble was > 20 cm; and was more severe with greater amounts of loose stubble and tall stubble. Higher stubble accumulation with furrow openers in the absence of cutting disks was observed even with very low retention (<0.4 t ha^{-1}) when the retained loose rice or wheat stubble were >10 cm long (Table 6)

Table 6. Height and weight of retained stubble of rice, wheat, and mungbean using VMP under various tillage systems.

Crop and height (cm) of retained stubble	Stubble retained (mean of all (n) determinations)							
	Strip planting		Bed planting		Zero tillage		Conventional tillage	
	n	t ha^{-1}	N	t ha^{-1}	N	t ha^{-1}	N	t ha^{-1}
Rice, >50	27	4.8	27	4.4	27	4.5	27	4.6
Rice, 20- 50	267	3.1	20	3.1	8	2.8	253	3.2
Rice, <20	414	1.5	21	1.5	8	2.5	322	1.5
Wheat,>40	342	2.9	28	2.8	8	2.3	167	2.7
Mungbean,>30	12	2.8	12	2.8	-	-	12	2.8
Total:	1062	-	108	-	51	-	781	

The following conclusions about stubble retention may be drawn based on the above discussions:

- Strip planting is the best planting option for handling stubble using VMP and can handle up to 50 cm height (5.5 t ha^{-1}) of rice or wheat stubble with an experienced operator.
- Sharpened straight blade aligned to furrow openers performed well in clearing stubble for reliable seed and fertilizer placement and seed covering using strip planting.
- Higher stubble accumulation with furrow openers were observed in ZT.
- Higher stubble accumulation around the rotary shaft was observed with loose stubble.
- Field preparation for stubble handling starts at harvesting by cutting the crop at a suitable height for planting the following crop (by VMP or another planter).

STRIP SEEDED WHEAT AND LENTIL IN RICE-BASED CROPPING SYSTEMS

PLANTER TYPES

A VMP drawn by a 2WT was used to place seeds and fertilizer with minimal soil disturbance (strip seeding with 4-5 cm strip width and 5-7 cm seeding depth). Sufficient separation distance between fertilizer and seed was maintained to avoid toxicity to the germinating seed from the fertilizers.

The standard recommended seed rates for wheat (120 kg ha^{-1}) and lentil (34 kg ha^{-1}) were suitable for strip seeding.

PRE-PLANT WEED ASSESSMENT

After rice harvest, the land remains often relatively free from weed infestation (Figure 14, 15). In some cases, pre-plant weed control before sowing of wheat or lentil was not necessary. Generally, application of Roundup® @ 250 ml/15 L H_2O applied 1-2 days (24-48 hours) before sowing of lentil resulted in suppression of newly emerged weeds and regrowth rice (ratoon rice). Subsequently, weeds in the lentil fields were controlled by one hand weeding at 3-4 weeks after seed sowing.

STUBBLE LEVELS

Historically, farmers of Bangladesh retained little crop stubble because of its valuable use as fodder, fuel, fencing material and for household activities. Some farmers burt stubble to ease the seed bed preparation.

Figure 14: Field condition after rice before planting of Rabi season crop.

The VMP has been extensively tested for planting seed into tall stubble (50 % cereal stubble by height and 100 % legume stubble) and low stubble (20 % cereal stubble by height) using strip seeding. During sowing, there were no difficulties to operate VMP through 50 % or even 70 % rice stubble cover on a strip seeded plot. Thus, with an experienced operator the VMP managed rice stubble up to 70 % cover, but for less experienced operators it is preferable to target 40-50 % stubble retention. With 50 % stubble retained the weight was equivalent to 3-4 t ha^{-1}, while for 20 % it was about 1-2 t ha^{-1} (Figure 14).

There were two types of stubble retained: 1) stubble or anchored standing stubble-, and 2) loose stubble chopped and laying on the soil surface. The former is generally easier for the VMP to handle during planting without clumping and blocking of the tines.

SOIL WATER

Strip planting appears to work well across a range of soil water conditions as shown in Table 7 and 8 for lentil, wheat and mungbean planting.

Table 7. Soil volumetric water content (%) at strip planting of crops in the lentil-mungbean-Aman cropping rotation at Alipur, Durgapure, Rajshahi.

Crop number	Soil water content (%) at different depth (cm)		
	0-5 cm	5-10 cm	10-15 cm
Crop 1 (lentil)	24.1	25.5	27.6
Crop 2 (mungbean)	13.2	19.4	23.4
Crop 4 (lentil)	37.0	33.6	31.8
Crop 5 (mungbean)	10.7	14.9	18.3
Crop 7 (lentil)	36.4	31.0	29.0

A light pre-sowing irrigation may be necessary for strip planting if soil is too dry during planting. On the other hand, if the soil is too wet planting should be delayed for a couple of days to allow it to drain to field capacity level.

Table 8. Soil volumetric water content (%) of strip planting of crops in the wheat-mungbean-Aman cropping system at Digram, Godagari, Rajshahi.

Time	Soil water content (%) at different depth (cm)		
	0-5 cm	5-10 cm	10-15 cm
Crop 1 (wheat)	29.7	29.6	28.5
Crop 2 (mungbean)	18.0	22.8	26.1
Crop 4 (wheat)	24.4	24.0	24.8
Crop 5 (mungbean)	18.2	18.9	12.2
Crop 7 (wheat)	40.8	34.2	30.0

After tillage, the soil moisture dried more quickly in conventional tillage than the strip planting system, where stubble retention would help to conserve soil water. In rainfed agriculture, the reduction in soil water by conventional tillage had persistent effects throughout the growing season and reduced yields compared to strip-planting system. After a few cropping cycles, strip-planting and stubble retention improves soil structure to conserve soil water relative to conventional tillage. In dry condition, strip-planting is more advantageous compared to conventional tillage due to development of soil structure and conservation of soil moisture. In wet condition, strip-planting is also advantageous compared to conventional tillage system specially for non-puddled rice (Hossen et al., 2017).

SEEDING DEPTH AND COVER

Seeding depth, evenness of depth and soil cover of seed are important for germination and has an impact on strip planting success. Seeding depth by strip planting is about 2-3 cm. In fields with uneven surface or dry soil condition, poor seed cover with the planter may result in poor stand establishment.

Seeding of crops between rows in previous crop (the inter-row space without stubble) generally results in better germination and emergence as a result of better seed-soil contact. Using alternate row for each crop helps to even out the distribution of fertilizer across the field in strip planting.

PLANT DENSITY AND CROP YIELD

Significant positive correlation between lentil seed and straw yield with plant population was reported by Islam (2017). The relationship between plant population m^{-2} and yield of lentil across three years (2010-13) was positive (R^2 = 0.31) and linear (Figure 15) (Islam, 2017). This result confirmed that use of VMP for establish various crops including lentil could achieve optimum plant density which is highly desirable to get maximum seed and straw yield.

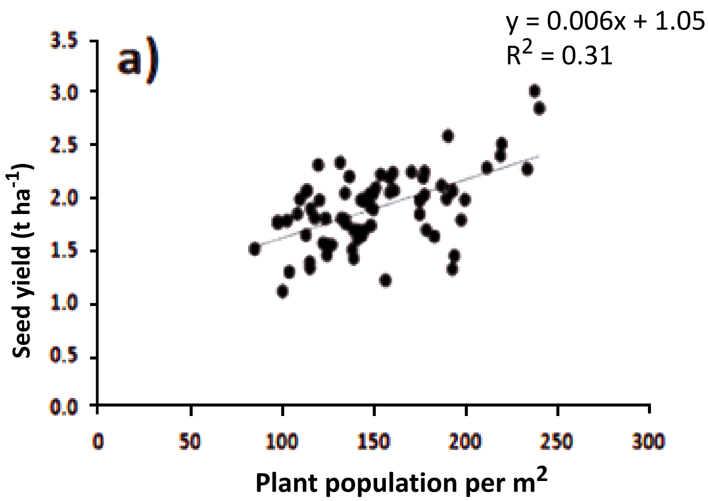

Figure 15: Relationship between plant population and seed/grain yield of lentil, Rajshahi, Bangladesh.

STRIP SEEDED CHICKPEA IN RICE-BASED CROPPING SYSTEMS

Figure 16: VMP planted chickpea (early stage).

The annual chickpea production in Bangladesh is close to 15,000 t mostly in the North-West region (Barind area). The practice in High Barind is generally a single, long-duration Aman rice that is harvested in late November to mid-December. The soil dries quickly (within 3-7 days) after harvesting of the Aman rice. Land preparation and establishment of Rabi crops using country plough covers minimal land area within the short time before the soil is too dry for planting. Delayed planting of chickpea reduces seed yield substantially. Chickpea planting by machine is an option for wider area coverage, and also to maximize seed yield and profitability (Figure 16).

The VMP was used to establish chickpea for strip planting (Figure 17), zero tillage (Figure 17), single pass shallow tillage and bed planting in several districts. Higher seed yield of chickpea and net return were achieved for all single-pass minimum soil disturbance planting by VMP compared to the full-tillage systems (Bell et al., 2017). If the lands are free from weed, application of knock-down herbicide can be ignored. About 20 to 32 % water content in soils is suitable to establish chickpea by VMP. If soils are dry, a light irrigation is recommended immediately after seed sowing. Vertical disk seed meter delivering 40 kg of seed ha^{-1} is recommended for chickpea planting by VMP. Before sowing, the priming of chickpea seed with sodium molybdate and Rhizobium at 1.5 g kg^{-1} and 10-40 g kg^{-1}, respectively, is beneficial for better crop stand on dry acid soils. At planting, triple super phosphate fertilizer (20 % P, 1.3 % S, and 20 % Ca) use is suggested for chickpea at the rate of 100 kg ha^{-1} while planting by VMP. The row distance between two lines of chickpea depends of chickpea varieties, but could be between 30-40 cm. If the fields have optimum soil moisture, the suitable depth of seed placement should be 2-5 cm.

