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1 Acknowledgments

The rice-maize project is highly obliged to the participatory farmers of the project as they allowed the project staff to work with them in their fields and also for their active participation in the trials and trusting the rice-maize project teams in the six *upazillas* of the three districts. The project team members are highly thankful to national core partners -Bangladesh Agricultural Research Institute (BARI), Bangladesh Rice Research Institute (BRRI), Bangladesh Academy for Rural Development (BARD) and Rangpur-Dinajpur Rural Services (RDRS) and also thankful to International Plant Nutrition Institute (IPNI) for providing additional support for the project. We are thankful to project team members Mr. Moniruzzaman, Md. Abul Khayer, Mr. Nuruzzaman and many others who actively participated in various capacities during the project period. We are especially thankful to Mr. Tapash Bose, BARD, Comilla who served as BARD's R-M Coordinator during the first three years of the project before he retired and also assisted the project on a need basis after his retirement. We also thankful to Dr. Meera Bhatia, CIMMYT-Socioeconomist, Dr. Rafiqul Islam, IRRI-Socioeconomist, and Shafiqul Islam, BARD-Socioeconomist for conducting base line and mid-adoption survey.The project team reconizes the support from Dr. Zainul Abedin, IRRI-representative and Dr. TP Tiwari, CIMMYT-representatives for Bangladesh. The project team members from CIMMYT and IRRI and from all national partners are grateful to ACIAR for providing funds for conducting all research and dissemination activities in Bangladesh.

2 Executive summary

The ACIAR-funded joint IRRI-CIMMYT project “Sustainable intensification of rice-maize (R-M) production systems in Bangladesh” involves core partnerships with four national research and development partners—the Bangladesh Agricultural Research Institute (BARI), Bangladesh Rice Research Institute (BRRI), Bangladesh Academy for Rural Development (BARD), and Rangpur-Dinajpur Rural Services (RDRS). Bangladesh Rural Advancement Committee (BRAC), a national NGO, collaborated with the project with their own funds during the first 2 years, and the International Plant Nutrition Institute (IPNI) provided some nominal funds for 2 years (2010 and 2011) and linked their activities on site-specific nutrient management (SSNM) with this project. The ACIAR R-M project is formally linked to the IRRI-CIMMYT-IFPRI-ILRI-led Cereal Systems Initiative for South Asia (CSISA) project and the IRRI-CIMMYT-World Fish Centre-led CSISA expansion in Bangladesh (CSISA-BD) project. The project had four objectives: (i) Assessment and prioritization of the constraints to, and opportunities for, uptake of improved management options in R-M systems, (ii) Screening for seedling and late vegetative stage excessive moisture tolerance for maize, (iii) Conducting adaptive trials on conservation agriculture (CA) and SSNM in farmers’ fields and at research stations, and (iv) Dissemination of R-M technologies through capacity building and innovative communication and extension methods.

Activities were conducted and milestones met through the four core national partners with technical expertise of CIMMYT and IRRI. The standard protocols and meta data sheets were developed for implementation of activities and data collection. All data under each objective from the beginning of the project have been critically examined, cleaned, scrutinized and finalized, statistically analysed, and a database has been prepared for future use by researchers or other users. The project management team has maintained and documented all information and data for the entire duration of the project.

Under objective 1, there were three major surveys conducted from the beginning to the end of the project which include: baseline village and house hold survey, mid-term adoption survey and final adoption and impact survey. The baseline survey was conducted at the beginning in April 2009 through farmer group discussions for characterization of the project villages and districts. The dominant cropping patterns were rice-based because 92-100% areas were grown to rice in *Aman* season. There was no mechanization, except a few machines used in Rajshahi, in all three districts for seeding/planting but machines were used marginally for post-harvest activities like harvesting and threshing. New emerging cropping systems like R-M, rice-potato-maize (R-P-M) and rice-potato-jute were getting popularized in all three districts.

At the end of project in April-May, 2013, a final adoption and impact survey was carried out in all six *Upazilla*s covering 24 villages (18 project and 6 control) in all three districts. A total of 606 farm households (200 in each *Upazilla*) covering 236, 194 and 176 households from participant and non-participant (project village) and control (control village) farmers, respectively, were surveyed. Results revealed that *rabi* maize was adopted rapidly by 33%, 23% and 61% farmers by 2013 compared to 5%, 2% and 23 % farmers in 2008 in Rangpur, Rajshahi and Comilla, respectively. Such increase in adoption of *rabi* maize resulted in decrease in mainly *boro* rice cultivation in all three districts. Increase in adoption of *Kharif-1* maize over baseline, however, was noted only in Rangpur. The CA-based crop management practices (zero-tillage, strip tillage, bed planting and minimum tillage, etc.) became familiar with the farmers through on-farm participatory trials. The participant farmers were the main adopters of the technologies due to on-farm trials established and conducted in their fields but thel CA technologies were still unknown to the farmers in control villages. Zero and minimum tillage was adopted in more than 13% of *Rabi* maize area, with highest (23%) in Rajshahi and least (8.4%) in Comilla. The adoption of bed planting was higher in *Kharif-1* maize grown after potato than *rabi* maize and the adoption was more in Rangpur than other two districts. The adoption of CA-based crop management practices was higher in maize than in rice. Non-participatory farmers in the project villages were well aware of these technologies but they could not adopt the technologies in large scale due mainly to lack of machineries. Farmers gave mixed opinion about the performance of rice under CA-based crop management practices.

Under Objective 2, several inbreds/hybrids were evaluated for the early and late excess moisture tolerance through cup screening, field evaluation, and S1 to S2 advanced generation. From the cup screening experiments conducted in control conditions none of the existing hybrids in Bangladesh were found to possess acceptable high moisture/water logging tolerance at early stage. From the four years of trials, a few hybrid and inbred lines were identified as comparatively less susceptible to waterlogging, but none of them were found worth advancing for on-farm trials. From multi-location field trials for evaluation of hybrids/inbreds for late water logging tolerance, only a few hybrids, Uttaran-2, 900M Gold and Pinnacle, were found to be moderately tolerant, which can be recommended for *rabi* and *kharif -1* maize in Bangladesh.

Under Objective 3, several on-farm and on-station trials were conducted under different cropping systems rice-maize-mungbean (R-M-MB), R-P-M and rice-maize-rice (R-M-R) with the principles of CA. Approximately 200 on-farm participatory trials were executed under different tillage options including conventional tillage (CT), fresh beds (FB), and minimum tillage (MT) by a power tiller operated seedder (PTOS), permanent beds (PB), strip tillage (ST) and zero-tillage (ZT) for different crops and cropping systems. Performance of rice under different tillage options was similar in terms of grain yield and economics but higher numbers of labours were used in CT than the alternative tillage options. From the cumulative profit margins analysis it showed that CA-based tillage options performed consistently better than the CT. In *rabi* maize, CA-based tillage options produced 9% higher grain yield with lesser input cost and more profit margins than in the CT. The labour used was much lower under CA-based tillage options (50-52 person-day's ha^{-1}) than the CT (80 person day's ha^{-1}). Cumulative profit margin analysis showed that CA-based tillage options, especially PB and ST, performed consistently better at all probability levels than CT, indicating that these technologies can be less risky and more profitable to the farmers. Similarly, as in *Aman* rice, different CA-based tillage options performed similar to or better than CT in *Aus* rice too. R-M-MB system trials showed that PB produced 11% higher system grain yield than CT followed by other CA-based tillage options which also produced higher net returns and lesser labour use. But on other hand in the R-M-R system all tillage-options produced similar system grain yield, even though, CA-based systems provided more net returns over conventional-tillage.

Several on-farm nutrient omission and sufficiency trials were conducted in rice and maize for evaluation of Crop Manager/Nutrient Manager and to provide site-specific nutrient management (SSNM)-based fertilizer recommendation through decision support tools to farmers. The results indicated no positive correlation between available soil nutrients (N, P, K) and yields of maize and rice, indicating that there were factors other than nutrients which can affect crop yields. The Rice Crop Manager was endorsed by BRRI and now is available at IRRI web page for free access to the farmers, extension officers and researchers but the Maize Crop Manager is still under development stage and is expcted to be available in coming years.

On-station experiments indicated that crop residue retention in CA-based tillage options can produce more grain yield than residue removal of all crops in the R-M-MB system. The CA-based crop management practices on rice had carry-over effects on the succeeding maize under permanent beds in the R-M system. Likewise, integrated weed management in combination with pre- and post-emergence herbicides with one hand weeding in direct seeded rice was more effective than either manual weeding or herbicides alone.

Under Objective 4, under capacity building and training programme, several short- and long- term training courses were organized for researchers, extension officers, private sector partners, input dealers, and service providers. More than 30 training courses were conducted which benefited approx. 800 participants of the project, staff of the national partners, and various stakeholders. Likewise, more than 3500 people (farmers and others) were directly benefited through approx. 60 field days and farmers' exchange visit programmes. Under the extension and dissemination activities, various extension activities were conducted for large scale adoption of the CA-based and nutrient management technologies both within and outside the project domain. Under the communication activities, a large number of leaflets, posters, bulletins, books and other materials were developed and distributed to farmers and various stakeholders. The R-M project also evaluated various CA-based machineries (PTOS, bed planter, strip till drills, inclined plates, etc.) in all the project sites and facilitated for fine-tuning and developing new prototype planters, which are now commercially available in Bangladesh.

3 Background

3.1 Partner-country and Australian research and development issues and priorities

Cropping systems vary in intensity and by land type in Bangladesh. Rice-based systems are practised in medium uplands and medium lowlands and typically include a main rice crop (predominantly transplanted and locally known as T. *aman*) during June-July to October-November (the hotter *kharif-II* or monsoon) season. Where water is available, rice (known as *boro*) is also grown in the cooler period from late January-February to April-May (*rabi* or winter) season. Where irrigation water is scarce during *rabi*, especially in northern districts, wheat, potatoes, legumes, maize, or oilseeds are grown. Of all systems, rice-rice (R-R) and rice-wheat (R-W) have historically underpinned food security in Bangladesh. Market forces and the availability and cost of irrigation water influence farmers' decisions on which crop to grow in *rabi*. For example, water consumption of irrigated *boro* averages 3,000 L per kg grain (>20 irrigations), whereas wheat and maize during the same season consumes only about 400-850 L per kg grain (2–4 irrigations).

In recent years, market demand for maize has been increasing from rapidly expanding poultry and fish industries and emerging demand as human food due to severe shortages and increased prices of rice and wheat. As a result, maize production in Bangladesh has increased rapidly, from 4,910 ha in 2000 to >310,000 ha in 2012-13 (Fig.3.1) of which about 70% is grown in *rabi* after *aman* rice and 30% is grown in kharif-I (or pre-monsoon) during February-June, after Potato/vegetable and before *aman*. Maize has replaced mostly *boro* rice but also wheat and other crops in *rabi*, and is becoming popular in kharif-I. Maize demand for poultry feed in Bangladesh is projected to increase at about 15% per year; in 2015, this demand will be 1.36 million t while that for food and other uses will be 0.26 million t (Ali et al , 2008). Although temporary events such as the avian flu may slow down feed grain demand from the poultry industry, recent rice and wheat shortages have also generated new interest in growing hybrid maize for food purposes.

The omnipresence of T. aman rice in Bangladesh implies that maize is typically grown in rice-maize (R-M) rotations (hereafter R-M systems). In the past 5–6 years, R-M systems in Bangladesh have expanded rapidly (Fig. 3.1). Advantages of R-M systems for farmers are ease of cultivation of maize and potential for high yields and profits, especially from maize hybrids. In contrast to the rise in maize and R-M area, rice area per se has been decreasing rapidly each year because the boro rice is being replaced by upland crops, new housing, industrial development, and other infrastructure. Rice lands are projected to

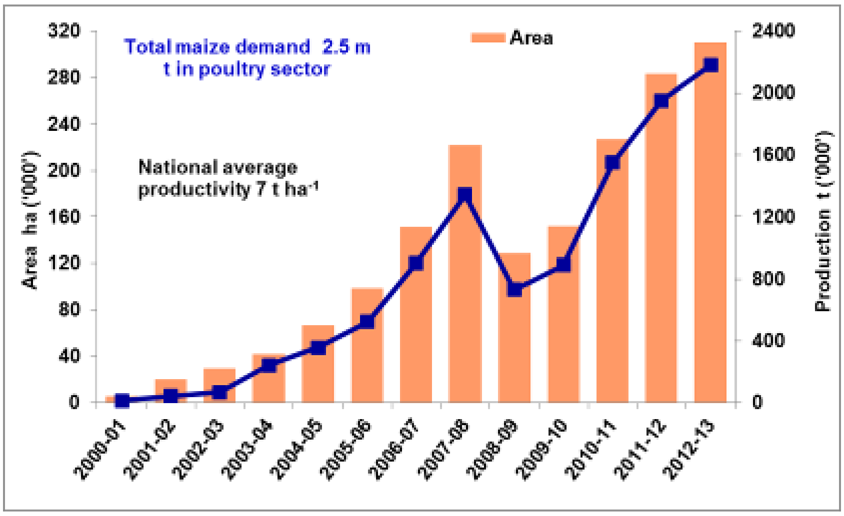


Fig 3.1 Expansion of rice-maize system in Bangladesh

decrease to 7.8 million ha in 2016 compared with 11.3 million ha in 2006 (Ali et al , 2008; Fig. 3.2). Hence, to maintain household and national food security, new opportunities for increasing the cropping intensity on existing land must be explored.

To achieve high yield from maize, it must be planted as early as possible in the *rabi* season although this carries the risk of excess field moisture at that time. In kharif-I, maize becomes waterlogged late in the season. Maize is highly susceptible to waterlogging during seedling emergence and at flowering stage (Zaidi et al , 2007). The climatic grain yield potential (Yp) of maize hybrids of differing maturity in Bangladesh is 11–14 t ha^{-1} for *rabi* or 9–12 t ha^{-1} for *kharif-I*. For rice varieties with varying maturity, the climatic Yp in aman is about 5–9 t ha^{-1} while in boro it is 6–12 t ha^{-1} (Timsina et al., 2010, 2011). We consider that, using best management practices (BMPs), 70–80% of climatic Yp in rice and 80–90% in maize can be achieved at the farm level (called farm-level maximum attainable yield) in tropical and subtropical Asian environments through improved germplasm and better agronomy. For example, in the Philippines with a comparable climate as Bangladesh, average farmers yields of hybrid maize with farmers' management practices and under reduced tillage conditions are around 10 t ha^{-1} (Medina et al., 2008) with an estimated climatic yield potential of 13 t ha^{-1} (Timsina et al., 2011). This indicates that average maize yields up to about 10 t ha^{-1} in *rabi* and 8 t ha^{-1} in *kharif-I* are attainable with optimal BMPs, well-adapted varieties, and existing socioeconomic conditions and amounts of investment. Yet, national average yields are only 5.7 t ha^{-1} for *rabi* maize, suggesting a large yield gap and scope for improvement. Similarly, average rice yield of about 5.5 t ha^{-1} in *aman* and 7.5 t ha^{-1} in *boro* have been reported by "good farmers" whereas national averages are only 4 t ha^{-1} in aman and 5 t ha^{-1} in *boro*. These attainable yields under BMPs, in reality, can be limited by socio-economic conditions, such as lack of information on BMPs, labour shortage, market failure, lack of credit, etc. This project analysed the socio-economic constraints to the adoption of currently known BMPs. Likewise, the project tried to identify and develop the biophysical BMPs that would lead to high attainable yields. Detailed discussions with researchers and extension workers from Bangladesh Agricultural Research Institute (BARI) and Bangladesh Rice Research Institute (BRRI) revealed that the potential causes for current low yields and yield gaps for rice and maize in R-M systems at the farm level include the use of low-yielding rice and maize cultivars and waterlogging-susceptible maize hybrids, late planting, and inappropriate nutrient management, resulting in soil fertility depletion and nutrient mining. There is a need to increase yields and close yield gaps at the farm level in order to improve food security and increase farm income. An additional issue in R-M systems is, however, whether further intensification of these systems through relay or intercropping can be achieved sustainably, satisfying the anticipated increase in food and feed demand while meeting acceptable standards of environmental quality and maintaining soil health and nutrient balances. Adequate crop nutrition to address the large extraction and removal of nutrients with intensive

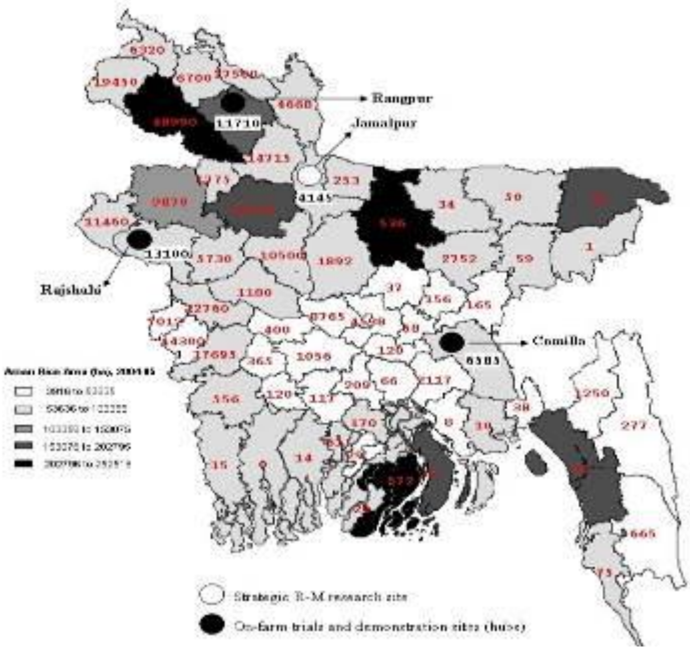


Fig. 3.2. Map of Bangladesh showing district-wise aman rice area (2004-05, in ha, in legend) and maize area (2007-08, in ha, within each district). The numbers shown within each district are also the current R-M areas.

cropping, use of high-yielding rice varieties and waterlogging-tolerant maize hybrids, and timely planting and improved crop and soil management (e.g., raised beds) has potential to close yield gaps and intensify R-M systems in a sustainable manner at the farm level.