Figure 17: VMP planted Chickpea field (later stage).

STRIP SEEDED JUTE IN RICE-BASED CROPPING SYSTEMS

The VMP was used for jute sowing by strip seeding as well as zero tillage, and bed planting. Due to very small seed size, the seed was mixed with rice husk (1:2 volumetric ratio) and delivered through the fluted roller-type seed meter. Jute seeds were sown at the depth of 2-3 cm in zero tillage, 5-7 cm in strip planting, 8-10 cm in bed planting and 5-7 cm in convention tillage.

PRE-PLANT WEED ASSESSMENT

For strip planting of jute, Roundup was sprayed on the field 2 days before sowing to suppress weeds.

In the 1st year of jute cultivation, the highest weed stubble was in bed planting, followed by zero tillage and strip planting while the lowest weed stubble was found in conventional tillage. In subsequent years, zero tillage and bed planting produced higher weed stubble than strip planting while the lowest stubble was in conventional tillage.

The retention of lentil stubble as a mulch produced fewer weeds than complete removal of lentil straw from jute field.

SOIL WATER

Soil water content (SWC) was consistently lower in bed planting by VMP than zero tillage or conventional tillage. Strip planting tends to maintain the highest soil water content in 0-15 cm depth.

Averaged over 3 years, highest jute fibre yields were obtained on a light textured soil at Rajbari, Bangladesh with strip planting and zero tillage, followed by conventional tillage and bed planting (Figure 18).

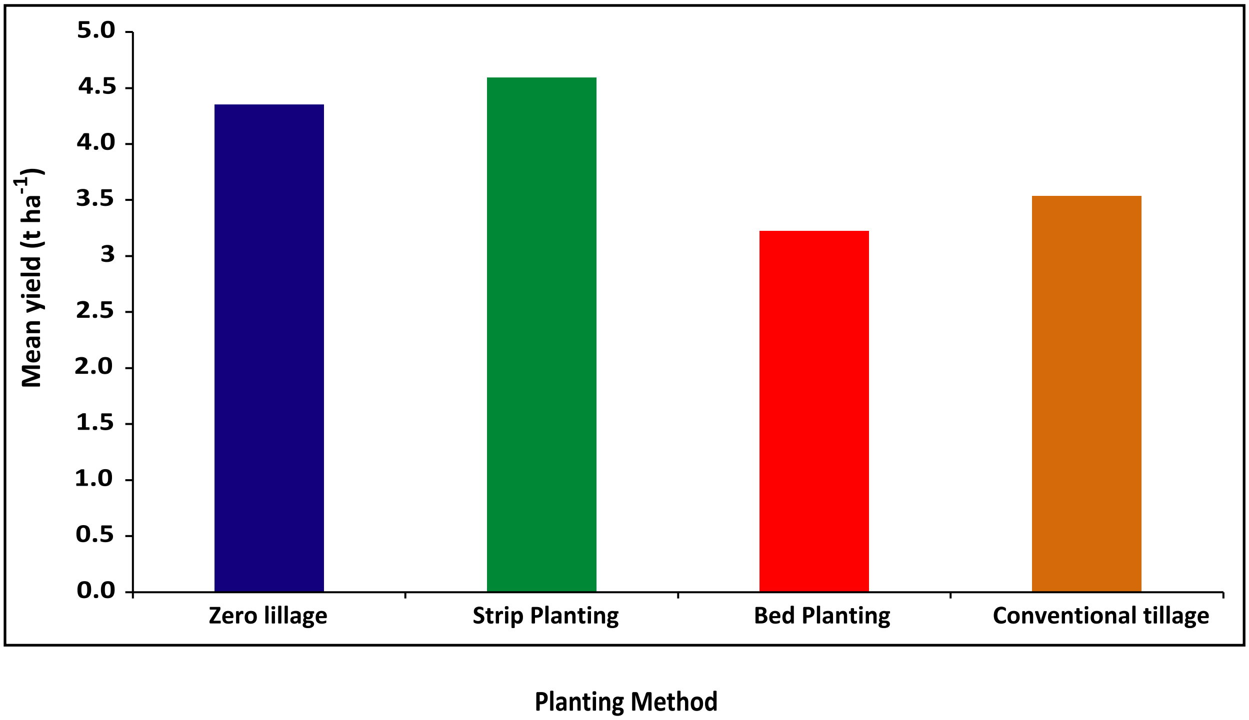

Figure 18: Mean jute fiber yield (t ha^{-1}) over three consecutive years at Rajbari, Bangladesh with zero tillage, strip planting, bed planting and conventional tillage (Salahin 2017).

NON-PUDDLED TRANSPLANTING OF RICE SEEDLING IN RICE-BASED CROPPING SYSTEMS

Shortage and increased cost of labour are forcing farmers to look for alternatives to traditional puddling of soil and manual transplanting of rice. Non-puddled strip tillage saved 50-70 % time and 46 to 60 % fuel consumption for crop establishment relative to the puddled conventional tillage. In addition, non-puddled strip tillage reduced fuel consumption for mechanical transplanting by 10-18 %. Non-puddled strip tillage and zero tillage reduced the irrigation water required for transplanting by 14-22 and 22-28 %, respectively. Overall, for non-puddled strip tillage and zero tillage the transplanter had significantly higher rate of area coverage than puddled conventional tillage and bed transplanting. Non-puddled strip planting of rice gave significantly higher grain yield followed by zero tillage and puddled conventional tillage. Highest benefit-cost ratio (BCR) was attained in strip tillage rice followed by zero tillage then puddled conventional tillage.

FLOODING DURATION

Mechanizing the transplanting of wetland rice can decrease costs and use of labour while transplanting into non-puddled soils should decrease irrigation water requirements for land preparation. The performance of a 4-row walking type mechanical rice transplanter for wetland rice establishment on clay loam, loam and sandy loam soil during the Boro and Aman seasons were evaluated from 2012 to 2015. Compared to conventional transplanting, the transplanter showed better performance and gave higher yield in strip planting as well as zero tillage under 18- 24 hrs inundation of soil irrespective of soil type prior to transplanting.

SEEDLING TRAY PREPARATION

In manual transplanting, 30-40 days old root-washed seedlings are used whereas mat type seedlings are used in mechanical transplanting. Mat type seedlings are raised either on a plastic tray (280 × 580 × 25 mm) or on a polythene sheet divided by frames. The mat type seedlings are raised with 20-25 mm thick, well-sieved soil mixed with farm yard manure or organic manure placed in trays or over polythene sheets. The mat thickness for best results of seedling raising is about 20 mm. The success of rice transplanter depends on the quality of seedling. Growth media in the tray has a great influence on seedling quality, root-shoot ratio, seedling strength and rolling capacity of the seedling mat and hence on plant establishment. Both seedling mat movement in the holding tray of the transplanter during field operation and seedling quality affect the percentage of missing hills and seedling mortality after transplanting. Hossen et al. (2014) found that 140 g of seed/tray for bold grain, 130 g per tray for medium and slender grain and 120 g per tray for extra-long and slender paddy were suitable for minimum percentage of missing hills and optimum number of seedling per hills under different seedling adjustment options for the present transplanter. However, the evaluation was only completed for one soil type and may need validation under a greater diversity of field conditions.

MECHANICAL TRANSPLANTING OF RICE SEEDLINGS

Manual transplanting is tedious and time consuming which often causes delayed establishment. The rice yield loss due to delayed planting was 60, 55 and 9 kg ha^{-1} day^{-1} in the Boro, Aman and early wet (Aus) seasons, respectively, in Bangladesh. Mechanized rice transplanting is seen as a solution of labour shortage. Likewise, using mechanized rice transplanting ensures uniform plant spacing as well as fast and efficient planting. The mechanical transplanting reduces cost, saves labour, ensures timely transplanting and attains optimum plant density that contributes to high productivity. Both root-washed and soil-attached seedlings are used for mechanical transplanting. The attached soil with seedlings helps to maintain uniform, erect seedlings, reduce transplanting shock and prevents floating, all crucial prerequisites for mechanical transplanting. The smooth operation of the rotary picker and successful isolation of seedling hills from the mat is largely determined by whether the seedling roots were properly bound to soil and evenly distributed.

TWO-WHEEL DRIVE SELF-PROPELLED RICE TRANSPLANTER

It is known as the walking-type rice transplanter. Mat type nursery seedlings are used to transplant the seedling uniformly without damage. The planting depth and hill-to-hill spacing can be adjusted with the help of adjustment lever. Automatic depth control helps in maintaining uniform planting depth. The machine has a safety clutch mechanism to save the planting device from the impact of stones in the field.

There are three options (shallow, medium and deep) in the rice transplanter (DP 480) to adjust the hill spacing (plant-to-plant spacing). The transplanter was set to maintain 150 mm distance between each hill spacing in the row. Spacing between rows (line to line spacing) is fixed to 300 mm for the rice transplanter.

In the puddled field, the transplanting depth control lever was adjusted to the shallow mode whereas it was adjusted to the deeper mode in the non-puddled field to maintain 20-30 mm depth of seedling placement. Number of plants hill^{-1} was adjusted based on seedling density. There have nine options to select number of plants hill^{-1}. The picker was set at point 5 to maintain similar numbers of seedlings hill^{-1} in all tillage types.

SELF-PROPELLED RICE TRANSPLANTER

The weight of the self-propelled rice transplanter is supported by the drive wheels on the hard pan. Weight of the planting portion is supported by the float that slides on the surface of the paddy field. Depth of transplanting is controlled at the base of the float. It has an automatic control device for the float which slides on the surface of the field. Row to row distance is fixed to 300 mm. The hill spacing can be adjusted from 100 mm to 170 mm. Planting depth is also adjustable in the range of 0~50 mm according to the changing distance between the float and the transplanting portion.

SINGLE-WHEEL DRIVE SELF-PROPELLED RICE TRANSPLANTER

Diesel engine is used as power source in the single wheel drive self-propelled rice transplanter. This is a 6-8 row riding type transplanter and transplants seedlings from mat type nursery. The drive wheel receives power from the engine through V-belt, cone clutch and gearbox. A propeller shaft from the gear box provides power to the transplanting mechanism mounted over the float. The tray containing mat type seedling is moved sideways by a scroll shaft mechanism, which converts rotary motion received from the engine through belt-pulley, gear and universal joint shaft into linear motion of a rod connected to the seedling tray having provision to reverse the direction of movement of tray after it reaches the extreme position at one end.

FOUR-WHEEL DRIVE SELF-PROPELLED RICE TRANSPLANTER

Petrol engine is used as power source in the four-wheel drive self-propelled rice transplanter. This is a six-row riding type rice transplanter using mat type seedlings and employs a double acting transplanting mechanism for enhanced transplanting speed and rate of area coverage. The double acting transplanting mechanism is run with one and four planetary gears. The machine has provision for adjustments of number of seedlings hill^{-1}, depth of transplanting and hill-to-hill distance. The depth of transplanting is maintained constant, automatically during transplanting. The row-to-row spacing is 300 mm and five settings of hill-to-hill distance from 120 to 220 mm can be fixed depending on desired plant population. Depth of transplanting can be adjusted from 10 to 45 mm with five stages. Horizontal balance of the transplanter is automatically controlled by an electronic solenoid valve. Steering method is synchronized steering wheel.

STRIP PLANTED DIRECT SEEDED RICE

Dry direct seeding of rice is becoming an attractive option for rice culture as it saves irrigation water, reduces the labour requirement and gives the expected yield compared to the transplanted Boro rice. In Bangladesh, Boro (winter) rice is mainly cultivated by transplanting of seedlings on puddled soil with flood irrigation which requires about 1400 mm water while use of alternate wetting and drying (AWD) technology can reduce the water requirement by 20-25 %. On the other hand, direct seeding of rice on dry land at field capacity reduces the irrigation water requirement by 50-60 % without any yield penalty. The dry direct seeded crop also reduces greenhouse gas emission to a great extent. The reduction in withdrawal of ground water in dry direct seeded rice may reduce the arsenic and heavy metal contamination in soil and crops, especially in case of contaminated groundwater areas. Dry seeding can be done using VMP according to CA principles. The dry direct seeding can also be practiced in Aman and Aus seasons to achieve similar benefits, if high soil moisture does not create any barrier during sowing to early tillering stages for rice. However, water scarcity for rice production in Boro season is a matter of great concern in Bangladesh. Thus, agronomic practice for dry direct seeded Boro rice has been described here.

LAND AND SOIL TYPE

Dry direct seeded rice (DSR) in Boro season can be grown on the same soil types as puddled transplanted rice. DSR can be cultivated in high to medium low lands, where there is no possibility of standing water during the period from sowing to early tillering stage or where the wet soil condition does not prevent the sowing operation. In principle, DSR should not be practiced in 'Haor areas' as there is possibility of flash flood during ripening stage that may damage the crop.

SOWING TIME

Optimum time of sowing for Boro rice is late January to mid-February. The late sowing helps avoiding seedling mortality due to cold injury. Sowing during this period would help in adequate stand establishment.

LAND PREPARATION

Conventional land preparation is by 3 to 4 ploughings followed by laddering. Instead, sowing in CA is done directly by VMP with one pass strip planting. If the plot has dense weeds, a pre-planting knockdown herbicide (e.g., Roundup) is highly recommended in the case of strip planting or zero tillage system.

VARIETY SELECTION

All rice varieties recommended for puddled transplanted in Boro season are also suitable for cultivation in DSR. The varieties such as BRRI dhan28, BRRI dhan58, Binadhan-14, BRRI hybrid dhan3, Hira hybrid dhan2 etc. can be used for dry seeding in late Boro season but not BRRI dhan29 as this variety is subjected to high spikelet sterility due to high temperature stress at flowering stage.

SEED PRIMING

Seed should be primed by soaking in clean water for 24 hours and then incubated for 24 hours. After incubation seeds should be surface dried in shade to make them ready for sowing.

SOWING METHOD

Traditionally primed rice seed is sown on dry cultivated land at 'joe condition' (moist soil) by hand at 25 cm x 15 cm spacing in 2-5 cm depth allocating 4-5 seeds/hill. In CA DSR sowing is done by VMP at 20 cm row spacing with continuous seed dropping at 16-18 kg seed ha^{-1}. Generally, sowing is done utilizing residual soil moisture, however, if the field capacity does not prevail at sowing a light irrigation should be given shortly after sowing to facilitate uniform seed germination.

FERTILIZER MANAGEMENT

The rate of fertilizer application depends on many factors including variety, soil type, stubble level, fertility of soil, fertilizer management in previous crops, the crop rotation and yield goal. In general, the recommended rate of fertilizer for a rice variety is similar both for traditional puddled transplanted rice and dry DSR rice. All fertilizers except urea need to be applied at the time of final land preparation. It would be better to apply cowdung or compost or farm yard manure @ 5 t ha^{-1} prior to sowing/final land preparation. Urea should be applied in three equal splits such as at 25, 40 and 55 days after sowing (DAS). Triple super phosphate could be applied during seed sowing using the VMP. It is preferable to apply urea after irrigation or rain.

WATER MANAGEMENT

Water management in DSR Boro should aim to reduce the amount of irrigation while maintaining the maximum yield level because of high water scarcity and high cost of pumping irrigation water. No standing water is required up to panicle initiation (PI) stage of the crop while standing water (2-5 cm) is maintained from PI stage to heading or early grain filling stage.

Depending on soil and geographic location, DSR requires 4-15 irrigations. However, the irrigation requirement depends on the soil type and weather of the locality. The lighter soil requires more frequent irrigation than the heavy soil. However, addition of organic matter through application of manure, compost, or crop stubble retention will improve soil water holding capacity and can reduce the irrigation frequency over time. Good establishment of seedings requires assured moisture supply during the first 2 weeks. Thus, light irrigation during this period may be needed but ponding of water for more than a few hours is undesirable. In this case drain off excess water from the field. Irrigation should be applied when the top soil become dry and leaves show signs of rolling (no longer flat) in the early morning. For clay soils, the appearance of hairline cracks on the soil surface is a general indication of the need to irrigate.

WEED MANAGEMENT

Weed control is the major constraint to the adoption of DSR. The aerobic soil condition in DSR field favours abundant germination and growth of weeds while prolonged flooding period after transplanting retards the weed growth in puddled transplanted field. Different weed species belonging to grass, sedge and broadleaf categories grow in the DSR field which can be controlled successfully by 3-4 hand weeding. 'Seni weeder' can be used to control in-row weeds. Now-a-days, labour scarcity is increasing and the wage rate also has been increased manifolds. Under this condition, herbicide use is the best option to control weeds at minimum cost and minimizing soil disturbance.

Herbicide use for weed control in conventional puddled rice fields is now quite common in Bangladesh (Haque et al., 2017c). The same herbicide molecules can be used for DSR fields for successful weed control. Several strategies may be adopted for efficient weed control in DSR. Application of pre-emergence herbicides such as pendimethalin or pretilachlor or Oxadiargyl at 2-3 days after sowing (DAS) and then one hand weeding at 21-25 DAS followed by application of any of the pre-emergence herbicides immediately after hand weeding would give very effective weed control.

Sequential application of pre-emergence, early post emergence and post emergence herbicides would eliminate the need of hand weeding. Pre-emergence herbicides such as pendimethalin or pretilachlor or Oxadiargyl applied at 2-3 DAS, then early post-emergence herbicides such as Bispyribac sodium, orthosulfamuron, pyrazosulfuron ethyl to be applied at 10-18 DAS and then post emergence herbicides such as 2,4-D or MCPA can be applied at 30-35 DAS. In case of machine seeding with single pass strip planting, a knockdown application of glyphosate @ 1 kg a.i. ha^{-1} is required to kill the standing weeds. Glyphosate provides good control to most of the grass, sedge and broadleaved weeds but weak control to Ipomoea triloba and Commelina species. In addition, retention of crop stubbles on the soil surface will also help to suppress weeds.

CROP PROTECTION MEASURES

Disease infection and insect infestation in DSR are lower than those in conventional puddled transplanted rice. Whenever, pest problems occur, integrated pest management and integrated crop management approaches should be adopted to tackle the problem.

HARVESTING

Crop duration (seed to seed) is lower in DSR by 10-15 days than puddled transplanted rice. The yield of rice in DSR is similar to or higher than the crop grown under puddled transplanted system. The higher yield is attributed to vigour root growth and higher tiller production capacity than the conventional puddled transplanted crop. In CA systems combine harvesting is the preferred harvest technique to retain the straw in the field without additional labour requirements.