Various short- and long-term system-level management concerns need to be addressed for R-M systems to become sustainable. For systems in which maize or other *rabi* crops are grown after rice, potential solutions include (i) early planting of the *rabi* crop to maximize yield and profit requiring (a) high-yielding early-maturing *aman* rice varieties, (b) shortening the duration of *aman* rice by direct-seeding and/or early planting, (c) using maize cultivars that germinate and establish with excess soil moisture, and (d) fine-tuning existing machinery for faster crop turnaround; (ii) balancing nutrients to avoid soil fertility depletion and nutrient mining, and increase nutrient-use efficiency; and (iii) reduced/no-tillage/residue/crop establishment practices for fast crop turnaround and conservation of water and soil organic carbon (SOC). For systems in which maize is grown in *kharif-I,* maize varieties tolerant of late-season waterlogging are required. For both systems, maize varieties should have good food and feed value.

Switching from late- to early-maturing rice varieties and from transplanted rice (TPR) to direct-seeded rice (DSR) in *aman* will reduce water, labour, and energy use as well as enable early planting and establishment of *rabi* crops. Reduced or no tillage in rice, maize, and other crops would save energy, water, labour, and overall costs, but no-tillage in maize is also required to avoid SOC decline and enhance soil N supply (Pampolino et al , 2008). Improved nutrient management practices based on concepts and principles of site-specific nutrient management (SSNM) will be required to improve nutrient-use efficiency, conserve resources, and increase profitability (Fairhurst et al , 2007, Govaerts et al , 2007). Sustainable management of macro- and micronutrients is a high priority in Bangladesh because intensive cereal systems have the potential to deplete soil fertility if they are not managed properly (Timsina et al , 2006).

Mechanized solutions will be required for fast crop turnaround; alleviating early-season waterlogging risks; maintaining or increasing yield; reducing energy, labour, and water costs; and facilitating intensification and diversification. Conservation agriculture (CA)–based resource-conserving technologies (RCTs) such as zero/reduced tillage, raised beds, and residue retention help reduce the cost of cultivation, improve soil health, increase productivity, and improve system resilience and sustainability (Sayre and Hobbs, 2004). In a nutshell, germplasm and system-level management constraints must be overcome to ensure that intensive double- and triple-cropping R-M systems are implemented in a profitable, resource-efficient, and sustainable manner that ensures food security and system sustainability. To achieve this, on-station research is needed to understand emerging constraints related to system sustainability such as SOC decline and nutrient mining, and identify potential remedies. Farmer participatory on-farm research and training activities are needed to solve the problem of low crop yields and large yield gaps at the farm level, while extension and dissemination activities are needed to achieve impacts on a large scale. Both the public and private sector and NGOs will have to work together to ensure that the viable and proven technologies generated from strategic and adaptive research are disseminated widely to many farmers to achieve household and regional food security.

3.2 Research and/or development strategy and relationship to other ACIAR investments and other donor activities

To sustainably intensify R-M systems in Bangladesh, the project included five major types of research and outreach activities: (1) socioeconomic characterisation of farm households, village-level surveys, stakeholder analysis, and impact assessment at the project sites/districts; (2) screening and evaluation of new maize germplasm for tolerance of excessive soil moisture, and of short-duration rice inbreds and hybrids that can fit best into different R-M systems; (3) farmer participatory adaptive research; and (4) building new public-private-NGO sector networks for improving the capacity of researchers and extension workers and delivering new technologies to farmers.

The project was implemented in three districts (central-western, central-eastern, and northwest regions) and focused on integrated and optimized germplasm and sustainable management solutions for R-M systems. It derived strength from ongoing International Maize and Wheat Improvement Centre (CIMMYT) Asian regional maize program activities in India on waterlogging-tolerant maize and from the German Federal Ministry for Economic Development Cooperation (BMZ)–funded project on “Abiotic stress-tolerant maize for increasing income and food security among the poor in eastern India and Bangladesh” in terms of the results of large-scale screening of germplasm, training, and establishing excess-moisture screening sites, etc. Under a CIMMYT-India collaborative project, a large set of germplasm from a wide genetic background, including hybrids, OPVs, and inbred lines from CIMMYT and the Indian maize program, had been screened for seedling and early vegetative stage excess-moisture tolerance. For *aman*, the project obtained and used the high-yielding and highly adaptable rice varieties developed under two IRRI projects—the Bill & Melinda Gates Foundation project on abiotic stresses in rice in South Asia and the Japanese government-funded project on submergence tolerance in rice in South and Southeast Asia. For adaptive research, active farmer participation was ensured when diagnosing, identifying, testing, monitoring, and evaluating technologies. Promising technologies of all crops were tested first in farmers’ fields and then the proven and viable ones disseminated to many farmers. The overall process was complex and could not be addressed by the public sector alone, and thus joint participation by the public and private sector and NGOs was needed.

Baseline data were collected and used to estimate the ex ante impacts of alternative R-M systems management technologies, and the impact assessment of those technologies at the end of the project. These activities helped prioritize and fine-tune research and development (R&D) interventions for R-M systems.

The project focused on developing BMPs for intensive R-M systems. Our primary objective was to achieve fast impact by building consensus on contents and approaches for extension/dissemination and using a wide range of partnership mechanisms. The strategy we proposes aimed at overcoming the following key weaknesses in the existing research-to-impact pathway, thereby accelerating the extension and uptake of improved management of intensive R-M systems in Bangladesh: (i) institutionalized focus on crop-specific research and technologies rather than on system management solutions that farmers need, (ii) lack of strategic research on integration of improved germplasm and crop management aimed at achieving high system yields, (iii) lack of consistency and consensus among researchers and between the public and private sector, and (iv) inherent weaknesses in the current extension system that prevent farmers from accessing new information and technologies.

The project attempted to overcome these weaknesses by bringing together knowledge and expertise of CIMMYT, IRRI, and NARES representing both GOs (BARI, BRRI, and Bangladesh Academy for Rural Development–BARD) and NGOs (Bangladesh Rural Advancement Committee–BRAC and Rangpur-Dinajpur Rural Services–RDRS). The approach aimed for a broad coalition of public sector and NGO partners involved in all stages of the project. For the research component, we formed a Technical Expert Group (TEG) composed of lead investigators from GOs (including representatives from the Bangladesh Agricultural Research Council and agricultural universities) and NGOs. The three focal districts (Rangpur, Rajshahi, and Comilla) represented a gradient and development of R-M systems. Rangpur (and adjoining Dinajpur) is an area with a relatively long tradition of R-M cropping, whereas R-M is an emerging system in Comilla (Fig. 3.2). Rajshahi represented a district where CA-based RCTs have been evaluated and adopted by some farmers; thus, there were prospects for further adoption of such technologies.

The project built on existing linkages and experience gained from several recent activities on R-R, R-M, and R-W systems in Asia. CIMMYT and IRRI, under the umbrella of the Intensive Production Systems in Asia (IPSA) project, had conducted a strategic assessment of the future potential and critical needs for developing R-M systems in nine Asian countries, including Bangladesh (Timsina et al , 2011). In collaboration with BARI, a more detailed review and assessment of R-M systems in Bangladesh had also been completed (Ali et al , 2008). Through the Irrigated Rice Research Consortium (IRRC, www.irri.org/irrc) and the Food Security for Sustainable Household Livelihoods (FoSHoL) project (www.foshol.org), IRRI and its NARES partners were adapting and disseminating crop and resource management technologies (e.g., direct seeding, SSNM, and water-saving irrigation, etc.) to large numbers of rice farmers through close partnerships with NGOs. Most of the partners in the proposed project were also involved in the CSISA project, through which RCTs continue to be developed, tested, and disseminated in the country. For maize management, the project drew upon CIMMYT's research on CA solutions, the SSNM in maize project led by IPNI, and the IRRI-CIMMYT Alliance IPSA project.

Past and current research by IRRI, CIMMYT, and their partners in Bangladesh revealed that much work has been done on the component technologies for managing rice in Bangladesh, but little on fine-tuning maize management for exploiting the yield potential and on optimizing whole-system management practices for different R-M systems. CIMMYT's BMZ project focused on breeding and evaluation of waterlogging-tolerant maize for *kharif* in India and kharif-I in Bangladesh, but not on widespread evaluation in farmers' fields in the *rabi* and *kharif-I* seasons. Work on mechanized solutions for maize planting after rice under reduced tillage is has been underway since 2008 at IRRI, but needed to be expanded under a range of cropping systems. The proposed project tried to build on earlier and ongoing projects of IRRI, CIMMYT, and NARES but differed in three aspects: (1) Widespread evaluation of new maize germplasm developed for waterlogging tolerance from the BMZ project in *rabi* and *kharif-I* was carried out under different R-M systems; (2) SSNM principles, guidelines, and tools developed specifically for rice and maize were fine-tuned and tested for the first time in R-M systems, including fine-tuning of these guidelines to the specific conditions of different residual effects of indigenous and applied nutrients. The decision tools were used in capacity building, and in facilitating rapid dissemination and uptake of improved sustainable nutrient management; and (4) Out-scaling of key technologies, for sustainable R-M systems management, through new public sector and NGO partnerships.

The proposed project built on the experience from the past two ACIAR projects in Bangladesh and India (LWR/2000/089—Permanent beds for irrigated R-W and alternative cropping systems in northwest India and southeast Australia, and # 9432—Irrigation and nutrient management for sustainable R-W cropping systems in Bangladesh and Australia), and linked with two other projects in Bangladesh (LWR/2005/146—Expanding the area for *rabi*-season cropping in southern Bangladesh, and LWR/2005/001—Addressing legume constraints in cereals-based cropping systems). Other ACIAR projects in Asia to which this project had complementarity are (i) CIM/2007/027 (Development of conservation farming implements for two-wheel tractors or power tillers in Cambodia, Laos, and Bangladesh) and (ii) LWR/2004/033 (Crop and weed ecology under changing tillage and crop establishment systems in India and Australia). We interacted and shared our experience on crop intensification/diversification through alternative *rabi* crops with Australian and Bangladeshi researchers involved in the three ACIAR projects (LWR/2005/146, LWR/2005/001, and CIM/2007/027) in Bangladesh. Our R-M project was developed after three field visits by scientists from IRRI and CIMMYT, including a visit by the ACIAR research program manager, Christian Roth, in March 2008, and inclusive consultations with NARES, NGOs, and private-sector partners in Bangladesh. The R&D priorities identified in the proposal aligned with ACIAR's research strategy for Bangladesh (ACIAR Annual Operation Plan). The project fitted well with three priority goals (water use; overcoming soil loss, salinity, and acidity; sustainable use of biodiversity) set under the first research priority—“Environmentally Sustainable Australia”—by the Standing Committee of the Australian Government’s National Research Priorities. The project also aimed at developing sustainable ways of improving water productivity by using less water, especially in rice, and developing sustainable soil and nutrient management practices. It aimed for sustainable intensification and diversification of intensive cereal systems, and thus focused on sustainable use of biodiversity.

4 Objectives

Aim:

The overarching goal of this project was to increase income, reduce poverty and hunger, improve the quality of life, and conserve natural resources in rural areas of Bangladesh by empowering farmers with ecologically and economically sound R-M systems that match their specific requirements in selected irrigated and favourable rainfed R-M areas.

4.1 Objective 1: To assess and prioritize the constraints to, and opportunities for, uptake of improved management options in R-M systems.

Activities:

1. Strategic assessment of R-M systems, with special emphasis on risk, regional diversity, targeted options, and research-to-impact pathways (district/regional/national levels).
2. Economic analysis of R-M systems and interventions for selected sites (district level).
3. Impact assessment of key R-M options for intensification/diversification of rice-based cropping systems.

4.2 Objective 2: To evaluate elite maize germplasm for tolerance of excess moisture during emergence and at flowering stage for the *rabi* and *kharif-1* seasons.

Activities:

1. Screen elite hybrids and OPVs, and advanced-generation inbred lines (for food and feed), for tolerance of excess soil moisture during emergence and flowering stage.
2. Evaluate top-ranking promising cultivars (5) through on-farm adaptive trials in target environments.
3. Develop test-crosses using excess-moisture-tolerant promising lines, and evaluate them under managed-stress conditions using the tolerant hybrids identified in activity 1 as a check.
4. Do seed multiplication and on-farm evaluation of promising test-crosses and elite inbreds and hybrids.

4.3 Objective 3: To develop locally adapted integrated management solutions for high-yielding, profitable, resource-efficient, and sustainable R-M systems.

Activities:

1. Conduct farmer participatory adaptive trials comparing farmers' practices with promising new technologies for sustainable R-M systems management.
2. Conduct researcher-managed on-station field experiments to provide technologies to be tested in on-farm trials

3. Adapt, test, and refine different small-scale farm implements for planting maize, rice, and other crops in *rabi and kharif-1* across different intensive cropping systems.

4.4 Objective 4: To build capacity and disseminate key management options for R-M systems through public-private sector partnerships.

Activities:

1. Build approval and consensus across stakeholders through a Technical Working Group for adapting, testing, and disseminating key BMPs for R-M systems.
2. Conduct orientation training and demonstrations for researchers and extension workers from within the project.
3. Conduct training of trainers (TOT) for high- to mid-level extension workers from public and private sector, and NGOs.
4. Conduct training for grass-roots-level extension workers and farmers, and on-farm demonstrations within and outside the focus districts through grass-roots-level GOs and NGOs.
5. Disseminate new scientific knowledge and promising technologies to different stakeholders and farmers through farmers' fairs and field days, local communication means, printed and electronic media and Cereals Knowledge Bank, and other Web site publications, etc.
6. Catalyse production and delivery of quality seeds of rice and maize.

5 Methodology

The project has four major objectives as described in above section: All field activities were implemented by the NARES core project partners (BARI, BRRI, BARD, RDRS) under all 4 project objectives and it was jointly coordinated by IRRI andCIMMYT. All data obtained from all partners were centrally coordinated by CIMMYT Dhaka office.

In this section, we will cover the general descriptions of the project sites, soils, and weather followed by the information and data for each of the four objectives. All survey reports and on-station and on-farm data were synthesised and analysed for 5 years basis and presented against each objective and activity. Daily weather data for each of the project sites were not included in the previous Annual Reports. Hence, in this Report, we have included the weather data from the beginning of 2009 until the end of the *rabi* season 2012-13.

5.1 Description of sites, soils, and weather

5.1.1 Site characterization:

The site characteristics for the three project districts in Bangladesh are presented in Table 5.1. The table presents major land types, latitudes and longitudes, and soil fertility status of the three districts.

Fallow land after rice due to lack of moisture in North-West Bangladesh

Comilla and Rajshahi are under the Middle Meghna River Floodplain and Active Ganges Floodplain agro-ecological zones, respectively, while Rangpur is under both Active Tista Floodplain and Tista Meander Floodplain. The land types in Comilla and Rajshahi are highlands (HL), medium highlands (MHL), and medium lowlands (MLL) while in Rangpur are HL and MHL.

Table: 5.1. Site characteristics of Comilla, Rangpur and Rajshahi (Source: BARC, 2012)

Characteristics	Comilla	Rangpur	Rajshahi
Agro-ecological zone	Middle Meghna River Floodplain (AEZ-16)	Active Tista Floodplain (AEZ-2) and Tista Meander Floodplain (AEZ-3)	Active Ganges Floodplain (AEZ-10)
Major land types	MHL: 29% LL: 25% VLL: 11%	HL: 36% MHL: 64%	HL: 12% MHL:33% MLL: 18%
Latitude	23°28'N	25°42'N	24°22'N
Longitude	91°10'E	89°22'E	88°39'E
Nutrient status	SOM varies from low to medium; N, P, K, and S content are low, low to medium, low, and medium to	SOM is low; N, P, K, and S are low to very low, low to medium, low, and low, respectively.	SOM is low; N, P, K, and S content are low, low to medium, medium, and low to medium,

	optimum, respectively.	respectively.

5.1.2 Soil characterization:

The soils of Comilla (Daudkandi and Borura) and Rangpur (Gangachara and Mithapukur) are quite acidic (pH 5.6) but in Rajshahi (Paba and Durgapur) are slightly alkaline (Table 5.2). Soil organic carbon (SOC) in the three districts ranged from 0.75 to 0.88%, and was higher in Rajshahi (0.88%) than in the other two districts (0.75-0.78). Total N in all districts was quite low with 0.1% in Comilla and 0.06% in the other two districts. Available P concentration in the three districts showed a relatively higher value (26.7, 32.8, and 46.8 mg kg^{-1}, respectively) than the critical level of 14 mg kg^{-1} for aerobic crops. Exchangeable K concentration in the soils of Comilla and Rajshahi had 0.15 and 0.19 cmol kg^{-1} (more than the critical level of 0.1 cmol kg^{-1} for lowland rice and less than 0.2 cmol kg^{-1} for upland crops) while the Rangpur soils contained very high level of K (0.32 cmol kg^{-1}).

Table:5.2. Soil properties in farmers' fields of Comilla, Rajshahi, and Rangpur, Bangladesh

Soil property	Comilla (n = 75)		Rajshahi (n = 49)		Rangpur (n = 26)	
	Mean	SD	Mean	SD	Mean	SD
pH	5.67	0.53	7.58	0.59	5.62	0.79
OC (%)	0.78	0.26	0.88	0.32	0.75	0.31
Total N (%)	0.10	0.05	0.06	0.02	0.06	0.03
Avail. P (mg kg^{-1})	26.67	20.95	32.76	20.01	46.81	32.89
Exch. K (cmol kg^{-1})	0.15	0.07	0.19	0.09	0.32	0.16

5.1.3 Weather:

Monthly average maximum and minimum temperature (^{0}C), monthly average sunshine hours (hrs) and monthly total rainfall (mm) over five years from January, 2009 to May 2013 showed that the maximum temperature in Comilla ranged from 24 ^{0}C-34 ^{0}C during 2009 to May 2013, without much variation in maximum temperature across 5 years, i.e., only less than 1^{0}C variation was recorded (Fig. 5.1b). The maximum temperature sometimes reached up to 38^{0}C in April and May. The minimum temperature ranged from 11^{0}C-26 ^{0}C and came down by 8^{0}C during winters in December and January. Total annual rainfall was 1775, 1547, 1898 and 1636 and 506 mm during 2009, 2010, 2011 and 2012, respectively, and 506 mm until May in 2013. 80-85% precipitation was occurred during May to October and in rest of the years only 15-20% rain appeared. On an average, monthly sunshine daily hours ranged from 4 to 8.30 hrs, during 2009 to May 2013. The overall sunshine hours were low which could be due to the cloudy weather. The sunniest days were recorded for February to April as compared to rest of the months.

The monthly average maximum daily temperature from January 2009 to May 2013 in Rajshahi ranged from 22^{0}C to 39^{0}C. The maximum temperature reached up to 42 ^{0}C in April and May. The monthly average minimum daily temperature was recorded from 8 ^{0}C to 27 ^{0}C but it dropped to 4^{0}C in December and January (Fig. 5.1a). The total yearly rainfall ranged from 833 to 1478 mm and minimum rainfall of 833 mm was received during 2009. The same rainfall pattern was followed as in Comillla. The manthly average daily sunshine hours ranged from 3 to 9 hrs and sunniest days were recorded during February to March as compared to rest of the months.

Forced harvesting of Kharif-1 maize due to water logging

Rangpur also followed the same pattern as Comilla (Fig. 5.1a). The monthly average maximum daily temperature ranged from 20 to 33 ^{0}C and minimum temperature ranged from 9-27 ^{0}C. The maximum temperature went up to 39 ^{0}C during peak summers in April-May and minimum temperature dropped to 7^{0}C. The total annual rainfall ranged from 1877 to 2230 mm and was highest during 2009. The total monthly average daily sunshine hours was recorded from 3-7 hr. per day and as the other two districts the sunniest days were observed for February and March.

As shown in Fig 5.1, Rajshahi has extremes in terms of maximum and minimum temperature, more sunshine hours and low total rainfal .

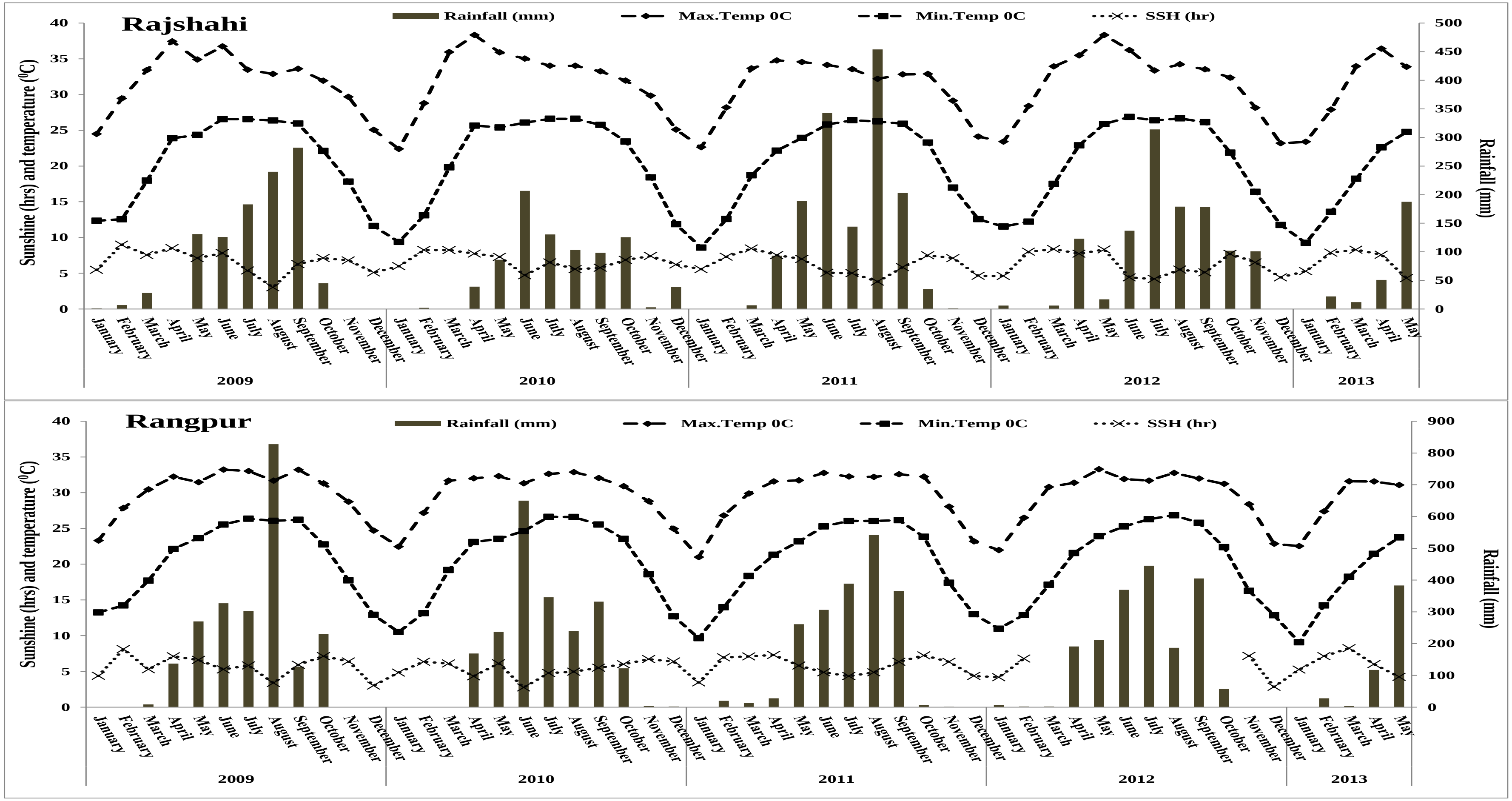


Figure 5.1a Daily weather data (monthly averages) for Rangpur and Rajshahi

:

as compared to Comilla and Rangpur districts. In Rajshahi, more droughts were occurred due to erratic rainfall pattern and also more chilling effects in winter crops due to very low temperature. Both Rangpur and Comilla districts had more rainfall. Due to heavy rainfall and storms in Comilla, both *Kharif*-1 and winter maize, especially the late crops, commonly faced the waterlogged situations. Since both of these districts have higher humidity and tropical in nature, it provides better favorable conditions for diseases and pests. Despite these problems, these districts provide more opportunities for diversification in low, medium and highlands topography due to the favorable weather round the year.

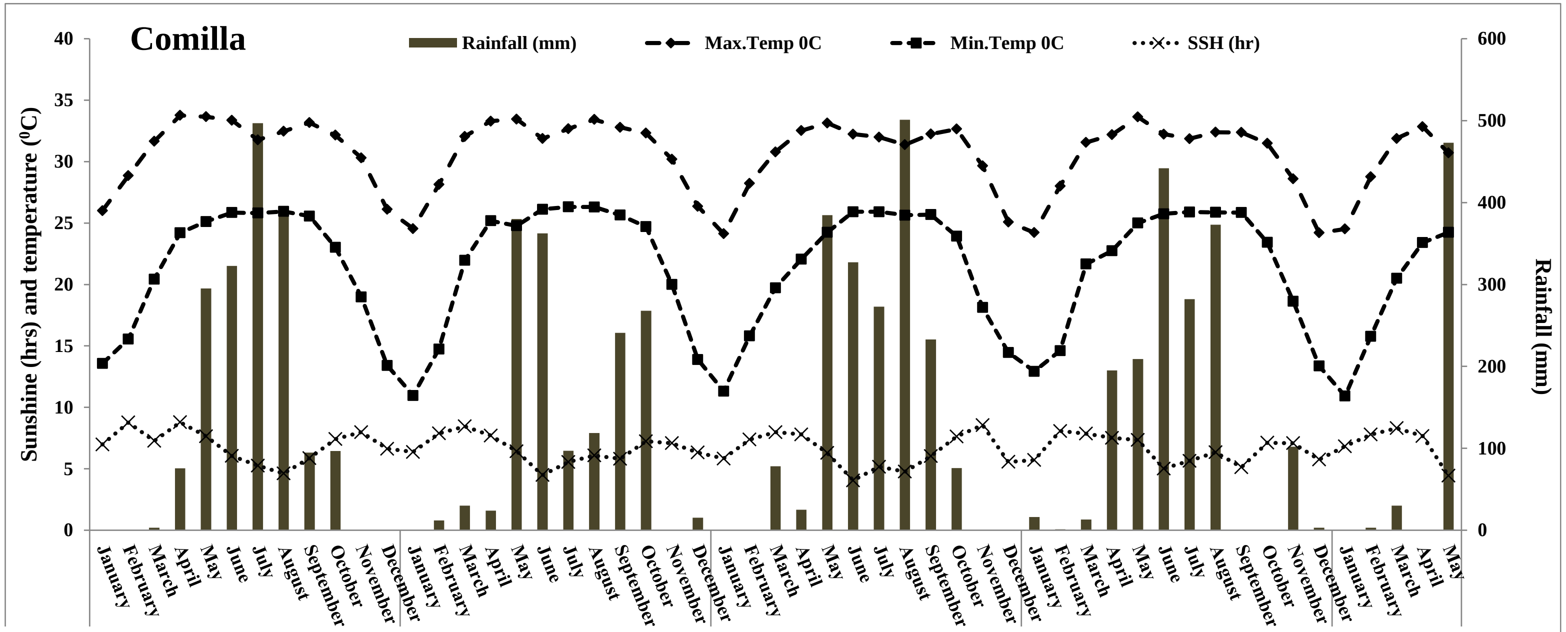


Figure 5.1b Daily weather data (monthly averages) for Comilla

5.2 Description of experimental design and methods

5.2.1 Objective 1: To assess and prioritize the constraints to, and opportunities for, uptake of improved management options in R-M systems

5.2.1.1 Baseline village survey and household survey:

Village selection: Baseline village surveys in each district (two *Upazillas)* were conducted in consultation with extension personnel, research scientists of the respective regional stations of BRRI and BARI, and BARD and RDRS and other partners. In each *Upazilla*, two project and one control village were selected, with a total of 18 villages in the three districts (Table 5.3). Framers from these 18 villages were surveyed using a structured village survey questionnaire.

Table 5.3: List of the selected *Upazillas* and villages

District	*Upazilla*	Project villages	Control villages
Rangpur	Gangachara	Talukhabu	Goalu
		Joydeb Bakshitari	
	Mithapukur	Sitalgari	Chitouli-Purba Para
		Durgapur	
Rajshahi	Paba	Madhavpur	Borgachi
		Gosaipur Suvi para	
	Durgapur	Alipur	Shyampur
		Nandigram	
Comilla	Barura	Puntala	Chototula Gaon
		Jalgaon	
	Daudkandi	North Mohammadpur	Bitashar
		Dekrikhola	

Village survey team and partner organizations: The data was collected using a questionnaire used for focus group discussions (FGDs) with farmers between April 1 and 8, 2009. A group of 12 to 15 farmers were chosen from each village, divided into 3 groups and interviewed by the scientists using the village survey questionnaire.

5.2.1.2 Mid-term adoption household survey:

Village and sample selection: Mid-term adoption survey was conducted after 3 years of project during April-May, 2011. All three project districts were covered as by using same techniques as in the village survey conducted in 2009. Two *Upazillas* from each district and two villages from each *Upazilla* were selected for the household survey. Out of the two villages, one was project village (but in village survey we considered two villages) and another was control village same as in village survey (Table 5.4).

Once the villages were selected, a list of 20 farmers from each of the project villages (10 participating and 10 non-participating) including at least 2 women in each category was made in consultation with project research scientists from the respective core project partners. Similarly, 10 farmers from each of the control villages were selected. In all 180 farmers from 12 villages provided the information. Table 5.5 shows details of the sample distribution. The farmers represented the different farmer categories such as large, medium, small, marginal and landless particularly those who are cultivating others' land either on shared and/or rental basis. Sub-Assistant Agriculture Officers (SAAOs) from Department of Agricultural Extension (DAE) of respective area were also invited during survey of the village farmers.

Table 5.4: List of selected survey districts, *upazillas* and villages

District	***Upazilla***	**Project villages**	**Control villages**
Rangpur	Gangachara	Talukhabu	Goalu
	Mithapukur	Durgapur	Chitoli Purbapara
Rajshahi	Paba	Madhabpur	Bargachi
	Durgapur	Alipur+Nandigram	Shyampur
Comilla	Barura	Jalgaon	Chototula Gaon
	Daudkandi	South Mohammadpur+Dekrikhola	Bitashar

Table 5.5: Distribution of sample farmers provided information

District	***Upazilla***	**Villages**	**Farmer group**	**Sample size**
Rangpur	Gangachara	Talukhabu (PV)	PF	10
			NF	10
		Goalu (CV)	NF	10
	Mithapukur	Durgapur (PV)	PF	10
			NF	10
		Chitoli Purbapara (CV)	NF	10
Rajshahi	Paba	Madhabpur (PV)	PF	10
			NF	10
		Bargachi (CV)	NF	10
	Durgapur	Alipur+Nandigram (PV)	PF	10
			NF	10
		Shyampur (CV)	NF	10
Comilla	Barguna	Jalgaon (PV)	PF	10
			NF	10
		Chototula Gaon (CV)	NF	10
	Daudkandi	S.Mohdpur+Dekrikhola (PV)	PF	10
			NF	10
		Bitashar (CV)	NF	10
Total= 3	**6**	**12**	**18**	**180**

Data collection: Both FGDs and household survey techniques were used to collect information. All 12 FGDs, each with 10 farmers including at least 2 women from each of the selected villages, were conducted for collecting village level information. The concerned SAAOs were used to assist farmers providing some of the village level statistics, especially when they were beyond the knowledge of farmers' group. In each the project village 2 FGDs and in the control village one FGD, were conducted followed by household interviews with the same farmers. Data collection through FGDs and survey was done by the researchers themselves with the assistance from core partners.