LONG-TERM TRENDS AFTER ADOPTING CONSERVATION AGRICULTURE

Transforming from conventional tillage-system to CA system is a process and it can take up to 5 years to establish a new CA systems while benefits and improvements begin to accrue. Beyond that the process of improvement in soil and crop health and productivity continues until a new equilibrium is established in another five to 10 years. During this period, soil and landscape functions, factor productivities (efficiencies) and output and its stability improves while multi-year profitability improves at the system level.

Figure 19: Map of Bangladesh showing long-term Conservation Agriculture Experiment sites.

Long-term experiments on CA have been conducted in (i) Alipur (E1), Durgapur, Rajshahi (since 2010-11); (ii) Digram (E2), Godagari, Rajshahi (since 2010-11); and at BAU Farm (E3), Bangladesh Agricultural University, Mymensingh (since 2012-13) (Figure 19). These experiments provide insights into the long-term trends with practicing CA in intensive, rice-based cropping system in Bangladesh. The Rajshahi experiments were set up in farmer's fields with the involvement of farming communities. Three planting practices: strip planting (SP) including non-puddled transplanted [NPT] rice), bed planting (BP) and conventional tillage (CT) at Alipur and Digram; and either SP or CT at BAU Farm were used to establish the crops. All experiments had current (low) and increased stubble retention levels. The cropping systems were lentil/mustard-mungbean/jute/Boro rice Aman rice (for Alipur); wheat/chickpea-mungbean/Aus rice/jute-Aman rice (Digram; and wheat-mungbean-Aman rice (BAU Farm) in these experiments.

The VMP was used for sowing all upland crops (lentil, mustard, chickpea, Aus rice) in single pass operation for SP and BP. However, 3-4 tillage operations by 2WT followed by hand-broadcast seeding and fertilizing were done for CT. In case of irrigated and rainfed rice, NPT were practiced in SP and BP; and for CT conventional puddling was followed.

LONG-TERM TRENDS FOR CROP YIELD AND PROFIT MARGIN

In the first two years, the rainfed monsoon rice yield using NPT was the same as conventional tillage (and puddling) and bed planting (Figure 20, 21, 22).

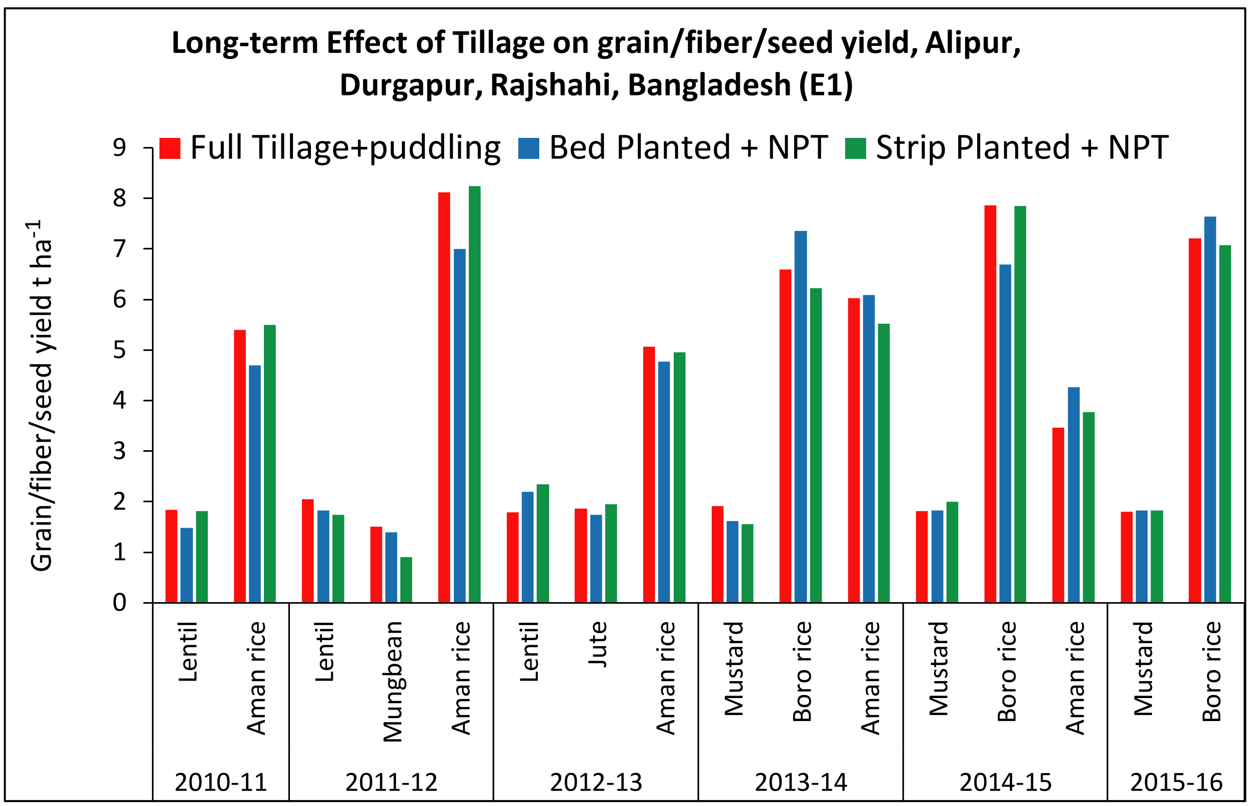

Figure 20: Long-term effect of CA on grain/fiber/seed yield, Alipur, Durgapur, Rajshahi, Bangladesh, 2010/11 - 2015/16.

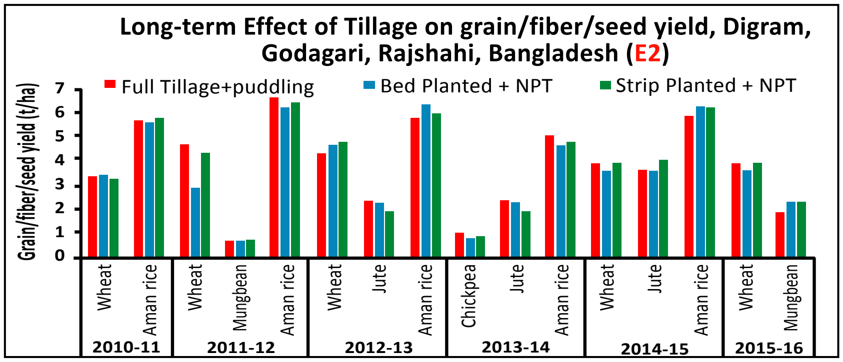

Figure 21: Long-term effect of CA on grain/fiber/seed yield, Digram, Godagari, Rajshahi, Bangladesh, 2010/11 - 2015/16.

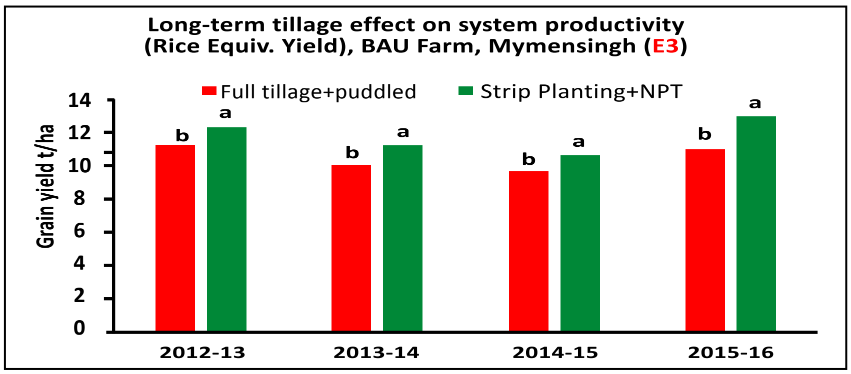

Figure 22: Long-term effect of CA on system productivity, Bangladesh Agricultural University, Mymensingh, Bangladesh, 2012/13 - 2015/16.

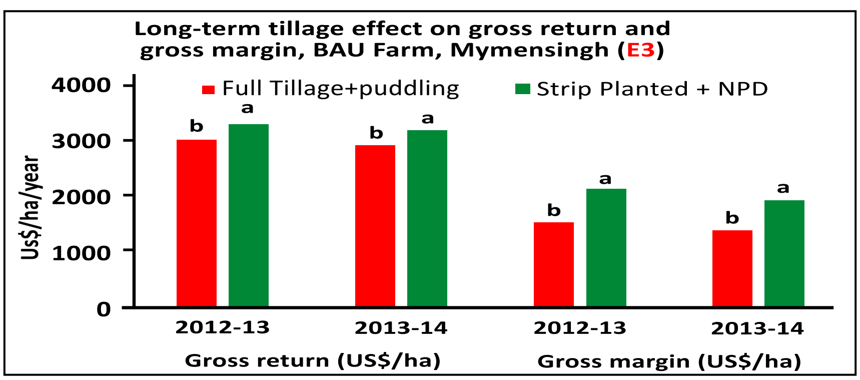

Figure 23: Long-term tillage effect on gross return and gross margin, BAU Farm Mymensingh, Bangladesh.

Thereafter, significantly higher grain yield of rainfed rice in NPT was recorded in SP (Figure 20-23). However, since beginning, the SP plots showed higher grain yield with greater profit margin of irrigated NPT. In comparison with CT, considerably higher soil organic carbon was observed in SP at 0-10 cm soil depth after 3-4 years of cropping. Practicing SP for upland crops and NPT for rice crop accumulated 4.24 and 3.79 t CO_2eq ha^{-1} in Alipur and Digram experiments, respectively, after 4-5 years. The SP reduced greenhouse gas emission relative to CT by about 30 %. The long-term experiments demonstrated substantial benefits from the adoption of CA in the intensive rice-based cropping systems.