5.2.1.3 Final adoption and impact survey:

The study was based mainly on a quantitative survey carried out in April-May 2013 and performed a descriptive analysis. Background and supporting information used for this survey report was derived from village and household level surveys and FGDs carried out under the project in April 2009 and June 2011. We also used production and input data for the trial plots from the project scientists.

Site selection: In 2008, the project identified 3 districts purposively based on their potential for R-M systems to carry out the research. The detailed characteristics and information of all 6 *Upazillas* and 3 districts are presented in table 5.6.

Table 5.6 Summary information for sample *Upazillas* and villages in Rangpur, Rajshahi and Comilla districts.

Rangpur	**Rajshahi**	**Comilla**
Northwest Bangladesh between 25.18' and 25.57'N latitude and 88.56'- 89.32' E longitude A relatively long tradition of R-M cropping; Maize is grown in *Rabi* and *Kharif-1* (K1)	Western Bangladesh between 24.22' latitude and 88.6' longitude CA-- based resource conserving technologies have evaluated and adopted by farmers; Maize is grown in *Rabi* and K1	About 100 kms from Dhaka in the eastern Bangladesh R-M is an emerging system;
Gangachara	**Paba**	**Barura**
Located about 15 km to the north east of the district *sadar; loamy soil with* about 20% irrigated; yield of maize is around 6.4 t ha^{-1} ; *Rabi* rice-fallow-*T.Aman* rice, potato-*Rabi* rice-*T.Aman* rice, potato-*T.Aus* rice-*T.Aman* rice and potato-maize-*T.Aman* rice; wheat and maize are competitive Project villages(PVs): (1) Talukhabu, (2) Joydeb Bakshitari Coltrol village, CV: (1) Goalu	about 12 km to the north of the district *sadar;* soil is mostly loamy; cropping pattern: *Rabi* rice-fallow-fallow, potato-maize-*T.Aman* rice, potato-maize-fallow, wheat-fallow-*T.Aman* rice, maize-fallow-*T.Aman* rice, and sugarcane Project villages (PVs): (1) Madhavpur, (2) Gosaipur Siuvipara Control village, CV: (1) Borgachi	located about 12 km south-west of Comilla town; cropping pattern: potato-maize-*T.Aman* rice, *Rabi rice*-T.Aus rice- *T.Aman* rice and *Rabi*-fallow-*T.Aman* rice Project villages(PVs): (1) Puntala (2) Jalgaon Control village, CV: (1) Chototula Gaon
Mithapukur	**Durgapur**	**Daudkandi**
about 30 km to the south of the district *sadar; loamy soil with* about 80% irrigated ; yield of maize is around 6.7 t ha^{-1} PVs : (1) Sitolgari (2) Durgapur CV: (1) Chitli Purba Para	about 30 km to the north east of the district *sadar;* drought-prone and the soil is mostly clayey loam; cropping pattern: *Rabi* rice-fallow-fallow, mustard-*Rabi* rice-fallow-*T.Aman* rice, *Rabi* rice-*T.Aus* rice-fallow, potato-maize-*T.Aman* rice and mustard-	30 km west from the Comilla district town; PVs: (1) North Mohammadpur (2)

	onion-*T.Aus rice*- fallow PVs : (1) Alipur (2) Nandigram CV: (1) Shympur	Durgapur CV: (1) Biteshar

Project an control villages: Experiments were conducted in close vicinity in villages of the selected *Upazillas. W*e call hereafter project villages (PVs). One village, which was located far from the experiment villages in the same *Upazilla* was chosen for control, called hereafter control village (CV). The characteristics of CV were Rice-Rice, Rice-Wheat, Rice-Maize as important cropping systems; low productivity; water logging; excess moisture at planting; etc. Site selection was done through consultation with knowledgeable people, such as experienced extension personnel and research scientists from local partner organizations of the project. The same consultation was used to select the villages at the same time.

Survey team and timeline: The survey team comprised of team leader, one local consultant, an international consultant, project scientists (2 each in Rangpur, Rajshahi and Comilla), project field staffs and 3 appointed enumerators, who were also agriculture graduates. The consultants trained the enumerators in a training session as well as through pretesting and close supervision during data collection. The consultants explained every question included in the survey instrument so that enumerators were not confused about anything. The consultants also participated directly into the data collection together with the enumerators to complete field work quickly and correctly. The survey was conducted in April and May to ensure that farmers were available for interview and that it would be possible to collect required information for rice and maize for the whole year covering *Rabi, Kharif-1 and Kharif-2* seasons. Field staffs and farmers were also available as harvest of maize experiments and farmers' maize fields were not yet started. Crop and livestock production referred to crop year covering 2012 *Rabi* (winter/dry), 2012 *Kharif-1* (rainy/pre-monsoon), and 2012/13 *Kharif-2* (monsoon) seasons.

Sample selection: First we prepared the list of participating farmers (PFs) from the Excel diary sheet maintained by the project scientists. We decided to interview a large number of PFs randomly to make the analysis unbiased. Until 2012, the R-M project intervened with technologies to around 400 PFs in all six selected *Upazillas* for the project. However, in some *Upazillas* the maximum number of PFs did not exceed 40, for example Mithapukur in Rangpur district and Barura in Comilla district. So we decided to interview 40 PFs from each of the 6 *Upazillas* where PFs were located; approximately a complete survey in Upazillas where there were around 40 PFs and randomly selected 40 farmers where PFs exceeded 40.

Second, from the list of PFs we identified the farmers having trials (CA and NM plots) and extension plots in 2012 because we required technology and season specific data for the year 2012. This screening gave us a list of around 250 PFs. The final year of the R-M project was still continuing during the survey. We found majority of the PFs were continuously participating in the project (2009-2012) but some farmers exited and new farmers entered into the project. Some farmers participated until 2011 then dropped and so we didn't include them because they had no information for 2012 crop seasons. Number of PFs was around 40 in all Upazillas except Durgapur in Rajshahi. In Durgapur we had 50 PFs, so we interviewed all PFs in all locations except Durgapur where we randomly selected 40 out of 50. In Mithapukur, Rangpur only 37 PFs were present durin interview, so we interviewed 236 PFs (37 in Mithapukur, 39 in Barura and 40 in all other

*Upazilla*s)[1]. So this was almost a complete survey of PFs who were with the project in 2012.

Third, the comparison groups were non-participating farmers (NFs) coming from the same PVs and control farmers (CFs) from the CVs. Both groups are control groups. NFs did not receive direct support from the project but expected to expose with spill over effects; they might learn some CA and NM technologies from the PFs or project staffs as they are located in the same villages. CFs were located in the CVs of the same *Upazillas*. CVs were far from PVs and lacked well communication network with the PVs. So the chance of transmission of project information to CVs was negligible and therefore they were expected to be exposed with negligible spillover effects.

We thought that the same number of NFs/CFs would produce reliable results and would be representative of all the farmers. However, we interviewed 60 NFs, a higher number than PFs. We selected 30 from PVs and 30 from CVs from each *Upazilla*. Thus we planned to interview 100 farmers (40+30+30) from each *Upazilla* making sample size 600 from 6 *Upazillas*, which was quite large to obtain reliable results. The final sample came from 24 villages from 6 *Upazillas* in 3 districts. We interviewed more than 30 NFs from some PVs. In total we collected information from 606 farmers.

The list of selected *Upazillas* and villages along with number of farmers interviewed is presented in table 5.7. The survey instrument was a detailed 14 pages structured survey questionnaire. The questions include household level characteristics including literacy rate, assets, technology adoption, production, consumption, marketing, constraints and lessons. The literacy rate was measured by the percent of 7 years and older members of households who could read and write a letter in this research following household income and expenditure surveys in Bangladesh (HIES, 2010).

Table 5.7. Distribution of sample *Upazillas*, villages and farmers, R-M Project final survey, 2013.

District	*Upazilla*	Village	Participating	Non-participating	Control	Sample size	Sample size %
Rangpur	Gangachara	Talukhabu	19	9		28	4.6
		Madhyapara	11	6		17	2.8
		Munshipara	7	10		17	2.8
		Joydeb Bakshitari	3	8		11	1.8
		Goalu*			30	30	5.0
	Mithapukur	Sitalgari	28	9		37	6.1
		Durgapur	9	22		31	5.1
		Chitli Purba Para			30	30	5.0
	Total		77	64	60	201	33.2
Rajsha	Paba	Madhabpur	22	19		41	6.8

hi		Gosaipur Suvipara	6	8		14	2.3
		Sobsar	6	7		13	2.1
		Kakail Kathi, Chargat	4	0		4	0.7
		Khanchipara	2	0		2	0.3
		Borgachi			30	30	5.0
	Durgapur	Alipur	23	21		44	7.3
		Nandigram	17	9		26	4.3
		Shyampur			29	29	4.8
	Total		80	64	59	203	33.5
Comilla	Barura	Puntala	7			7	1.2
		Jalgaon	32	33		65	10.7
		Chototula Gaon			30	30	5.0
	Daudkandi	Mohammadpur	17	9		26	4.3
		Dekrikhola	10	18		28	4.6
		Barkota	13	6		19	3.1
		Bitashwar			27	27	4.5
	Total		79	66	57	202	33.3
Total			236	194	176	606	100.0

* This village is currently under the Sadar *Upazilla* due to administrative rearrangement.

Supervision, quality Control, data entry and analysis: The study requires technical information on technology adoption and so qualified persons were engaged in data collection. In order to collect such information the full team worked together in data collection, data entry and data cleaning under the guidance of the team leader and international consultant. Due to budget limitation, only 3 enumerators and one data entry operator were appointed. So the consultants and local scientists employed full time in data collection and supervision. The interviewers and consultants regularly checked the information after the interview for any inconsistency and corrected next day in the field. Some data were entered in Excel during the data collection time and remaining data were entered and cleaned diligently within three weeks of data collection. Data were then analysed in STATA software. Simple descriptive statistics such as averages, sums, frequencies, and percentages were used in this study, along with some graphs.

5.2.2 Objective 2: To evaluate elite maize germplasm for tolerance of excess moisture during emergence and at flowering stage for the *rabi* and *kharif*-1 seasons.

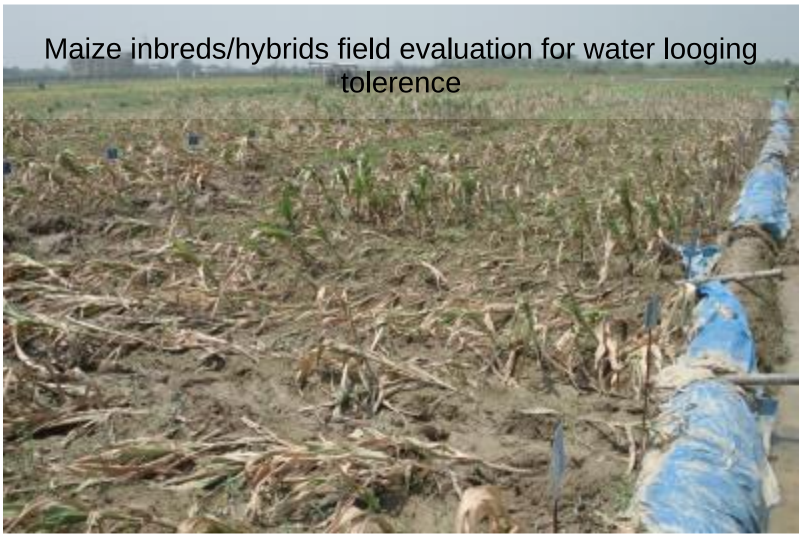
Under this objective all activities was taken-up by the Maize program of the Division of Plant Breeding, BARI at Gazipur and also these activities were replicated in other regional stations including Jamalpur and Barisal. A number of greenhouse and field experiments were carried out during 2009 to 2012;

5.2.2.1 Cup screening of promising inbreeds and hybrids against water logging stress:

Cup screening of maize inbreds/hybrids at BARI, Gazipur

The experiments were conducted under control condition in the laboratory chambers during 2009 to 2012 (Table 5.8). The objective was to find out degree of waterlogging tolerance of inbreds and hybrids collected from public and private sectors. Screening was done using the cup screening method with cup size of 250 ml (10 cm height, 3.5 cm diameter). The materials were exposed to waterlogging stress after emergence. Each plastic tray (40cm x 28cm x 14cm) contained 15 cups. Ten cups remained under normal condition outside the tray (as check). The experiment was set up in completely randomized design (CRD) with three replications. The number of inbreeds and hybrids varied from season to season and ranged from 58-250. Different morphological parameters, such as first leaf length (FLL) mm, first leaf width (FLW) mm, first length and width ration (FLWR), root length, cmm (RL), shoot length (SL) cm, root shoot ration (RSR),. root dry weight, g (RTW), shoot dry weight, g (SDW) and survival percentage (%) were recorded at 7, 14 and 21 days after emergence.

5.2.2.2 Field evaluation of maize hybrids for water logging tolerance at multiple locations:



Maize inbreds/hybrids field evaluation for water looging tolerence

The experiment was conducted at five regional offices of BARI (Barisal, Rangpur, Gazipur, Jamalpur and Satkhira) from March 2009 to July 2011 in both *rabi* and *kharif-1* maize (Table 5.8). A randomized complete block design with 3 replications was used. In 2009, 2010 and 2011, the numbers of hybrids used were 58, 86 and 5, respectively. In 2011, five previously selected promising hybrids (Pacific-60, Pinnacle, CML254XCML247, 900M Gold, and Uttaran-2) were used; each hybrid was sown in 5 rows each of 5 meter long. At 35-40 days after seeding (DAS), water from the outside source was supplied up to one inch above the ridge continuously for 5 days followed by drainage. Fertilizers were applied at the rate of 150 kg N, 32 kg P, 64 kg K, 20 kg S, and

2.8 kg Zn. Half of the N was applied at the time of sowing and remaining half at V9-V10 stage (40 DAS). At 35-40 DAS, water from the outside source was supplied up to one inch above the ridge continuously for 5 days followed by drainage. All weeds, pests, and diseases were controlled as and when required. Data on phenology, plant and ear height, and yield were recorded on a whole plot basis. Combined analysis was done to interpret the experiment with the help of Cropstat 7.2 software.

5.2.2.3 Advancing S1 to S2 generation of excess water tolerant maize inbred lines:

The experiment was conducted at Joydebpur, Gazipur, during *kharif –I* in 2010. The materials consisted of two sets of S_1 lines (set 1:5 selected excess water tolerance inbred lines, and set 2:6 selected excess water tolerance inbred lines). Seeds of both sets were sown on 20 February and 29 March 2010. Each S_1 material was sown in single row of 5 m long. Spacing was 75x20 cm (one plant/hill). Fertilizers were applied @ 120, 80, 80, 20, 5 kg ha^{-1} of N, P_2O_5, K_2O, S and Zn, respectively. After earthing-up at V8 stage, water was applied continuously for 6 days at 15 cm height from the soil surface. Plants were kept under observation for 2 to 3 weeks without any cultural operations. Selected plants were selfed by hand pollination. A total of 50 plants were selfed. The selfed plants were harvested individually and dried properly. Finally 20 ears of both the sets were selected and were preserved separately for advancing from S_2 to S_3 generation for further use.

Table 5.8 Maize screening/evaluation trials from 2008-09 to 2012-13 (BARI, Gazipur)

District	2008-09 (*rabi and kharif-1*)		2009-10 (*rabi and kharif-1*)		2010-11 (*rabi and kharif-1*)		2011-12 (*rabi*)
	Cup screening	Field evaluation	Cup screening	Field evaluation	Cup screening	Field evaluation	Cup screening
Gazipur	108	58	250	86	180	5	30
Jamalpur	–	58	–	–	–	5	

5.2.3 Objective 3: To develop locally adapted integrated management solutions for high-yielding, profitable, resource-efficient, and sustainable R-M systems.

Under this objective several farmers' participatory on-farm trials and researchers' managed on-station trials on CA-based crop management systems and SSNM by using decision support tools for rice and maize inr R-M systems were tested. In addition, the systems optimization on-farm and on-station trials like intercropping, introduction of new crops (legumes) in existing systems and diversification were evaluated, and testing of new prototype for 2-wheel tractor operated machineries and implements was undertaken.

5.2.3.1 Conservation agriculture (CA) based crop management practices through adaptive on-farm research trials:

Conservation agriculture (CA) is a concept designed to optimize crop yields while reaping economic and environmental benefits. The key elements of CA are minimum disturbance of soil, permanent soil cover with growing crops or crop residues, and crop rotation. These CA principals are not "site specific" but represent "unvarying objectives" that are followed to develop practical, efficient, sustainable and socially acceptable CA systems adapted to the diverse production environments and farmer circumstances. In this context, R-M project designed the on-farm and on-station trials to refine the CA based crop

management practices for better understating and adaptation in rice-based small holding farming systems in Bangladesh. Several farmers' participatory on-farm research trials were implemented through project partners. Approximately 185 farmers' trials were implemented, mainly in R-M-R and R-M-MB systems during 2008-09 to 2012-13 (5-yr) in all 6 *Upazillas* of three districts. The R-M-MB system experiments were under taken in Rajshahi and Rangpur and R-M-R system trials were conducted in Comilla. At least, 60

CA-based adaptive trials were conducted in each season in both cropping systems; in addition, new farmers joined the project each year but also few of the earlier-participating farmers left due to unavoidable circumstances. In R-M-MB system, 69 permanent (system-based) farmers' trials were maintained during the whole project duration in both Rajshahi and Rangpur and similarly, 37 triails were conducted in R-M-R system in Comilla. In CA trials, the 3 CA components were maintained as much as possible in all those trials. Six treatments were included with combination of different tillage and crop establishment methods, in both R-M-MB and R-M-R systems but only 4 alternative tillage options together with the conventional tillage were implemented in individual farmers' fields to keep the trials as simple as possible with less number of treatments. The treatment details are presented and described in below table 5.9.

Table 5.9. Description of the tillage and crop establishment options

Treatment	Rice	Maize
CT (Conventional tillage)	2-3 dry tillage operations by 2-wheel tractor operated power tiller before rain occured; then rain or supplementary irrigation followed by wet tillage by power tiller with planking; =~25-d-old 2-3 rice seedlings transplanted at 20x20-cm plant-hill spacing; Mainly rainfed and farmers rarely applied irrigation; transplanted rice (TPR)	Conventional tillage with 2-3 passes prepared by a power tiller in residual moisture after rice harvest; followed by pre- sowing irrigation and then 2 passes at optimum soil moisture by the power tiller followed by planking; maize dibbled manually at 60x20-cm line-plant spacing at 5-7-cm depth
FB (Fresh bed)	Same type of dry tillage operations as for CT followed by either direct drill-seeded rice (DSR) with help of 2-wheel tractor operated bed planter with fluted roller or inclined plate seed metering device, or if DSR is not feasible due to heavy rain bed formation with the bed planter followed by transplanting of rice seedlings at the slope of beds; supplementary irrigation provided in furrows if not enough rain; farmers practised both DSR and TPR depending on the amount and intensity of rain.	1-2 dry tillage after rice harvest by the power tiller; followed by maize seeding with help of 2-wheel tractor operated bed planter with fluted roller or inclined plate seed metering device at 20-cm spacing; followed by a light irrigation in furrows to ensure maize seed germination
MT (Minimum tillage)	Sowing of DSR in a single operation by a 2-wheel tractor operated power tiller-cum-seeder (PTOS) at optimum soil moisture condition, or if DSR is not feasible due to heavy rains, then one pass of PTOS followed by transplanting of ~25-d-old 2-3 rice seedlings at 20x20-cm plant-hill spacing; farmers practised both DSR and TPR depending on the amount and intensity of rain.	By using the PTOS with the inclined plate type maize planter at 60x20-cm line-plant spacing in a single operation after rice harvest

PB (Permanent raised bed)	In the first year, beds prepared as in FB; same beds were used for both crops and in all years by reshaping of the beds but without damaging them; DSR was sown through a bed planter, or if DSR not feasible due to heavy rains transplanting of rice seedlings in the slope of beds; farmers practised both DSR and TPR depending on the amount and intensity of rain	Same rice beds used for maize planting with the help of bed planter as in FB
ST (Strip-tillage)	After rains or pre-sowing supplementary irrigation under no-till field, DSR was sown with the help of a 2-wheel tractor operated strip-till inclined plate seeder in a single operation followed by a light irrigation for seed germination, if necessary. In case of heavy rains, rice seedlings were transplanted in strips under unpuddled no- till saturated fields	After harvest of rice, maize seeds were sown in strips with the help of 2-wheel tractor operated strip tillage inclined plate planter in a single operation under no-till condition in residual moisture condition but if necessary then a light pre-sowing irrigation was given.
ZT (Zero-tillage)	After rains pre-sowing supplementary irrigation under no-till field, DSR was sown with the help of 2-wheel tractor operated zero-till seeder in a single operation followed by a light irrigation for seed germination, if necessary. In case heavy rains, rice seedlings were transplanted in line under unpuddled no- till saturated fields	After harvest of rice, maize seeds were sown in strips with the help of 2-wheel tractor operated strip tillage inclined plate planter in a single operation under no-till condition in residual moisture condition but if necessary then a light pre-sowing irrigation was given.

In R-M-MB system, in all treatments except CT, mungbean was established either as a relay crop into standing maize crop with light irrigation before 15-20 days of harvesting, or by surface seeding just after harvest of maize crop followed by a light irrigation. In rice-maize rice, both rice crops followed the same crop establishment techniques.

Design of the on-farm research trials: Two villages were selected in each *Upazilla* and two *Upazillas* were selected in each of the three districts. Initially, 5 farmers were identified in each village but later on the number of farmers was increased; individual farmer was treated as a replicate. The 4-6 tillage and crop establishment combinations were evaluated in 100 m^{-2} plot for each treatment. Same treatment plots were maintained for next crop to see the short-medium term effects of the individual treatments.

Agronomic management: In all 5-6 treatments, similar fertilizer, irrigation and insect-pest management were followed except the herbicide application. The recommended fertilizers as per BARI, BRRI under BARC fertilizer guidelines (BARC, 2012) were followed (Table 5.10).

Table 5.10. Recommended nutrient management used in different crops in on-farm trials.

Nutrient	Kg ha^{-1}					
	Aman rice	*Rabi* maize	*Aus* rice	*Boro* rice	Potato	*Kharif-1* maize
N	77	255	77	128	96	137
P	8	48	8	20	24	21
K	23	140	23	30	96	52
S	6	30	6	13	12	20
ZnSO4	0	14	0	10	9	3
Boric acid	0	8	0	0	10	3

Data collection: The standard meta-data sheets were prepared for each crop for uniform data collection across the project sites, the individual farmer identification number were defined in each site; data were collected by project staff and partners and processed for further analysis.

Cost benefit analysis: In all on-farm trials individual input and output information were collected for profit analysis of the individual technologies. Input resources, labor, seed, and fertilizer, no. of irrigation, machineries rent-in cost, fuel, herbicides and pesticides, were collected. Outputs like economic yield (grain and straw) price were collected from the current market and were used for economic analysis (Table 5.11).

Table 5.11. Prices and input rates used for calculating costs of key inputs and outputs in economic analysis during different seasons

Particulars	2009-10	2010-11	2011-12	2012-13
Rice sale price (BDT Kg^{-1})	17.2-18.8	17.5	17.5-18.5	16.5-17.5
Maize sale price (BDT Kg^{-1})	18.8-20	18.8-21.3	18.8-21.3	17.5-20
Rice straw price (BDT Kg^{-1})	2	2	2	2
Maize stover price (BDT Kg^{-1})	0.5	0.5	0.5	0.5
labor wages (BDT person-day^{-1})	150-180	150-200	200-300	200-250
Irrigation charges (BDT hr^{-1})	100	125	150	150
Maize seed (BDT Kg^{-1})	290	190	290	350
Rice Seed (BDT Kg^{-1})	45	45	45	45
Urea (BDT Kg^{-1})	12	12	22	20
TSP (BDT Kg^{-1})	40	22	24	22
MoP (BDT Kg^{-1})	25	15	15	15
Gypsum (BDT Kg^{-1})	12	12	12	10
ZnSO4 (BDT Kg^{-1})	140	140	140	150
Borax (BDT Kg^{-1})	170	170	170	170
Tillage cost (BDT ha^{-1} pass^{-1})	2000-2500	2000-2500	2000-2500	2500-3000

Seeding cost (BDT ha^{-1} $pass^{-1}$)	2500	2500	2500	3000
Threshing cost (BDT 40kg $grain^{-1}$)	30-35	30-40	30-52	30-52
Herbicides*				
Glyphosate (Round-up) (BDT lt^{-1})	840	840	840	840-950
Pendimethalene (Panida) (BDT lt^{-1})	880	880	880	880
Pesticides*				
Fipronil (BDT lt^{-1})	1000	1000	1000	-
Cabosulfuron (BDT Kg^{-1})	1300	1300	1100	1150
Hexaconazole (BDT lt^{-1})	900	900	950	900
Chloropyriphos (BDT lt^{-1})	600	600	600	600
Emidachloropid (BDT lt^{-1})	-	-	2600	2600
Furadon (BDT Kg^{-1})	-	-	120	120

*The herbicides and pesticides listed only most commonly used by farmers but other also included in input cost which might be not listed here

Data analysis and reporting: All data were inputted in excel sheets as per the standard meta-sheets, tabulated and data were analysed for individual crops by using a mixed model in SAS as designs were imbalanced. Pooled treatment adjusted means were compared by Tukey's honest significant difference (HSD). The ANOVA was presented by year, replication, treatment, year X treatment interactions but in overall analysis the district was also included in ANOVA. The results were also presented for systems trials for both R-M-R and R-M-MB systems from the permanent trials and analyzed by using same techniquesResults were interpreted on system perspective.

5.2.3.1.2 Performance of rabi maize under different environment x tillage x hybrid in three districts of Bangladesh:

A study was conducted to identify the environment x genotype x tillage and nutrient interactions in farmers' fields. The objectives of the study were 1) to evaluate the performance of maize hybrids under different tillage systems; 2) to evaluate the performance of decision tool based nutrient management under different tillage systems and variety; 3) evaluate the performance of maize genotypes under different environments. There were 6 environments (*Upazillas*) in 3 districts and two tillage options viz. conventional tillage and strip tillage and on six maize hybrids (BHM-9, Sunshine, Pinnacle, 900 M Gold, 981, and Pacific 984) were superimposed on the tillage options . The experiment was conducted in split-split plot design keeping the 50 m^{-2} smallest unit plot size and 3-replicates in each *upazillla*.

Tillage:

1. Strip tillage (Nutrient management by NM): Single pass seeding + basal fertilizer application using strip tillage with 20-25 cm standing *T. Aman* residue height retention
2. Conventional tillage (Nutrient management by NM): Three full tillage passes with a power tiller, followed by a single planking, and then manual seeding by dibbling.

*Maize hybrids***:** The prominent 6 maize hybrids chosen considering the maturity group were:

1. BHM-9 (BARI hybrid)
2. Sunshine (Syngenta hybrid)
3. Pinnacle (Monsanto)
4. 900 m Gold (Monsanto)
5. 981 (Monsanto)
6. Pacific 984

5.2.3.1.3 Performance of hybrid rice in boro/rabi season across Bangladesh (2010-11):

Hybrid rice trials were conducted in five districts across Bangladesh. The three districts in central and north (Gazipur, Rajshahi and Rangpur) represented R-M sites while the other two in the south (Barisal and Satkhhira) represented the CSISA sites. The southern sites have considerable amount of salinity during the boro season. BRRI hybrid dhan 2 and 3 are developed by BRRI, Alloron and Shathi hybrids are developed by BRAC while Hira 2 is already grown hybrid for some time in Bangladesh. The two hybrids, BIO404 and BIO452 are developed by BioSeeds, India. BRRI dhan 28 is a popular inbred recommended for Boro while BRRI dhan 47 and BINA dhan 8 are salt-tolerant inbreds, also grown in boro. The locally-grown inbreds were used for comparison.

5.2.3.2 Site specific nutrient Management (SSNM) through decision support tools (Crop Manager/Nutrient Expert):

In SSNM study, several nutrient omission and sufficiency plot trials were undertaken in *Aman* and *Boro* rice and in *Rabi* and *Kharif*-1 maize during 2008-2011 to determine the indigenous nutrient soil-supplying capacity in various *upazillas* and for evaluation of the decision support tools for nutrient management. Further, decision support tool based SSNM evaluation and validation trials were conducted during 2011-2013.

5.2.3.2.1 Nutrient omission plot trials for boro rice:

Nutrient omission plot trials were conducted in all three districts. These trials aimed at determining the inherent nutrient-supplying capacity of soil and formulate nutrient requirements for *boro* rice through the yield gain approach. Eight nutrient treatments were compared in each of those fields in the three districts (Table 5.12). The treatments included: (i) a base of NPKSZn (the dose of each nutrient was determined based on the national fertilizer recommendation for the region), (ii) omission of N (– N), (iii) omission of P (– P), (iv) omission of K (– K), (v) omission of S and Zn (– SZn), (vi) omission of Zn (– Zn) from the base treatment, and (vii) regular application of NPSZn but reduced K dose. All the treatments were compared in each farmer's field, considering one farmer as one replication. The complete NPKSZn-treated plot at each district received 132 kg N, 15 kg P, 59 kg K, 10 kg S, and 5 kg Zn, respectively.

5.2.3.2.2 Nutrient Manager (NM) for aman and boro rice evaluation:

Nutrient Manager trials for aman and boro rice were evaluated in several farmers' fields (Table 5.13) in seven upazillas of the three districts during different years. Three treatments were evaluated in the Nutrient Manager for *aman* rice trials: (i) farmer's fertilizer practice-FFP, (ii) BRRI recommendation, and (iii) NM based recommendation. Likewise, four treatments were evaluated for *boro* rice: (i) farmer's fertilizer practice (ii) soil test based recommendation provided by SRDI (iii) BRRI recommendation and (iv) NM-based recommendation. Different rice cultivars/hybrids were used in different farmer's field. For further validation and outreach of Crop Manager in 2012-13, project initiated the SSNM through decision support tool (Crop Manager) prescription for boro rice, and with the help of project partners,and project staff, DAE prescribed the fertilizer recommendations based on Crop Manager for rice to 200 farmers' fields in each district (600 farmers in three districts) after collecting the information as desired for Crop Manager, and out of them 10 farmers were closely monitored for data collection.

5.2.3.2.3 Nutrient omission and sufficiency trials and Nutrient Manager trials for rabi maize:

During the initial three years from 2008-09 to 2011-12, the project conducted nutrient omission and sufficiency plot trials in *rabi* maize but we also included reduced fertilizers rates treatments to know the efficiency of the individual nutrients across the three project districts. As expected, *rabi* maize response to N, P, K, S and Zn was variable across sites. However, in Comilla, it was not clear from those trials whether there was S and Zn deficiency or whether more than expected yield response to K was real or artefact. On the basis of three years' results, we decided to evaluate the prototype version of NM for *rabi* maize in Rajshahi and Rangpur during 2011-12 and continued to conduct one more season of omission plot trials in Comilla. The planning and design of omission plot trial was done upon discussion and in collaboration with the CSISA-BD. CIMMYT scientists involved with CSISA-Bangladesh conducted several omission plot trials in CSISA hubs, including the central and northern hubs. By considering the previous 2 years of data from omission plot trials in Comilla and also in line with CSISA-BD, five treatments were evaluated: -N, -P, -K, Full NPK and Full NPKSZn (Tables 5.13, 5.15). In the NM for *rabi* maize evaluation trial also, five treatments were evaluated: NM (NM-based recommendation), NMKr (NM recommendation with reduced amount of K, NM-S (NM-based recommendation but without S), SRDI recommendation and SRDI NM-N (SRDI recommendation for other nutrients except NM-based recommendation for N (Table 5.14). Further, in 2012-13, again evaluation trials were conducted with several farmers across Bangladesh jointly with CSISA-BD by keeping the omission and sufficiency treatments.