LONG-TERM EFFECTS OF MINIMUM SOIL DISTURBANCE AND STUBBLE RETENTION ON SOIL ORGANIC CARBON

The long-term effects of minimum soil disturbance and stubble retention on soil organic carbon (SOC) were assessed at the long-term CA experiment at BAU Farm, Mymensingh. The effect of CT and SP along with stubble management and N fertilization on SOC concentration of the surface and sub-surface soil was assessed just after the harvest of the 8th crop (i.e., wheat). A significant (P<0.01)

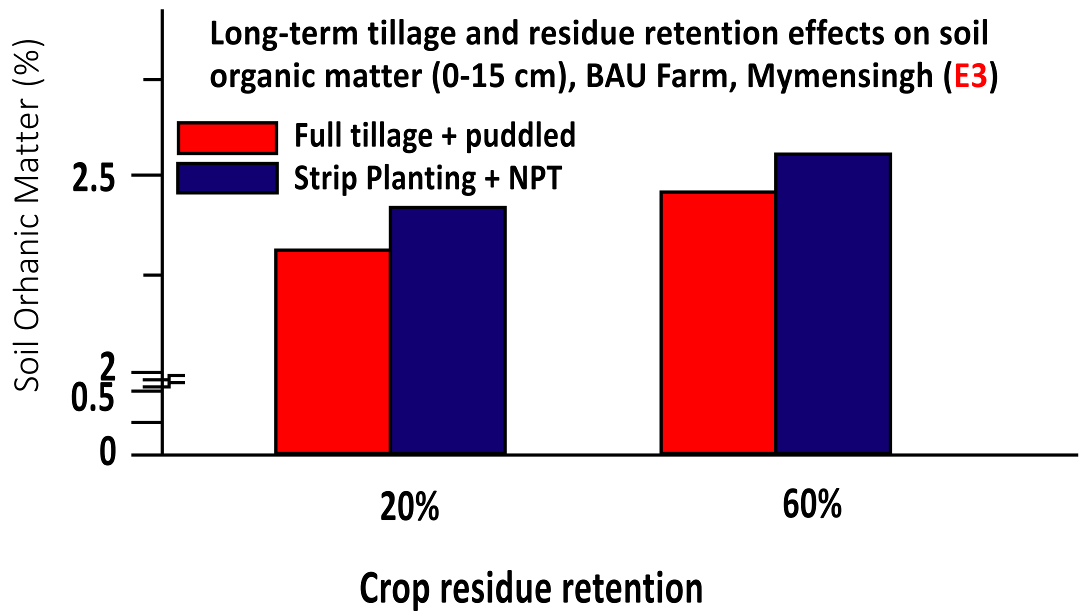

Figure 24: Effect of minimum soil disturbance (strip planting and non-puddled transplanting (NPT) and increased stubble retention on soil organic matter after CA practice for 8 consecutive crops, BAU Farm, Mymensingh, Bangladesh.

increase in SOC concentration was observed in the 0-5 cm soil layer between CT (1.58 %) and SP (1.83 %) when SOC was averaged over the stubble management and N fertilizer treatments (Figure 24). The SOC concentration of the surface soil layer was not significantly influenced by level of stubble retention and N fertilizer treatments or their interactions with crop establishment systems. Similarly, sub-surface SOC content was not significantly influenced by any of the treatments (crop establishment, level of stubble retention and N fertilizer) and their interactions. Over time there was a stratification of SOC towards the surface layer of SP plots and with high stubble retention relative to the CT and with low stubble retention plots. Soil organic carbon stock (t ha^{-1}) showed the similar trend to SOC concentration, however, the differences were not significant between any of the treatments (crop establishment, level of stubble retention and N fertilizer) and their interactions.

In field experiments that lasted for 5 years involving 13 or 15 consecutive crops, CA (strip planting or NPT for rice plus increased stubble retention) boosted SOC in the 0-10 cm soil layer by 60-63 % (Alam et al. 2018). There was a similar increase in total nitrogen concentration in the 0-10 cm layer. Minimum soil disturbance alone, without increased stubble retention, also boosted SOC by 38-40 %. Most of the increase in total soil N after 5 years could be attributed to the increased stubble retention in the CA practice (Table 9).

Table 9. Effect of minimum soil disturbance (strip planting and non-puddled transplanting) and increased stubble retention on soil organic carbon (SOC) stock and total nitrogen in the 0-10 cm layer after 5 years at Alipur and Digram (Alam et al. 2018).

Soil disturbance and stubble retention	Alipur		Digram	
	Soil organic C stock ($t\ ha^{-1}$)	Total N ($g\ kg^{-1}$)	Soil organic C stock ($t\ ha^{-1}$)	Total N ($g\ kg^{-1}$)
Minimum soil disturbance + increased stubble	10.8	0.86	10.2	0.76
Minimum soil disturbance only	9.1	0.64	9.0	0.59
Conventional	6.6	0.53	6.4	0.49
SD ($P < 0.05$)	0.84	0.06	0.53	0.06

DISEASE INFECTION

While on-going monitoring of disease incidence in SP plots particularly with high stubble management is important, the levels of infection were not high in the BAU Farm, Mymensingh experimental sites. Disease infection of rice leaves occurred at the maximum tillering stage only in the third rice crop. Sheath blight infection (Rhizoctonia solani) was marginally higher in SP compared to CT whereas it was opposite for bacterial leaf blight (Xanthomonas oryzae). Both the disease infections were higher in high stubble retention treatment but the differences were not substantial. Generally, the severity of both diseases responded more to the N rates. There was no interaction effect of N rates with crop establishment systems or stubble levels for either disease.

SUCCESS STORIES

FARMERS LEVEL IMPACT ON CA ADOPTION

The impact of cost saving CA crop production technologies on farmers' profit has been studied by Miah et al. (2017). The study was conducted at three Upazillas of Rajshahi and Thakurgaon districts of Bangladesh to assess the adoption status and impacts of CA technologies at farm level during January-February, 2017. A total of 135 CA practitioners' farmers were randomly selected and studied.

The impact study confirmed that the adoption of CA has started. The rates of adoption of CA practices decreased in the order: crop stubble retention (67 %), crop rotations (39 %), and the minimum soil disturbing (strip seeding) (19 %) in these areas. This study also, confirmed that the age, innovativeness, and extension contact with the farmers and availability of VMP had significant positive influence on the adoption of CA technologies. On farms the CA technology saved up to 34 % of labour cost, 31 % of seed, 6 % of fertilizers, 32 % of pesticides and up to 10 % of total cost of production for cultivating lentil, mustard, maize, and wheat (Miah et al., 2017) (Figure 25). Adopting farmers increased crop yield and net profit by up to 28 % and 460 %, respectively (Miah et al., 2017).

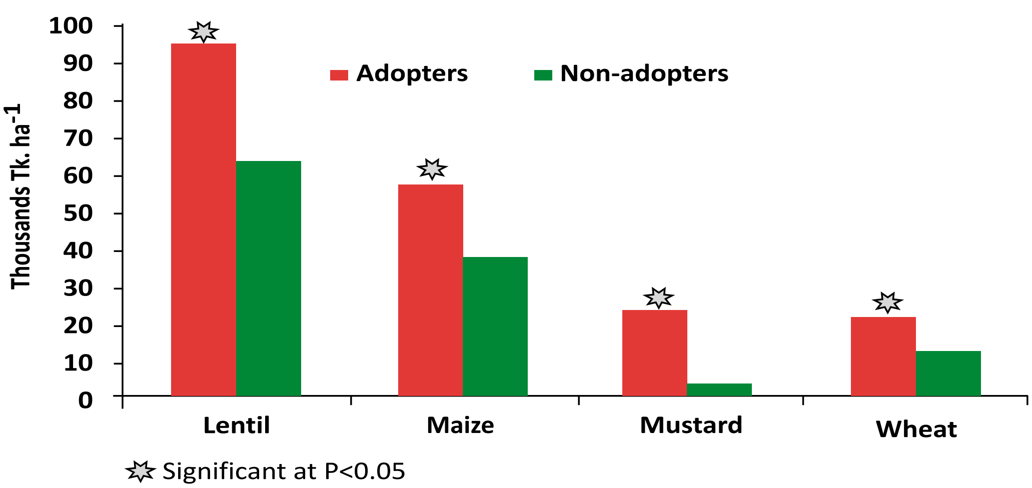

Figure 25: Financial benefit of CA adoption by farmers for different crop cultivation in Bangladesh.

LOCAL SERVICE PROVIDER OF VMP

Figure 26: Rashed Rana operating his VMP.

The nation-wide spread of 2WT and the development of the VMP, which is able to sow many crops, has provided a platform for implementing CA that decreases crop production costs and improves the fertility of soils, while maintaining or improving yield. Mr Rashed Rana saw the VMP in operation and he decided to buy one for his 22-year old business, which provides tillage services with a 2WT at Kathalbaria village under Durgapur upazila in Rajshahi district (Figure 26).

He attended a meeting organized by the ACIAR project to learn more about the VMP. With his own savings, money borrowed from relatives, and a loan from an NGO (BRAC) he accumulated Tk. 30,000 and purchased a VMP from Hoque Corporation with 50 % price support from the project. After receiving three days training on VMP operation, repair, maintenance; and safe use of herbicides, he gathered the farmers of his own village together and explained the benefit of VMP planting and of CA.

Mr. Rana started his VMP planting service business in mid-November 2015 and served about 160 farmers (41 ha) planting wheat, maize, mungbean, mustard, and preparing a field for non-puddled rice transplanting. Within a single season, he turned a net profit of Tk. 60,000 (A$1091), paid back the loan, constructed a shed for his two-wheel tractor and VMP, and bought a milking cow.