Table 5.13. Omission and sufficiency SSNM trials undertaken in different crops during 2008-09 to 2012-13

Location	2009-10 *Boro* rice	2008-09 *Rabi* maize	2009 *Kharif-1* maize	2009-10 *Rabi* maize	2010 *Kharif-1* maize	2010-11 *Rabi* maize	2011-12 *Rabi* maize	2012-13 *Rabi* maize
Rangpur	10	5	6	5	5	8	-	17
Rajshahi	10	5	4	9	14	8	4	20
Comilla	12	-	7	16	11	31	27	26

Table 5.14. Fertilizer decision support tool (Nutrient Manager) evaluation trials undertaken in different crops during 2008-09 to 2012-13

Location	2009-10		2010-11			2011-12					2012-13		
	Aman	*Boro*	*Aman*	*Boro*	*Kharif-1*	*Aman*	*Rabi* maiz	*Boro*	*Kharif-1*	*Rabi*	*Boro*	*Kharif -1*	*Aman*

					mai ze		e		maiz e	mai ze		maiz e	
Rangpur	6	5	9	20	7	58	20	-	10	-	10	10	20
Rajshahi	13	15	14	20	19	45	19	-	22	-	10	10	10
Comilla	30	10	19	29	26	50	-	-	23	-	31	-	30

Table 5.15 Treatment details for SSNM for *rabi* maize during 2008-09 to 2012-13

Treatment	2008-09	2009-10	2010-11	2011-12	2012-13
-N	√	√	√	√	√
-P	√	√	√	√	√
-K	√	√	√	√	√
NPK	√	√	√	√	√
NPKZnS	√	√	√	√	√
NK and low P	√	√	√	-	-
NP and low K	√	√	√	-	-
N and low PK	√	√	√	-	-
NM	-	-	-	√	√
SRDI (STB)	-	-	-	√	√
BARI/BARC	-	-	-	√	√
Nutrient Expert	-	-	-	√	√
Farmer practice	-	-	-	√	√

5.2.3.2.4 Nutrient omission and sufficiency trials and Nutrient Manager trials for kharif-1 maize:

In similar fashion, nutrient omission and sufficiency trials and Nutrient Manager evaluation trials in *kharif-1* maize under R-P-M system were conducted in 161 farmers' fields in three districts during 2008-09 to 2012-13. Forty-two trials were conducted during 2009 and 2010 only and 119 trials during 2011-2013. The treatment details for nutrient omission trials are presented in table 5.16 and summary of number of trials is presented in Table 5.14.

Table 5.16 Treatment details for SSNM for *kharif-1* maize during 2008-09 to 2012-13

Treatment	2009	2010	2011	2012	2013
-N	√	√	-	-	-
-P	√	√	-	-	-
-K	√	√	-	-	-
-N-P-K	√	√	-	-	-
Full NPK	√	√	-	-	-
Farmer fertilizer practice	-	-	√	√	√
BARI/BARC recommendation	-	-	√	√	-
Nutrient Manager high dose (NMH)	-	-	√	√	-
Nutrient Manager current dose (NMC)	-	-	√	√	-
Nutrient Manager(NM)	-	-			√

5.2.3.2.5 Field validation of soil K supplying capacity of low, medium and high K containing soil for rabi maize and boro rice 2011-12 and 2012-13

This experiment was conducted as part of a Ph.D. student's thesis to determine the soil K supplying capacity of 18 diverse soils of Bangladesh at BRRI greenhouse at Gazipur. The study was conducted in pots for 6-7 growth cycles for each rice and maize crop under control conditions in 2011-12. During 2012-13 further verification and validation of pot study was carried out through multi-location trials in all three districts. The study was conducted in farmers' fields with 7 treatments consisting of different levels of K (Table 5.17). A trial with one set of the five levels of K from low to high dose and NP were applied based on Nutrient Expert and Nutrient Manager and other micro nutrients were applied as blanket dose according to BARI/SRDI recommendation. The study was conducted in 2 farmers fields in each upazilla, with 12 trials in total.

Table 5.17. Treatment details for soil K supplying capacity study

Treatment code	Explanation
K0+NP based on NE	For determining indigenous soil K supply
K40+NP based on NE	For determining yield gain with low K rate
K80+NP based on NE	For determining yield gain with moderate K rate
K120+NP based on NE	For determining yield gain with optimum K rate
K160+NP based on NE	For determining yield gain with high K rate
NPK based on NE	Evaluation of Nutrient Expert
NPK based on NM	Evaluation of Nutrient Manager

5.2.3.3 On-station experiments:

5.2.3.3.1 Effect of rice and maize establishment methods on weed population and successive residual effects and annual productivity in R-M systems:

An experiment on tillage/crop establishment techniques and weed control methods in R-M system was established at the BRRI regional station, Rangpur, in 2009. The objectives of the experiment were to evaluate the new tillage/crop establishment techniques in rice and their effects on weed dynamics and carry over effects of rice tillage/crop establishment techniques on succeeding maize crop in a R-M system. Three crop establishment methods, dry direct seeding rice in zero tillage (ZTDSR), dry direct seeding in conventional tillage (CTDSR), and transplanting by conventional tillage (CTTPR) were compared with three weed control methods- no weed control (T0), two hand weeding at 28 and 56 days after sowing/transplanting (HW), and best-bet herbicide + one hand weeding at 28 days after sowing/transplanting (CW). Seeding of the following maize was done with two tillage options: conventional tillage maize seeding (CTM) and zero tillage maize seeding (ZTM). The two tillage options were superimposed on rice tillage/crop establishment options. Normal weed management practices were followed in all maize plots. The unit plot size was 6.2 × 3.6 m. The experiment was conducted in a split-split plot design (rice tillage/crop establishment method in the main plot, maize tillage in sub-plot and weed control in the sub-sub plot). Panida 33EC (pendimethalin), a pre-emergence herbicide, at 40 mL in 20 L of water for 5 decimals of land (at 2 L ha^{-1}) was applied in moist soil conditions in the CW plots under ZTDSR and CTDSR at 2 days after seeding and in TPR it was sprayed at 6 days after transplanting. Roundup (isopropyl salt of glyphosate), a pre-planting nonselective herbicide, was applied at 2.5 L ha^{-1} (1000 g a.i.ha^{-1}) in ZT 6 days before sowing maize. The CT plots received conventional land preparation for loosening soils and weed control by tilling the plots by power tiller. BRRI dhan 33, a short duration rice variety was used in all plots during all years and Hybrid maize (var. NK40) was sown by dibbling in ZT and in furrows in CT at a distance of 60 cm between lines and 20 cm between seeds. The soil of the experimental site had 6.44 pH, 0.86% organic matter, 0.1 cmol kg^{-1} K, and 13 mg kg^{-1} S. Cultivation was carried out "within plots" to avoid soil/seed spread. All plots were separated by small bunds of 0.5/0.4 m as per layout (copy attached).

Details of treatments:

The experimental design was randomized strip-split-split plot with four replications.

Sub- plot plots (maize): Zero tillage (ZTM) maize; Conventional tillage (CTM) maize

Main plots (rice): Dry-seeded rice (DSR) under ZT (ZTDSR); DSR under CT (CTDSR); Puddled transplanted rice (TPR)

Sub-sub-plots (rice): TC = no weed control; HW = two hand weeding at 28 and 56 days after sowing (DAS)/days after transplanting (DAT); CW= best bet herbicide (Rifit/Pretilachlor as pre-emergence herbicide applied @ 1.0 l ha^{-1} at 5-7 DAT or Serius/Pyrazosulphy as post-emergence applied @ 150 g ha^{-1} at 10-15 DAT for TPR, and Panida/Pendimethalin or Ronstar/Oxadiazon as pre-emergence for DSR @ 2.5 and 1.5 l ha^{-1} respectively at 2-3 DAS) (hence, Panida 33 EC (Pendimethalin) applied at rate of 2 l ha^{-1} at 2 DAS in DSR and at 6 DAT for TPR) + one hand weeding 28 DAS/DAT. Same herbicide will be used each year. So, caution will be made to select the herbicide in the first year so that it won't be changed from the second year.

5.2.3.3.2 Optimization of maize hybrid population

An experiment with different plant population on a maize hybrid NK40 was initiated at BRRI Regional station, Rangpur, from 2009-10 to 2011-12 in *rabi* season. Rangpur lies under AEZ-3 and the geological position is 25°41´42.09˝N and 89°16´ 07.28˝E with Elev. 108 ft. Soil type is sandy loam and pH level was 6.44. The experiment was laid out in a randomized complete block design with three replications.

There were different levels of plant population during the first year (2009-10). Based on the results of the first year (2009-10), five modified levels of plant population were chosen for evaluation in the second (2010-11) and third year (2011-12) (Table 5.18).

Table 5.18: Plant geometry and population (ha^{-1}) details

Treatment	2009-10		2010-2012	
	Spacing	Plant population	Spacing	Plant population
T1	75x25 cm	53000	70x20 cm	65000
T2	75x22 cm	60000	65x22 cm	70000
T3	70x22 cm	65000	60x22 cm	75000
T4	65x25 cm	70000	55x22 cm	82000
T5	60x22 cm	75000	50x22 cm	90000

The land was ploughed three times with a power tiller and sowing was done manually. Fertilizer was applied @ 532-250-200-250-13-11 as Urea-TSP-MoP-Gypsum-Zinc Sulphate-Boric acid kg ha^{-1} .One-third urea and fifty percent of MoP were applied as basal. 1/3 urea was applied at 6 leaves (V6) stage. The remaining urea and MoP were applied at 10 leaves (V10) stage. All TSP, gypsum and $ZnSO_4$ were applied as basal. Irrigation was applied at 15-20 (4-6 leaf stage; V4-V6), 30-35 (8 leaf stage; V8), 60-70 (tassel initiation stage; VT), and 85-90 (grain filling stage) days after sowing (DAS) in maize plots. Two-hand weeding was done at 28 & 56 DAS.

5.2.3.3.3 Evaluation of pre- and post-emergence herbicides for weed control in aman direct-seeded rice:

This experiment was conducted in 3 replications at BRRI station in Rajshahi and on a farmer's field near BRRI station; both experiment were managed by researchers. There were 14 treatments with different combinations of hand weeding and herbicides (Table 5.19). The unit

Table .5.19 Treatments details for the pre- and post-emergence herbicide trial in Rajshahi and Rangpur

Treatment	Treatment description
Panida(pre)	Pendamethalin (Panida) is a pre-emergence herbicide which was applied @1.0 kg a.i ha^{-1} in 500L water at 2 days after sowing rice seed
Topstar(pre)	Oxadiargyl (Topstar) is a pre-emergence herbicide which was applied @0.09 g a.i ha^{-1} in 500L water at 2 days after sowing rice seed.
Hammar(post)	Copentazole-ethyl (Hammar) is a post emergence herbicide which applied @0.035 kg a.i ha^{-1} in 500L water at 15 days after sowing rice seed
Sunrise(post)	Ethoxy (Sunrise) is a post emergence herbicide which applied @ @0.02 kg a.i ha^{-1} in 500L water 15 days after sowing rice seed
Panida+1HW	Pendamethalin (Panida) applied @1.0 kg a.i ha^{-1} at 2 days after sowing rice seed and d 1 hand weeding was done at 30 DAS
Panida+Hammar	Panida was applied @1.0 kg a.i ha^{-1} at 2 day after sowing rice seed and Hammar was applied @ 0.035 kg a.i ha^{-1} in 500L water at 15 days after sowing rice seed
Panida+sunrise	Panida was applied @1.0 kg a.i ha^{-1} at 2 day after sowing rice seed and sun rise applied @ @0.02 kg a.i ha^{-1} in 500L water 15 days after sowing rice seed
Topstar+1HW	Topstar which was applied @0.09 g a.i ha^{-1} in 500L water at 2 days after sowing rice seed before emergence weed and 1 hand weeding was done at 28 DAS
Topstar+Hammar	Topstar was applied @0.09 g a.i ha^{-1} in 500L water at 2 days after sowing rice seed before emergence weed and hammar was applied @0.035 kg a.i ha^{-1} in 500L water 15 days after sowing rice seed
Topstar+Sunrise	Topstar was applied @0.09 g a.i ha^{-1} in 500L water at 2 days after sowing rice seed before emergence weed and Sunrise was applied @0.02 kg a.i ha^{-1} in 500L water 15 days after sowing rice seed
Hammar+1HW	Hammar was applied @0.035 kg a.i ha^{-1} in 500L water at 15 days after sowing rice seed and 1 hand weeding was done at 28 DAS
Sunrise+1HW	Sunrise was applied @0.02 kg a.i ha^{-1} in 500L water at 15 days after sowing rice seed and 1 hand weeding was done at 28 DAS
Weedfree	3 times of hand weeding were done at 15, 30 and 56 DAS
Weedy	Only 1 time hand weeding was done at 28 DAS

plot size was 50 m^2. All the treatments received one application of glyphosate (Roundup) @1.0 kg a.i. ha^{-1} using 500 L water 3-7 days before sowing the DSR. Farmer's locally-made "Lithao" was used for sowing rice seeds under zero tillage condition. Objectives of this study were: (i) to evaluate the selected herbicides available in Bangladesh and (2) to recommend the best integrated weed management option for DSR. The experiment was conducted in randomized complete block design using three replications in two locations in 2010 and at one location in 2012 BRRI stations.

5.2.3.3.4 Effect of different tillage/crop establishment methods and residue management options in R-M-MB system:

An experiment was established at BRRI, Rajshahi station during 2009-10 to 2012-13, comprising of six tillage/crop establishment options and three residue management options in R-M-MB system. The tillage treatments included: 1) conventional tillage and rice seedling transplanting followed by conventional tillage maize seeding and then conventional tillage mungbean seeding (CTTPR-CTM-CTMB); 2) minimum dry tillage with PTOS then rice transplanting - minimum tillage manual maize seeding-mungbean seeding (MTTPR-MTM-MTMB); 3) strip tillage then transplanted rice -strip tillage maize-strip mungbean (STTPR-STM-STMB); 4) permanent beds (transplanted rice on side of beds - maize planting on beds-mungbean planting on beds (PBTPR-PBM-PBMB); 5) zero tillage transplanted rice-zero tillage maize-zero-till mungbean (ZTTPR-ZTM-ZTMB) and 6) fresh beds transplanted rice-fresh bed maize planting-fresh bed mungbean (FBTPR-FBM–FBMB). The residue management options included: no residue retention, 50% residue retention and 100% residue retention. The experiment was laid-out in a split plot design with unit plot size 50m^{-2} in three replications. Recommended fertilizer and management practices were followed in all treatments as per the protocol.

5.2.3.3.5 Study on tillage and maize hybrid options under R-M-MB system:

A CA-based medium-term replicated demonstration trial comprising of six tillage methods and three maize hybrids was initiated at the Regional Wheat Research Centre (RWRC), Rajshahi since the *rabi* season 2009-10. The tillage treatments included, reduced tillage (RT), strip tillage (ST), permanent bed (PB), fresh beds (FB), zero tillage (ZT), and conventional tillage (CT). The tested maize hybrids were 900-M Gold, Pinnacle, and BHM-8. The same tillage treatments were maintained in *aman* rice using the rice variety BRRI-39. All the maize plots were seeded manually and a flat dose of fertilizer (254 kg ha^{-1} N from urea, 39 kg ha^{-1} P from TSP, 71 kg ha^{-1} K from MoP, 27 kg ha^{-1} S from gypsum, 5 kg ha^{-1} Zn from zinc sulfate, and 1.4 kg ha^{-1} B from borax) was applied to maize. All the fertilizers except urea and MoP were applied basally. Urea was applied in three equal splits- basal and at the V6 and V10 stages. Half of the MoP was applied as basal and the rest was applied at V10. The recommended fertilizer practices were followed during rice. Plant population and grain yield were collected from a 5-m^2 area in three replicates within each plot and yield was adjusted to 15.5% and 13 % moisture content for maize and wheat, respectively.

5.2.3.3.6 Study on tillage options in R-M-MB system:

The experiment at BARI, Comilla, began in 2009 with mungbean as the first crop under the R-M-MB system. The soil in the experimental field was acidic in nature, low in organic matter, total N, and exchangeable K, but adequate available P and Zn (Table 5.20).

Table: 5.20. Chemical characteristics of soil before sowing of mungbean (BARI station, Comilla, March 2009)

Sampling depth (cm)	pH	OM%	Ca	Mg	K	Total N	P	S	B	Cu	Fe	Mn	Zn
	Meq 100 mL^{-1}					%	µg mL^{-1}						
0–20	5.8	1.01	1.5	0.55	0.09	0.053	18	14	0.36	6.00	337	93	5.1
20–40	6.5	0.49	2.8	0.98	0.10	0.026	14	12	0.34	1.10	72	38	6.3
40–60	6.8	0.42	3.8	1.30	0.11	0.022	26	27	0.30	1.80	236	74	6.5
Critical level			2.0	0.40	0.20		14	14	0.20	1.00	10	5.0	2.0

The experiment compared three treatments: (i) Conventional tillage (CT), (ii) Permanent beds (PB) and (iii) Reduced tillage (RT), each in 10 × 5-m unit plot size. Each of the treatments was replicated thrice in a randomized complete block design. The first crop, BARI Mug 6, was sown at 30 × 20-cm spacing and thinned to one plant per hole (or hill) 2 weeks after emergence. Mungbean received 40 kg N, 46 kg P_2O_5, and 33 kg K_2O ha^{-1} from urea, triple superphosphate (TSP), and muriate of potash (MoP), respectively. The crop was irrigated and all weeds, diseases, and insects were controlled, as and when necessary. Data on grain and straw yield were recorded from 5-m^2 area while number of plants/m^2, pods/plant, branches/plant, seeds/pod, pod length, and 100-seed wt were recorded from 1 m^2 area. Rice variety BINA dhan7 was grown after mungbean with spacing of 20 × 20 cm. The PB and RT plots received Roundup (glyphosate), a nonselective herbicide, 1 week before sowing and a pre-emergence herbicide Panida (pendimethalin) was applied 1 day after sowing. The CT plot did not receive herbicide but was kept weed-free by weeding manually. The rice crop was irrigated, and all diseases and insects were controlled, as and when necessary. At maturity, grain and straw yields were obtained from 5- and 1-m^2 areas. Following the rice harvest, the experimental field was sprayed with Roundup @ 10 mL L^{-1} 7 days before land preparation to control weeds. Maize hybrid NK40 was sown at 60 × 25-cm spacing. The crop received 255 kg ha^{-1} N, 100 kg ha^{-1} P_2O_5, and 170 kg ha^{-1} K_2O from urea, TSP, and MoP, respectively and 30, 5, and 1.4 kg ha^{-1} S, Zn, and B from gypsum, $ZnSO_4$, and borax, respectively. Nitrogen was applied in 3 equal splits: basal, and at the V6 and V10 stages; P as basal; and K in 2 equal splits: basal and at the V10 stage. All S, Zn, and B were applied as basal. Intercultural operations such as weeding, irrigation, and thinning were done as and when necessary. Insecticides, Furadan and Sevin powder, were applied just after sowing to control insects. Decis @ 2 mL L^{-1} was sprayed at 14 and 24 DAS to control leaf feeders. The sampling area for grain and stover was 5 m^2 and 6 plants, respectively. Grain yields of rice, maize, and mungbean were adjusted to 14%, 15.5%, and 12% moisture content and straw yield was determined on an oven-dry basis.

5.2.3.3.7 Study on tillage options in a R-P-M system:

This experiment was also initiated at BARI station in Comilla in 2009 with *Kharif*-1 maize as the first crop under R-P-M system. The experiment was located close to the R-M-MB system site as mentioned above with similar landscape and soil properties. In this experiment also, there were three treatments (CT, RT, and PB) each season during each year as above for R-M-MB system and so it is considered as a permanent experiment.

5.2.3.3.7 Evaluation of conservation tillage and weed management options on production potential and weed incidences for dry seeded rice

The experiment was carried out at BRRI Regional station, Rajshahi (24°69´latitude N, 88°30 longitude E) in the wet season of 2010 and 2011. The experiment was laid out in a split plot design with three replications. The main plot treatments were Zero tillage (ZT), Strip tillage (ST), Minimum tillage using PTOS (MT), Permanent bed (PB), Fresh bed (FB) and Conventional tillage (CT). Except conventional tillage, other treatments were termed as conservation tillage. The subplot treatments were Weed free (W_1); Post emergence herbicide + 1 hand weeding (W_2), Pre-emergence herbicide + Post-emergence herbicide (W_3), Post emergence herbicide (W_4) and Weedy control (W_5). Pendimethtlene and Nominee gold (bispyribac Na+), respectively were applied as pre- and post-emergence herbicides at 3 and 15 days after seeding. The soil of the experimental plot was low in organic matter (1.35%), very low in available N (0.07%) and low in P, K, S and Zn and having soil reaction in slightly alkaline range (8.3). Except CT, rice was established in dry direct seeding in all five conservation tillage treatments. Glyphosate (Roundup) was applied in untilled soil @ 1.0 kg a.i. ha^{-1} using 500 L water 3 days before sowing of seeds in all conservation tillage treatments. The rice variety was BRRI dhan 49 and the conventional transplanting method was followed in case of CT. Seeds @ 30 kg ha^{-1} were sown on 18 and 26 June, respectively and harvested in first week of November during both the years. In case of ZT, little slits apart from 20 cm distance rows were made in the untilled soil by hook like iron made structure locally called lithao and then the seeds were sown manually in the slits of land followed by covering the soil. In case of ST and MT, seed sowing was done in untilled soil through one pass with the PTOS. Fresh beds were prepared by a bed planter in untilled soil and seeds sown simultaneously through the bed planter. In the first crops, both permanent bed and fresh bed treatments were same. For the next season crop, permanent beds were not destroyed an they were just renovated and then seeds were sown. BRRI recommend fertilizer doses were used and irrigation and pest control measures were taken as and when necessary. Total weeds were counted and weights recorded on the dry matter basis at21 DAT/28 DAS (first weeding) and 42 DAT/56 DAS (second weeding). Other agronomic parameters were measured at harvest and data were analyzed using Crop Stat (version 7.2) program.

6 Achievements against activities and outputs/milestones

Objective 1: To assess and prioritize the constraints to, opportunities for, and uptake of improved management options in R-M systems

No.	Activity	Outputs/ milestones	Completion date	Comments
1.1	Strategic assessment (SA) of R-M systems	Focused synthesis report of the inception workshop	December, 2008	Inception workshop was successfully conducted at BRRI Gazipur, report were synthesized and submitted to ACIAR
		Past farmer studies reviewed and conceptual framework developed	May 2009	Information obtained from the secondary data has been fed into the village survey reports, Identified the key indicators trough farmers and extension agents group discussion in communities. Farmers were identified and selected in consultation with communities and local governess for adaptive trials.
		Stakeholder consultations and diagnostic village surveys completed in 3 project districts	Original surveys completed by 30 Jun 2009; but consultations an diagnosis continued till end of the project	There have been frequent interactions with, input dealers, service providers, extension agents and farmers through farmers' field days, farmers' training, household interviews, and on-farm monitoring during the conduct of on-farm trials and farmers' feedback on technologies received. Such information was used to design and/or modify the treatments in on-farm and on-station trials.
		Secondary data compiled and reviewed	December 2009 and 2011; IRRI-CIMMYT book released	Relevant information and data on R-M systems and Conservation Agriculture (CA) were reviewed based on the available literature in south Asia and incorporated into various decision making processes and in the annual technical reports submitted to ACIAR. A book “Rice-maize systems in Asia: current situation and potential” was published by Timsina et al. as joint IRRI-CIMMYT publication
		Comprehensive report	June 2010	A comprehensive report were prepared and published in IRRI IBO annual report and fed into household survey report
1.2	Economic analysis of R-M systems and interventions for selected sites	Base line village survey based on focused group discussion completed in 3 project districts	June 2010	Baseline survey was successfully conducted in six upazillas in three districts, data were inputted and analysed, data reported in a semi-annual report 2011 and in the technical report 2012. See detail in result section
		Base line Household survey completed in 3 project districts	June 2010	A baseline household survey was conducted using 20 households in each village of 18 villages in three districts. Data were analysed and report prepared.

				See detail in result section
		Survey report	June 2011	Both village surveys and household surveys were completed and covered in 2011 semi-annual report and in 2012 annual technical report See result section
		Partial budget analysis of on-farm trials	30 Jun 2009/10/ 11/12	Mid-term project adoption surveys were conducted using the control villages in all upazillas;farmers participating in the adaptive research trials were included in the surveys and reports prepared See details in result section
1.3	Impact assessment of key R-M options	Completion of impact survey work	June 2013	Final adoption survey was conducted in 18 villages of three districts; A total of 200 farmers representing each district were surveyed. Adoption rate and impact of new technologies were analysed.
		Survey report	December 2013	Report prepared. See details in result section

PC = partner country, A = Australia

Objective 2: To evaluate elite maize germplasm for tolerance of excess moisture during seedling emergence and at flowering for the *rabi* and *kharif*-I seasons

No.	***Activity***	***Outputs/ milestones***	***Completion date***	***Comments***
2.1	Screen elite hybrids and OPVs, and advanced-generation inbred lines	Screened 250 inbreeds/hybrids in 2009-10, 30 inbreeds/hybrids in 2010-11 and 2011-12 *rabi* season	June 2010, 2011 and 2012	The inbreeds and hybrids were screened trough cup screening methods at BARI Gazipur research station, promising genotypes/hybrids were identified for further breeding programs for both *rabi* (winter season) and *Kharif* -1 maize season. Only moderately less susceptible materials were notified.
		Screened 180 inbreeds/hybrids in 2010-11 and 2011-12 for /kharif-1 season		Details are presented in results section
2.2	Evaluate top-ranking promising cultivars (5) through on-farm trials (3.1)	Evaluated 28 imported hybrids along with three BARI developed hybrids–BARI Hybrid Maize 5 (BHM-5), BARI Hybrid Maize 7 (BHM-7), and BARI Hybrid Maize 9 (BHM-9) in 2009-10 *rabi* season.	June 2010	Five hybrids, Prince, JKMH-502, NA-04, Victory super, and BHM-7, were found relatively promising across the locations.
		Evaluation trials of 5 hybrids (Uttaran, Pacific 60, 900 M gold, Pinnacle, and F_1 of CML254 × CML 247) have been set up in 5 districts during 2010-11 and 2011-12.	June 2011 and 2012	Field experiments at Gazipur, Jamalpur, Rangpur, Satkhira, and Barisal were successfully conducted but only moderately water logged tolerance were observed at early stage but none of materials performed well when waterlogging was imposed at flowering stage. Details are presented in result section

		Excess moisture tolerance at late vegetative stage: field screening for excess moisture during V8 to V10 (kharif-1)	August 2010	Screened 90 inbred lines for excess water tolerance at V8–V10 stage under field conditions in kharif-1 in 2010. None of the inbred lines survived under excess moisture stress at V8 stage. Details are presented in result section
2.3	Develop and evaluate test-crosses using promising tolerant lines identified in 2.1	Test-crosses developed Test-crosses evaluated for early- and late-stage tolerance	Oct 2009 Apr 2010	In reality there was only little breeding program were under taken due to lack of resources but other CIMMYT supported BMZ project undertook advance breeding program for waterlogging at both early and late stages. BARI released the series of hybrid maize from BHM 5 to 9 and seeds were multiplied by BADC and BARI
2.4	Do seed multiplication and on-farm evaluation of promising test-crosses and elite inbreeds and hybrids	Seed of promising entries multiplied Early-season stress On-farm trials Late-season stress On-farm trials	Oct 2011 Mar 2012/13 Apr 2012/13	New hybrids which are more tolerant to abiotic and biotic stresses were promoted at farmers' fields; BARI maize hybrid seeds were distributed to farmers for popularization

Objective 3: To develop locally adapted integrated management solutions for high-yielding, profitable, resource-efficient, and sustainable R-M systems

No.	Activity	Outputs/ milestones	Completion date	Comments
3.1	Conduct farmer participatory adaptive trials	CA based Trials: CA- based crop management options for R-M-MB and R-M-R systems were evaluated with 6 tillage and crop establishment techniques through farmers' participatory trials. More details are described in methodology and key results and discussion sections.	Dec 2009 to May 2013	Farmers participatory trials were successfully conducted in all six Upazillas of three districts, each upazilla with at least 10 trials (at least 60 in each season) in each season were conducted by project core partners (BARI, BRRI, BARD and RDRS), most of trials were evaluated in system perspectives and try to maintain the same farmers over the years with addition of new farmers with time and year but a few farmers who joined initially left due to unavoidable situations (land tenancy with their owners, land fragmented due to separations of bothers in the joint family,etc). All 5 year data were compiled and analysed by using SAS and detailed results described under key results section
		Improved agronomic management in R-P-M system under reduced tillage farmers participatory trials (conventional, improved beds, and reduced tillage)	June 2009-May 2011	Trials were successfully implemented by core partners as mentioned above; at least 30 trials were conducted, 5 trials in each upazzilla, and data were collected in standard excel sheets and analysed and covered in annual reports and semi-annual reports
		Environment x tillage x hybrid interaction farmers participatory trials	May 2012	In 2011-12, farmers' participatory maize trials were successfully conducted in 18 farmers' fields by project partners; data were analysed by ExT, ExG, TxG, and ExTxG interactions and results are presented in key results section.

		Site-specific nutrient management trials: Nutrient omission trialstrials were conducted to determine inherent soil nutrient supplying capacity for Boro rice Validation and evaluation of Nutrient Manager for boro rice and NM recommendation for farmers	2009 to May 2010 2009 to June 2011	The 22 farmers participatory trials (10 Rajshahi, 12 Comilla and 10 Rangpur) were successfully conducted with the collaboration of IPNI to determine the soil inherent soil nutrient supplying capacity for boro rice to make the nutrient recommendation based on attainable yield target. The details were covered under IPNI-IRRI-CIMMYT final report (DPPC2009-141). In total 81 NM evaluations and validation trials were conducted at farmers' fields in three districts, each with 4 to 6 treatments. Further, in 2012-13, project partners and staff made recommendations to more than 600 farmers by interviewing them, out of which 60 farmers were closely monitored for complete data collection.
		Nutrient omission trials to determine inherent soil nutrient supplying capacity for Kharif-1 maize	February 2009 to May 2013	A series of nutrient omission and inherent soil nutrient supplying capacity for Kharif-1 maize under R-P-M system followed by nutrient evaluation and validation trials for Crop/Nutrient Manager development were successfully conducted. In 20 and 22 trials respectively in 2009 and 2010. Further, evaluation and validation trials were conducted with 120 farmers across the three districts during 2011-2013. Data were analysed and results partially reported in the IPNI-IRRI-CIMMYT final report (DPPC2009-141) and the IPNI annual reports of 2011 and 2012.
		Nutrient omission trials to determine inherent soil nutrient supplying capacity followed by evaluation and validation trials for *rabi* maize	2009 to May 2013	About 190 nutrient omission trials were conducted for feeding into the Maize Crop Manager during 2009 to 2012. Data were collected and fed in Crop Manager software followed by conduct of evaluation and validation trials in 100 farmers fields. Data compilation and analysis is going on. . Initials results are presented in Key results sections.
		Nutrient/Crop Manager evaluation and validation trials for Aman rice	2009 to November, 2013	The aman rice Nutrient Manager was in advance stage so, there was no further need for omission trials. , The project conducted around 230 farmers' participatory NM/CM trials. The results were shared with NARES in Bangladesh and their feedback obtained. Subsequently, Crop Manager was indorsed and released by BRRI for extension and the DAE has now taken up for large scale outreach in farmers' fields.
		Determine the soil K-supplying capacity for *rabi* maize and boro rice	November 2012- May 2013	This is part of Ph.D. research of Mr. Saiful Islam, under R-M-IPNI collaboration. 12 field trials in each of the crops were conducted. The initials results are presented in Results sections
		Key technologies accepted by a range of stakeholders for wide-scale dissemination	November 2011 to May 2013	CA-based crop management practices were well accepted by the farmers. Mechanized 2-Wheel Tractor operated seeders (Bed planter, strip tillage planter and PTOS) and SSNM for rice through Crop Manager were taken up by NARES

				and extension agencies. Details are covered in objective 4.
3.2	Conduct researcher-managed experiments on R-M systems	Tillage and crop establishment methods under rice-maize mungbean system for system optimization	June 2010 to Nov. 2013	3-yrs trial was conducted in R-M-MB system at BARI, Comilla station under the supervision of BRRI. Yearly data were analysed and re[ported in annual and semi-annul reports. 3-yr pooled data were analysed and presented in Key Results Discussion section
		Improved management practices under reduced tillage in R-P-M system at BARI station in Comilla	June 2009 to May 2012	4-yr experiment was successfully conducted and data were reported in annual reports and semi-annual reports. 4-yr mean data are presented on system perspectives with key results and finding in section 7
		Tillage and crop establishment techniques (DSR, Bed, PTOS, ZT, ST and CT) followed by tillage x maize hybrids in R-M-MB system at RWRC (BARI, Rajshahi)	2009 to May 2103	An experiment was set-up at the Regional Wheat Research Station (RWRC), Rajshahi in June 2009 and continued till November, 2013. Annually data were analysed and reported in technical reports and semi-annual report. Final data were pooled for 4-yr and presented in system perspectives.
		Performance of hybrid rice for boro in different environments of Bangladesh	2010 to May 2011	This trial with 10 hybrids was implemented through BRRI in 5 BRRI research stations. Results were reported in the semi-annual report 2012.
		Weed management options for direct drill seeded rice (DSR) through pre-and post-emergence herbicides in Rajsjahi and Rangpur BRRI Research stations	June 2010 to November 2012	An on-station experiment was setup with 14 different pre and post-emergence herbicides in Rajshahi and Rangpur during 2010 and was repeated during 2012 only at Rajshahi. Results were presented in l semi-annual report 2012; combined results are described in section 7
		Optimization of crop residue under different tillage and crop establishment techniques in rice-maize mungbean system at BRRI Rajshahi station	June 2010 to May 2013	This experiment was initiated in June 2010 at BRRI Rajshahi research station and continued till November 2013. Seasonal data were analysed and reported in technical annual reports. Overall data were analysed and reported under section 7 with key findings.
		Effect of tillage and crop establishment methods and weed management options for DSR and residual effects of tillage and weed management on succeeding maize crop under R-M system at BRRI research station, Rangpur.	2009 to November 2013	An experiment was initiated at BRRI Rangpur research station during June 2009. Results were shown encouraging on system perspective and were presented under section 7 with key messages. This experiment was also supported by IRRI weed management team led by David Johnson.
		Optimization of *rabi* maize hybrid plant population with different geometry	2010 to 2012	A plant population trial in *rabi* maize were successfully conducted for 3 –years from 2009-10 to 2012-13 and data were used for NARS and others for determining optimum plant population; the overall results are presented under section-7
		Assessment of productivity, profitability, energy-use efficiency, and soil fertility trends (organic C & N) of existing and new cropping systems	June 2012	All data were analysed and assessed for productivity and profitability and energy-use efficiency and also evaluated for sustainability for new systems as well as for existing systems. Results were synthesised on the basis of all on-farm and on-station trials

3.3	Adapt, test, and refine farm implements for planting different crops	Existing zero- or strip-till drills and bed planters tested for planting maize and other crops in different cropping systems and seasons in at least 10 farmers' fields in each district in each year.	Nov 2008/09 November 2013	The existing 2-wheel tractor operated seeders/planters were evaluated and tested for further refinement with the help of BARI engineers and local manufactures, identified the issues and problems with the help of different stakeholders' feedback and further refinement for further use. Project will try to popularize the other mechanized options like maize shellers, threshers and manual maize shellers etc .
		Implements refined and adapted in response to results from adaptive trials (3.1) and from previous years' testing	Apr/Oct 2009 to November, 2013	R-M project is the key for introducing the new generations inclined plate seed-metering systems in Bangladesh from India, National Agro, Ludhiana. Through this project the 2-wheel tractor operated seeders, planters and threshers were refined and fine-tuned up to a great extent. These interventions will be boosting the mechanization in Bangladesh.
		Refined and appropriate farm implements multiplied and sold by local manufacturers and operators	November 2013	Especially in north-west Bangladesh, we can see the significant adoption of the 2-wheel tractor operated planters, seeders, threshers and maize shellers. This project built the capacity of many manufactures and now they are producing bed planters and strip planters themselves for commercial use. More than 200 bed planters and seeders were sold to other projects like CSISA and also purchased by the local service providers. Now the Government. of Bangladesh has taken up it seriously for large scale and widespread use of these planters.