The VMP planting and CA technologies adopted by the farmers of his village produced higher crop yields and profit compared with their traditional system. And the demand for VMP is increasing. Mr. Rana's success has motivated another farmer in his village to buy a VMP next year.

COMMERCIALIZATION APPROACHES FOR VMP

Since 2015, the Project Implementation Office (PIO) of Murdoch University has been partnering with Hoque Corporation (HC), Dhaka to develop and test commercialization strategies for the sale of VMP (Figure 27). The partnership fostered demand creation among farmers/ LSPs through demonstrations, focus group discussions; quality assurance checking; service after sales; price support for LSP (50 and 25 % of purchase price in 2015 and 2016, respectively); inclusion of financing institutions (e.g., National Bank Ltd.); establishment and involvement of the Conservation Agriculture Service Providers Association; inclusion of government extension agencies (e.g., Department of Agricultural Extension [DAE] and the Barind Multipurpose Development Authority [BMDA]). This has led to two models for VMP commercialization that are showing promising signs of success as follows:

LSP LEVEL DEMAND CREATION MODELS

Model 1: 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 and 2016, both PIO and HC identified interested new 2WT service provider groups in nine districts (including six CA working hubs), because - i) most of the service providers already have a 2WT which is essential to operate planters/implements and they had the financial means to buy a 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 ideas and 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) service providers have established linkages with extension agencies, local administration and farmers of their community.

The live demonstration/hands-on training on VMP operation and on-farm demonstration of crop performances to LSP for establishing wheat, onion, garlic, lentil, chickpea, mungbean, jute, etc. were organized at Union level by PIO and HC to create demand for VMP service. The interested LSPs were asked to register with a deposit of Tk. 10,000 as a down-payment by mid-October.

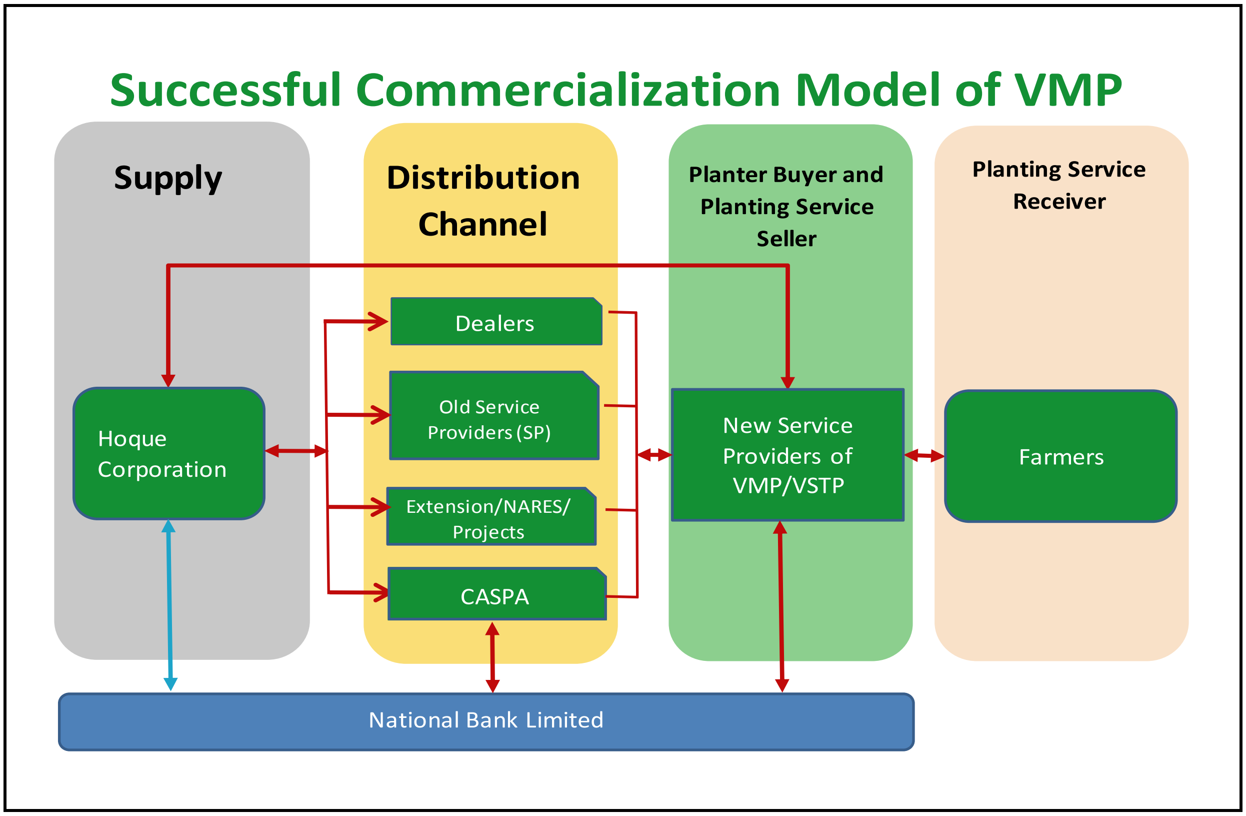

Figure 27: VMP Commercialization Model.

The PIO and HC and 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 takeover 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. 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 partnership activities created confidence by farmers, LSP, and involved stakeholders (e.g., DAE, BMDA, National Bank Ltd.) in VMP adoption and commercialization.

Model 2: As the use of VMP could save up to 34 % of irrigation water (Hossain et al., 2010) and reduce the cost of crop cultivation, the BMDA sought assistance from PIO and HC to promote VMP in Naogaon district in 2016. In collaboration with BMDA and National Bank Ltd., the PIO and HC identified 62 new LSP in Naogaon district, 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 to HC to confirm registration. The project organized the VMP training program as in Model 1. The BMDA engaged Chittagong Builders to deliver 62 units of 2WT in Naogaon. 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.

LEARNING FROM COMMERCIALIZATION APPROCHES

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 with receiving proper services from private companies after purchasing implements. Involvement of universities (e.g., Bangladesh Agricultural University, Murdoch University), research institutions (e.g., Bangladesh Agricultural Research Institute and Bangladesh Rice Research Institute), extension agencies (e.g., Department of Agricultural Extension 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' and service providers' demand, 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 been developed and supplied with the VMP to regulate the seed rate without further calibration. Also, further improvement was done 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, despite their differences. Continuation of these two models of expansion of VMP use for another two to three years is likely to lead to commercialization by the private sector.

REFERENCES

Alam, M.K., Bell, R.W., Haque, M.E., and Kader, M.A. (2018). Minimum soil disturbance and increased residue retention increase soil carbon in rice-based cropping systems on the Eastern Gangetic Plain. Soil & Tillage Research 183: 28-41.

Bell, R.W., Haque, M.E., Johansen, C., Vance, W., Kabir, M.E., Musa, M.A., Mia, M.N.N., Neogi, M.G., and Islam, M.A. (2017). Mechanized minimum soil disturbance establishment and yield of diverse crops in paddy fields using a two-wheel tractor-mounted planter suitable for smallholder cropping. Paper accepted for publication in Experimental Agriculture. (published on-line 17 Nov 2017).

Buhler, D.D. (1995). Influence of tillage systems on weed population dynamics and management in corn and soybean in the central USA. Crop Science, 35: 1247-1258.

Chauhan B.S., Gill G.S. and Preston C. (2006). Seedling recruitment pattern and depth of recruitment of 10 weed species in minimum tillage and no-till seeding systems. Weed Science 54: 658-668.

FAO (2014). What is Conservation Agriculture? FAO CA website (http://www.fao.org/ag/ca/1a.html).

Farooq, M. and Siddique, K.H.M. (eds) (2014). Conservation Agriculture. Springer International, Switzerland.

Friedrich, T. and Kassam, A. H., (2009), Adoption of Conservation Agriculture Technologies: Constraints and Opportunities. Proceedings of the 4th World Congress on Conservation Agriculture. 4-7 February 2009, New Delhi, India.

Giller, K.E., Witter, E., Corbeels, M. and Tittonell, P. (2009). Review. Conservation agriculture and smallholder farming in Africa: The heretics' view. Field Crops Research 114: 23-34.

Haque, M.E. and Bell, R.W. (2017c). Longer-term impact of conservation agriculture and herbicide in rice-based systems. Proceedings of the 7th World Congress of Conservation Agriculture, 1-4 August 2017, Rosario, Argentina. M. Bartz, Rafael Fuentes Llanillo and R. Ralisch (Eds). P. 167.

Haque, M.E., Bell, R.W., Kassam, A. (2016a). Versatile strip seed drill: A 2-wheel tractor-based option for smallholders to implement conservation agriculture in Asia and Africa. Environments 3, 1 doi:10.3390/environments3010001.

Haque, M.E., Bell, R.W., Islam, M.A. and Rahman, M.A. (2016b). Minimum tillage unpuddled transplanting: An alternative crop establishment strategy for rice in conservation agriculture cropping systems. Field Crops Research 185: 31-39. http://dx.doi.org/10.1016/j.fcr.2015.10.018.

Haque, M.E., Bell, R.W., Islam, A.K.M., Sayre, K.D. and Hossain, M.M. (2017a). An innovative Versatile Multi-crop Planter for Crop Establishment Using Two-wheel Tractors. Paper accepted for publication in Journal of Agricultural Machinery in Asia, Africa and Latin America. 48: 33-37+44.

Haque, M. E. Bell, R. W., Menon, R. K. Menon, Hossain M. M. (2017b). Comparative levels of soil disturbance under reduced and minimum tillage types with two-wheel tractor planting operations. 2nd Conference on Conservation Agriculture for Smallholders (CASH-II), Bangladesh Agricultural University, Mymensingh, Bangladesh, 14-16 February, 2017. Eds. ME Haque, RW Bell, WH Vance. pp 62-63.

Haque, M.E., Nabila, S.R. and Bell, R. W. (2013). Smallholders Minimum Tillage Planter Adoption in Bangladesh: A successful case of private sector involvement for technology commercialization. In Water, Environment and Agriculture: Challenges for Sustainable Development. Proceedings. Eds. N. Lamaddalena, M. Todorovic and L. S. Pereira. CIHEAM-Institute of Agronomy Mediterranean Bari, Valenzano. pp. 68-69.

Hartzler R.G. and Owen M.D. (1997). Weed management in conservation tillage system. Iowa State University, Ames. Available online: www.extension.edu/Publications /PM1176.pdf.

Heap, I. (2018) The International Survey of Herbicide Resistant weeds. Online. Internet. Tuesday, January 16, 2018. Available www.weedscience.org.

Hossain, M. I., Esdaile, R. J., Bell, R. W., Haque, M. E., Johansen, C. (2009). Development of a low cost two wheel tractor operated no-till seeder for better establishment of upland crop. Eco-friendly Agril. J. 2(11): 915-919.

Hossain, M.I., Islam, M.S., Hossain, I., Meisner, C.A., Rahman, M.S. (2010). Seeding performance of two-wheel tractor operated bed planter for cereal crop establishment. International Journal of Energy Machinery 3: 63-69.

Hossein, M.A. (2017). Development of rice transplanter for unpuddled condition. A PhD Thesis Department of Farm Power and Engineering. Bangladesh Agricultural University, Mymensingh.

Hossain, MA, Hossain MM, Haque, Bell RW and Rahman MA (2014). Optimization of seedling density as influenced by seed rate for mechanical transplanting. Paper published in the conference proceedings. Regional conference on conservation agriculture for smallholders in Asia and Africa. 7-11 December 2014, Mymensingh, Bangladesh. Pp. 48-49.

Islam, M.A. (2017). Conservation Agriculture: Its E?ects on Crop and Soil in Rice-Based Cropping Systems in Bangladesh, PhD Thesis. School of Veterinary and Life Sciences, Murdoch University, Australia.

Justice, S. E., Haque M. E., Meisner, C. A., Hossain, M. I., Sah, G., Tripathi, J., Rashid, M. H. (2004). Giving South Asia Farmers a Choice: A Single Drill for Reduced and Strip Till Crops for 2-Wheel Tractors. Proc. Int. Conf. 2004 CIGR International Conference. Beijing, China Ed. Wang Zhicai and Gao Huanwen. China Agricultural Science and Technology Press, 230- 237 pp.

Jat, R.A., Sahrawat, K.L. and Kassam, A.H. (eds) (2014). Conservation Agriculture: Global Prospects and Challenges. CABI, Wallingford. 393 pp.

Karlen D.L., Mausbach M.J., Doran J.W., Cline R.G., Harris R.F. and Schuman G.E. (1997). Soil quality: a concept, definition, and framework for evaluation. Soil Science Society of America Journal 61: 4-10.

Kassam A., Friedrich T, Derpsch R, and Kienzle J. (2015). Overview of the Worldwide Spread of Conservation Agriculture. Field Actions Science Reports Volume 8.

Kassam A., Friedrich T, and Derpsch R. (2018) Global spread of Conservation Agriculture. International Journal of Environmental Studies (in press).

Kumar R., Gopal R., Jat M.L. and Gupta R.K. (2010). Conservation agriculture based strategies for sustainable weed management in maize (Zea mays). Training Manual, Maize for Freshers. Directorate of Maize Research, New Delhi, India.

Locke M.A. and Bryson C.T. (1997). Herbicide-soil interactions in reduced tillage and plant residue management systems. Weed Science 45: 307-320.

Locke M.A., Reddy K.N. and Zablotowicz R.M. (2002). Weed management in conservation crop production systems. Weed Biology & Management 2: 123-132.

Llewellyn, R.S., D'Emden, F.H. and Kuehne, G. (2012). Extensive use of no-tillage in grain growing regions of Australia. Field Crops Research 132: 204-212.

Mahmud M.N.H., R.W. Bell and W. Vance. (2017). Strip planting increases yield and water productivity of wheat (Triticum aestivum) in Northwest Bangladesh. In: Proceedings of International Conference on Agri Biotech and Environmental Engineering. 11-12 September 2017, San Antonio, Texas, USA. Pp-32.

Miah M.M.A., Rashid, M.A., Haque, M.E., Bell, R.W. (2017). Adoption Impacts of conservation agriculture technologies at farm level in Bangladesh. Agricultural Economics Division, Bangladesh Agricultural Research Institute and Murdoch University, Australia. Pp-47.

Rahman, M.L., Hossain, M. I., and Hossain, M. A. (2017). Present status and prospect of conservation agriculture based tillage technology for crop production in Bangladesh. In Proceedings of the 2nd Conference on Conservation Agriculture for Smallholders (CASH-II) 14-16 February 2017, Mymensingh, Bangladesh pp. 34-36.

Rochecouste, J-F. and Crabtree, W. (2014). Conservation agriculture in Australian dry-land cropping. In Conservation Agriculture. Global Prospects and Challenges Eds R. Jat and K. Sahrawat. CABI, Wallingford, UK PP 108-126.

Roy K. C., Haque, M. E., Justice, S. E., Hossain, M. I., Meisner C. A. (2009). Development of Tillage Machinery for Conservation Agriculture in Bangladesh. Agricultural Mechanization in Asia, Africa and Latin America 40: 58-64.

Roy K. C., Meisner, C. A., Haque, M. E. (2004). Status of Conservation Tillage for Small Farming of Bangladesh. Proc. Int. Conf. 2004 CIGR International Conference. Beijing, China Beijing, China Ed. Wang Zhicai and Gao Huanwen. China Agricultural Science and Technology Press, 426-432 pp.

Thomas, G.A., Titmarsh, G.W., Freebairn, D.M. and Radford B.J. (2007). No-tillage and conservation farming practices in grain growing areas of Queensland - a review of 40 years of development. Aust. J. Exp. Agric. 47: 887-898.

FURTHER READING

Baker, C.J., Saxton, K.E., Ritchie, W.R., Chamen, W.C.T., Reicosky, D.C., Ribeiro, M.F.S., Justice, S.E. and Hobbs, P.R. (2007). No- Tillage Seeding in Conservation Agriculture- 2nd Edn. CABI and FAO, Rome. 326 pp.

Haque, M.E., Bell, R.W. and Vance, W.H. (2017). Proceedings of the 2nd Conference on Conservation Agriculture for Smallholders in Asia and Africa. 14-16 February 2017, Mymensingh, Bangladesh. Published as an E-book. p 201. http://researchrepository.murdoch.edu.au/id/eprint/36818/

Johansen, C.J., Haque, M.E., Bell, R.W., Thierfelder, C. and Esdaile, R.J. (2012). Conservation agriculture for small holder rainfed farming: Opportunities and constraints of new mechanized seeding systems. Field Crops Research 132: 18-32. doi:10.1016/j.fcr.2011.11.026

Vance, W.H., Bell, R.W. and Haque, M.E. (2014). Proceedings of the Conference on Conservation Agriculture for Smallholders in Asia and Africa. 7-11 December 2014, Mymensingh, Bangladesh. Published as an E-book. p 213. http://researchrepository.murdoch.edu.au/26081/

APPENDICES

APPENDIX I

PERSONAL SAFETY

For the safety of the operator, personal protective equipment (PPE) must be used to prevent exposure of the person to pesticides. The following Table 10 shows the potential absorption of the pesticide parathion via different parts of the human body.

Table 10: List of different body region for potential absorption of pesticides.

Parathion (an inse cticide) absorption rates through the skin on various bodily regions.	
Body region	**Percent relative absorption**
Forearm	8.6
Palm of hands	11.8
Ball of foot	13.5
Abdomen	18.4
Scalp	32.1
Forehead	36.3
Ear canal	46.5
Genitalia	100

Pesticides can enter into human body via skin, absorption by eyes, inhalation and ingestion. PPE must be used to protect the operator (Figure 29) and includes:

1. ***Clothing:*** Use cotton overalls, either disposable or washable. Wash overalls after every use with soap.

2. *Gloves:* Do not use rubber gloves. Rubber materials can react with certain chemicals and poison can be absorbed into human body. Use gloves up to elbow-length, it should be water-proof (usually PVC or nitrile) (Figure 28). Wash gloves thoroughly and carefully with water after each use. Never use a ripped or torn glove.

Figure 28: Personal protective equipment for spray operator.

3. *Hat:* Cover your head with a water proof hat of the same shape as a cricket hat.

4. *Shoes/boots:* Use high neck rubber boots (not canvas or leather) and cover by trouser bottoms. Wash boots and dry upside down when not in use.

5. *Goggles/face shields:* Tight-fitting, non-fogging goggles or full face shields should be worn to prevent any sort of eye contamination (Figure 29). Wash goggles with soap after use and keep them clean. Face shields are recommended for mixing and filling (handling of concentrates).

Figure 29: The spray operator must wear Goggles (e.g., non-foggy eye protector) to protect eyes.

6. *Respirators:* Many chemicals can directly go into blood circulation via respiration. Use of an appropriate respirator will absorb chemicals into the canister charcoal of the cartridge. Replace the cartridge when it is too old. It cannot be reconditioned. Test the respirator for effectiveness. When the respirator is on, spray strong perfume around the respirator. If you smell the perfume in your nose, this is the time to replace the cartridge. You can wash and clean the rubber components of the respirator and outside the cartridges but do not allow water to move into the cartridges. Respirators or face masks are only required for application of fine droplets above waist level, in closed spaces and with very volatile or toxic products (to be generally avoided) while preparing the spray mix.

7. If the pesticide is a dust, use a safe mask (dusts should be avoided).

8. If there is strong noise (e.g., engine operated sprayer), use an ear protector.

SAFE HANDLING OF PESTICIDES DURING USE

- Use only sprayers that conform to international safety standards (ISO or FAO).
- Read label before opening the container.
- Wear all PPE as appropriate.
- Open the lid carefully to avoid any pressure-driven injury. Carefully pour concentrated chemical into measuring jars/mugs to avoid any spilling.
- Carefully pour chemical into spray tank. Wash the measuring jar three times with clean water and pour rinsing water into spray tank.
- Add required oil or wetting agent into the tank if necessary.
- Add required water into spray tank. Never over fill.
- Place and tighten the lid of spray tank and pump up before starting spraying.

SAFETY DURING SPRAYING

Figure 30 shows the no safety and very safe practice on the right hand side. Points mentioned below should be followed:

- Never spray when there is strong gusty wind.
- Always spray in the same direction as wind so the chemical drift is away from the operator.
- For field crops do not wave the spray lance; hold it steady with the prescribed height over the crop row and move steadily with the same speed as in the calibration.
- Never spray when the plant foliage is wet, dusty or moisture stressed.

- Never spray when rain is expected within the rain-fast period.
- For herbicides, use larger droplet size (choose nozzle with large orifice and use low pressure) and use small droplet size for fungicides; for knapsack sprayers use spray management valves or adjustable pressure regulators to adjust spray pressure and droplet size.
- Never eat, drink or smoke during spraying.
- Night spray may be effective, if humidity is too low and temperature is too high during day time.
- After spraying, thoroughly wash your clothes, and have a clean shower.
- Follow the waiting period specified on the label for each chemical. Waiting period is the time between spraying and the commencement of grazing, harvesting or eating of sprayed products.

Figure 30: Left hand side: No safety; Right hand side: Very safe with personal Protective Equipment (PPE): overalls, respirator, PVC hand gloves, rubber/PVC gum boots, and eye protector.

APPENDIX II

IN CASE OF POISONING

- Remove the victim from the source of contamination to a fresh air area after protecting yourself first.
- If skin exposure occurs, remove the clothing, dilute the chemical by fresh cold water or wash the skin with soap and water.
- If eye contamination occurs, hold the eyelids open with clean hand and wash the eye with clean and cold water for 15-20 minutes.
- If chemical is inhaled, give fresh air to the victim, lie down the victim and loosen clothes. If convulsion occurs, protect the head of the patient. If breathing stops, give artificial respiration but never do anything mouth to mouth in case of poisoning.
- If chemical is swallowed, never induce vomiting. Read label about first aid, call doctor immediately and mention about pesticide poisoning.
- If chemical has burned skin, cover the burnt area loosely with clean soft cloth. Do not use any ointment, greases, powders or any other medication.
- Call a doctor or take the victim to hospital as soon as possible.

APPENDIX III

STORAGE OF PESTICIDES

Storage of pesticides must be located at least 15 m from the property boundary, 10 m from buildings occupied by people or livestock; 3 m from unrelated work areas, offices and amenities; 3 m from flammable materials and fuel storage; and 5 m from any watercourse, body of water, drain or sewer.

The minor storage area should:

- Be fire resistant and structurally sound.
- Be protected against extreme heat and exposure to sunlight.
- Have floors made from concrete or other material which is impervious and resistant to chemical erosion.
- Provide a method for containing spills i.e. bunding.
- Be located in an area that is safe from flooding or inundation and is also not in the immediate catchment of a dam or waterway.
- Be securely lockable.
- Have clear access to avoid hazards whilst carrying chemicals.
- Have sturdy, non-absorbent shelving that is adequate to store chemicals without stacking.

SEGREGATION OF MINOR STORAGE

Some types of pesticide and veterinary chemicals should be segregated from other chemicals and from each other to avoid cross contamination if there is a leaking container or spill. Therefore:

- Liquids should be stored as close to floor level as practicable to reduce the risk of breakage or spillage.
- Liquids should not be stored above solids to avoid any damage or contamination of other products through leakage.
- Flammable products should be segregated from non-flammable products by at least 3 m distance.
- Veterinary chemicals must be segregated from all other chemicals.
- Scheduled poisons should be segregated according to their schedule.

VENTILATION AND HANDLING PRECAUTIONS

Ventilation of the storage facility must prevent a build-up of chemical vapours. The areas used for handling, filling and decanting chemicals must have additional ventilation to ensure a safe working environment.

CONTAINING SPILLS

Spills can be contained by constructing a bunded area or sloping floor that drains to a containment pit or tank. The method used for containing spills must be capable of containing 25 % of the total liquid stored. A spill kit containing the following materials must be kept in the storage area:

- Absorbent material i.e.: 'kitty litter'.
- Hydrated lime.
- Shovel and broom.
- Containers for storage of contaminated substances used to treat a spill.

Contaminated substances used to treat spillages should be disposed of in consultation with the local municipal waste disposal authority or the Environmental Protection Authority.

SAFETY SHOWERS AND EYEWASH FACILITIES

A safety shower and eye wash facility should be installed in an area that is quick and easy to access in case of an emergency. Such facilities should not be located inside the storage area. The water supply will need to be adequate for a minimum of 15 minutes of full water flow.

OPERATIONAL AND PERSONNEL SAFETY

Control of entry:

All storage areas must be secured to prevent unauthorized access, including children accessing the storage area via windows or vents. Only authorized personnel should have access to storage area, including the keys. Persons other than employees should be accompanied at all times by an authorized staff member or should be aware of the hazards present.

SIGNAGE

On the entry point there should be a sign stating (Figure 31):

- "Danger."
- "Pesticide storage."
- "Chemical Store Keep Out" "Authorized Staff Only."
- "No smoking" "No naked flames."

Figure 31: Signage for pesticide storage.

- On the inside of the chemical store there should be signs stating "No Smoking" as well as one indicating the location of the "Spill Kit."

EQUIPMENT

Equipment and machinery such as PPE, first aid kit, spill kit, firefighting equipment, mixing equipment and spray applicators should be checked on a regular basis to ensure everything is fully stocked and operational.

APPENDIX IV

SPRAYER CALIBRATION AND CALCULATION OF SPRAY VOLUME AND HERBICIDE REQUIREMENTS

Determine walking or vehicle speed

For walking and backpack sprayer (need two persons to work together):

Step 1

- Mark out 50 m.
- Fill the tank of the backpack sprayer with clean water (make sure nozzles and pressure regulators are working OK).
- Record the time taken to walk up to 50 m. Repeat three times.
- Measure the width (swath) of the sprayer coverage.

Step 2

- Now, fill the tank again to the same level as at Step 1.
- Place a bucket under each nozzle.'
- Maintaining the same pressure as in Step 1, run the sprayer for exactly the same time as required at Step 1.
- Measure and record the water in each bucket for each nozzle in the following Table.
- Repeat for three times.

Step 3

- Calculate the average in Table 11 below:

Table 11: Calibration worksheet.

Items	Replication 1	Replication 2	Replication 3	Average
Walking time per 50 m (minutes)				
Water volume of nozzle 1 per 1 minute (mL)				
Water volume of nozzle 2 per 1 minute (mL)				
Water volume of nozzle 3 per 1 minute (mL)				
Mean volume (mL)				
Compare the average output of individual nozzle with the grand mean. Compared to the grand mean, if the average output of any nozzle varies more than ± 10%, the nozzle must be replaced.				

CALCULATE WALKING SPEED

Step 4

- Calculate the walking speed of the operator using the following Equation

Walking speed km hr^{-1} **={**(Distance (m) x 3.6)/ Time for walking 50 m (secs)}

={(50 x 3.6)/60}

=180/60

= **3 km hr^{-1}**

Where, 50 is the distance; 3.6 is constant; 60 is time (seconds) taken to walk 50 m by the operator.

CALCULATE OUTPUTS

Step 5

Sprayer output (L ha^{-1}) = {(600 x Total output of all nozzles (L min^{-1}))}/ {swath width (m) x (speed of spraying (km hr^{-1}))}

Example

Total output of nozzles = 0.5 L min^{-1}

Swath = 1 m

Speed = 3 km hr^{-1}

So, Sprayer output = (600 x 0.5 L min^{-1})/ (1 m x 3 km hr^{-1})

= 300/3

= 100 L ha^{-1}

600 is a constant to calculate sprayer output in L ha^{-1} from nozzles output in L min^{-1}, swath in m at speed in km hr^{-1}.

CALCULATE HOW MUCH CHEMICAL (e.g., herbicide X) IS REQUIRED PER HA

Step 6

- Determine tank size (L)
- Note the output (L ha^{-1}) required (determined by calibration)
- Obtain chemical rate (L ha^{-1}) from product label

Volume of chemical required (L ha^{-1}) = {Tank size (L) / herbicide rate (L ha^{-1})}/ sprayer output (L ha^{-1})}

Example:

Tank size = 10 L

Sprayer output = 100 L ha^{-1}

Chemical rate = 1 L ha^{-1}

Volume of herbicide required = {10 L / 1 L ha^{-1}} / 100 L ha^{-1}

=10/100

= 0.1 L (or 100 mL) of herbicide to cover 1000 m^2 (1/10th of a ha)

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