Objective 4: To build capacity and disseminate key management options for R-M systems through public-private sector partnerships

No.	Activity	Outputs/ Milestones	Completion date	Comments
4.1	Build consensus across stakeholders through Technical Working Group (TWG)	Three Technical working Group were formed in each district	2010	TWG were formed in each district including scientists, university professors and extension officers
4.2	Conduct training and demonstrations for researchers and extension workers.	Hands-on training on CA based crop management practices, weed management techniques and sprayers and nozzles, SSNM Nutrient/Crop Manager conducted, hands-on training on CA based 2-wheel tractor operated seeders/planters/implements conducted;, training on statistical tools for data analysis, data management and inventory, etc. conducted; and brainstorming and discussions onr different aspects were done on need basis	Feb 2009 To June 2013	Several trainings were conducted for research partners, extension officers and scientific project staff. More than 30 training were conducted and approx.. 800 researchers and extension officers and project staff were trained during the project period (Details were presented in section 7)
4.3	Conduct training of trainers for high- to mid-level extension workers.	Training course on CA-based crop management in Bangladesh as part of Advanced CA-course International Asia CIMMYT coarse were conducted at RWRC, Rajshahi jointly by CIMMYT andBARI Advanced CA course in Ludhiana and New Delhi Advanced courses on Crop Manager and Nutrient Expert for site specific nutrient management	11-15 June 2012 26 May-12 June, 2012 October-November 2102	About 25 participants from different organizations including research, extension, INGO's and manufactures participated and trained. (Details were presented in section 7) Two project scientists participated in the Advance CA course for potential experts in CA crop management in Bangladesh Three hands-on training courses were conducted for researchers and extension officers for use of both offline and web-based site specific nutrient management. More than 70 researchers were trained for further capacity building of the extension workers and service providers.
4.4	Conduct training for grass-roots-level extension workers and farmers, and on-farm demonstrations	Traveling seminars, farmer exchange visits, whole family trainings, field days, demonstration plots, motivational visits	Oct 09-Nov 2013	More than 60 such events were organized and where approximately 3600 farmers and stakeholders were trained, visited project sites and attended several demonstrations of trial and demonstration plots.. This information are available at CIMMYT training and communication inventory. Details are presented in section 7

4.5	Disseminate new technologies to different stakeholders and farmers	At least 2 farmers' fairs and field days conducted in both Year 4 and 5. Leaflets: *"Conservation agricultural based Crop management practices"* *"Bed planting techniques and methods"* *"Strip tillage establishment techniques"* Poster: *"Hybrid maize with leafy vegetable intercropping production technology"* *Bulletin: "Sustainable crop Intensification through conservation agricultural techniques"* Local communication means (TV, radio, whole-family training, etc.) used. Very high quality video were produced with support from CSISA-BD on CA "Save More Grow More" In collaboration with CSISA-BD and national partners, a manual on ""Made in Bangladesh: Scale-Appropriate Machinery for Agricultural Resource Conservation" published	Jun 2010 to June 2013 May 13 2013 2013 2013	Farmers field days were organized in all districts. In Rangpur, approx.. 1000 farmers attended the field days organised by RDRS alone. 15,000 leaflets of each of the technologies printed and distributed to extension departments, farmers, research institute and NGOs etc. throughout the Bangladesh. . 3000 poster were printed and distributed to the farmers, extension agents, input dealers and researchers With the help of BRRI, RDRS produced 300 copies and made available for researchers, extension workers and advance farners. The technologies and mechanization activities were well covered by print and audio-video media on a frequent basis on local and in the national TV channels More than 30,000 Cd's of "Save More Grow More" were produced in both Bangla and English versions and distributed to the farmers across Bangladesh A very high quality CIMMYT publication to provide the designs for small scale machineries was published and 500 copies printed. This book is highly appreciated by policy makers, researchers, and manufactures. This can be downloaded from the CIMMYT website
4.6	Catalyse production and delivery of quality seeds of rice and maize	Project linked with high quality seed providers with MNC and also BARI produced the BARI maize hybrid seeds	During project periods	Production of quality seed was facilitated by the project staff with high quality MNC and public sector for rice, mungbean and maize and also linked with input dealers for better quality agro inputs including fertilizers, herbicides and even pesticides

PC = partner country, A = Australia

7 Key results and discussion

The project has four major objectives as described earlier. The progresses and achievements of the project were reported in the annual and semi-annual technical reports submitted to ACIAR from 2009 to 2012 each year. The semi-annual report was submitted in October, 2012 just before the mid-term review meeting in November 2012 which covered the project progress by then. In 2013, the 5 years' data were synthesized, analysed and the key results are described under the 4 objectives in this section.

7.1 Objective 1: To assess and prioritize the constraints to, and opportunities for, uptake of improved management options in R-M systems

7.1.1 Village survey findings

71.1.1: Basic features of the surveyed villages

The cultivated land area was largest in the surveyed villages of Rajshahi, with an average area of 982 acres (Table 7.1.1). This was followed by Rangpur, where the average cultivated land area was 785 acres, and Comilla, which had the lowest cultivated area of 207 acres. Similarly, the population was highest in Rajshahi, followed by Rangpur and Comilla. The numbers of farming households were highest in Rajshahi (598 households) and in Rangpur and Comilla, they were 298 and 233, respectively.

Table 7.1.1: Basic features of the sample villages of the 3 districts

Parameters	Rangpur			Rajshahi			Comilla		
	Project villages	Control villages	All villages	Project villages	Control villages	All villages	Project villages	Control villages	All villages
Cultivated land (acres)	756	842	785	788	1370	982	262	96	207
Population (no)	4600	2150	3783	4188	7000	5125	2508	711	1909
No. of households	796	450	681	659	1240	853	351	125	276
No. of farmers	296	300	298	515	763	598	302	95	233
Large farm households (no)	88	150	108	206	260	224	33	34	33
Small farm households (no)	209	150	189	309	503	373	269	61	200
Landless households (no)	500	150	383	144	478	255	49	30	43
Land cultivated per farmer (acres)	2.3	4.1	2.9	1.8	1.8	1.8	1	1.1	1.1
Distance from town [kms]	3.75	5	4	7.3	5	6.5	8	10.5	9
Distance to agricultural markets [kms]	1.5	5.5	3	1.5	2.5	1.8	1.5	2.3	1.8

Distance to all-weather road [kms]	0.25	0.1	0.2	0	0	0	0	0	0
Co-operative society [total number]	1	1	2	2	4	6	2	2	4

*Source: Survey data

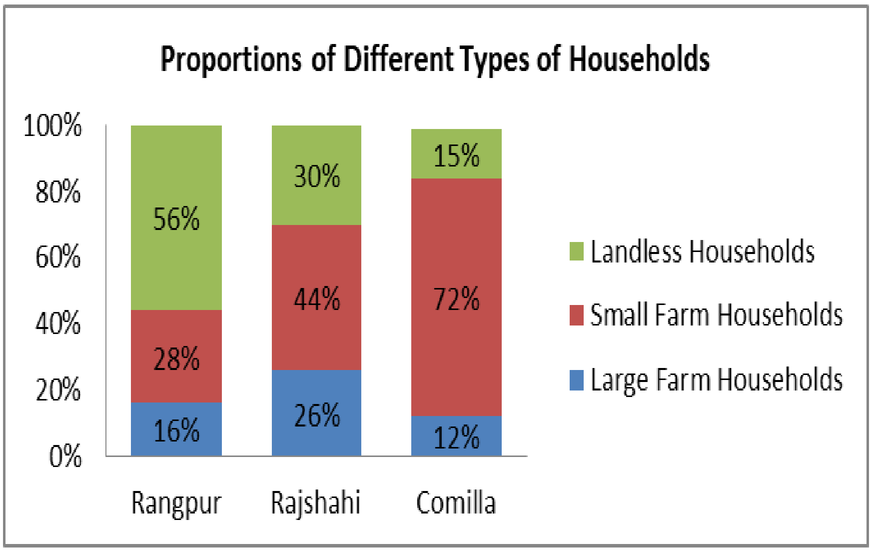


Figure 7.1.1 Proportion of different types of households in the three districts

In Rangpur, landless farmers, accounting for 56% of total households, make up a large proportion of the total households. Large farmers constitute 16 % while small farmers constitute 28% of the total householdsin the villages. In Rajshahi, the land distribution is more uniform with large farmers accounting for 26% of the total households, small farmers 44% andlandless people constitute 30% of the total households in the villages. In Comilla, small farmers are the largest proportion of the total households (72%) while 12% of the households are large farmers and 15% are landless. Land cultivated per farmer is highest in Rangpur (2.29 acre; 1.16 ha) followed by Rajshahi (1.8 acres or0.72 ha) and Comilla (1.1 acres or 0.44 ha).

Crop production is the major source of income in the surveyed villages in all the 3 districts. Livestock contributed to around 10% of income for the large farmers and around 20% for the small farmers (Table 7.1.2). The large farmers did not work as agricultural labour in any of the districts while the small farmers received from 19% to 36% of their income from the agricultural labour.

Table 7.1.2 Sources of income in the survey villages by farm size group

Source of Income (%)	Rangpur		Rajshahi		Comilla	
	Large farmers	Small farmers	Large farmers	Small farmers	Large farmers	Small farmers
Crops	66	46	70	41	39	35
Livestock	11	20	11	18	10	19
Agricultural labour	0	19	0	36	0	19
Non-agricultural labour	3	6	0	4	0	2
Services	10	3	7	1	28	7
Business	10	4	13	1	10	6
Other	0	0	0	0	13	13

7.1.1.2 Cropping patterns

In most of the villages surveyed, rice is grown in all three seasons – *kharif*-I, *kharif*-II and *rabi* while maize is grown primarily in *kharif*-I and *rabi*. Tables 7.1.3 to 7.1.5 show the crops and cropping patterns and the percentage of total cultivable land under rice, maize and other crops along with the percentage of total farmers cultivating these crops. In Rangpur, on average, rice is cultivated on 32% of land by 38% of the households in the project villages in *kharif*-I. Rice was not cultivated in the control villages in Rangpur in *kharif*-1. Maize is under 6% of the cultivated land cultivated by 26% of the farm households in the project villages in *kharif*-I. In the control village, maize is cultivated on 2% of the land by 6% of the households. The other crops cultivated in Rangpur in *kharif*-I are jute and vegetables (Table 7.1.3). In *kharif*-II, rice is grown on around 92% of land in all the surveyed villages and cultivated by 100% of the households. The other crops grown in *kharif*-II are vegetables and no maize is cultivated in *kharif*-II. In *rabi*, rice is cultivated on 74% and 88% of land in project and control villages, respectively. At the time of this survey, almost all farmers were cultivating rice. Maize is grown on 8% and 4% of land in project and control villages, respectively. Potato is another significant crop in *rabi* cultivated on 46% and 26% of land in the project and control villages respectively. The other crops in *rabi* include tobacco, mustard, wheat and vegetables.

Table 7.1.3 Crops cultivated in Rangpur villages in different seasons in 2008-09

Season	Crop	% of Total cultivable land			% of Total farm households		
		Project villages	Control villages	All villages	Project Villages	Control villages	All villages
Kharif I	Rice	32	0	21	38	0	25
	Maize	6	2	5	26	6	19
	Jute	12	7	10	23	58	35
	Vegetables	12	3	9	67	100	78
Kharif II	Rice	93	90	92	100	100	100
	Vegetables	5	1	4	59	50	56
Rabi	Rice	74	88	79	98	100	99
	Maize	8	4	7	21	50	31
	Potato	46	26	39	51	94	66
	Tobacco	10	10	10	13	43	23
	Mustard	1	1	1	2	8	4
	Wheat	3	1	2	6	11	8
	Vegetables	6	6	6	59	100	73
	Onion	1	0	1	4	0	3

* Some overlap exists due to the timing of different crops.

In Rajshahi, as in Rangpur, rice is cultivated in all three seasons. In *kharif*-I, the area and households cultivating rice is small, compared to *kharif*-II and *rabi*. In *kharif*-I, on average, 6% of land is cultivated with rice by 29% of farmers. Compared to Rangpur and Comilla, the land under maize in Rajshahi is much higher. In project villages, 40% of the land is under maize grown by 72% of farming households. In the control village, similarly, 34% of the area is under maize grown by 84% of the households. Other crops grown during this time are sesame, jute and vegetables (Table 7.1.4). In *kharif*-II, rice is grown on 72% and 65% land by almost all the farmers of the project and control villages respectively. The other crops grown during this time are vegetables, chillies and betel leaf. In *rabi*, rice is cultivated on an average of 36% of land in Rajshahi by 85% of the farmers. Maize is grown on 2% of the land and cultivated by around 14% of the households. The other crops cultivated during this time are potato, mustard, wheat and vegetables.

Table 7.1. 4 Crops cultivated in Rajshahi villages in different seasons in 2008-09

Season	Crop	% of Total cultivable land			% of Total farm HH		
		Project	Control	All villages	Project	Control	All villages

Kharif I	Rice	6	5	6	34	19	29
	Maize	40	34	38	72	84	76
	Sesame	2	2	3	9	25	14
	Jute	3	4	3	9	26	15
	Vegetables	5	9	6	37	52	42
	Chilly	1	4	2	7	43	19
	Mango	0	5	2	0	8	3
	Betel leaf	2	0	1	20	0	13
Kharif II	Rice	72	65	70	100	100	100
	Vegetables	4	4	4	5	27	12
	Chilly	1	0	1	15	0	10
	Betel leaf	2	0	1	20	0	13
Rabi	Rice	39	30	36	88	80	85
	Maize	2	2	2	11	21	14
	Potato	31	37	33	44	79	56
	Mustard	13	8	11	30	37	32
	Wheat	4	4	4	13	18	14
	Vegetables	3	1	3	34	14	27
	Onion	4	3	3	29	34	31
	Betel leaf	2	0	1	20	0	13

In Comilla, in *kharif*-I, rice is cultivated on 79% and 88% of land in the project and control villages respectively (Table 7.1.5). Almost all the farmers were growing rice at the time of this survey. Maize is grown on 13% of the land in project villages by 29% of the farmers. Farmers in the control village are not growing maize in *kharif*-I. The other crops during kharif-II are jute and vegetables. Rice is cultivated on an average on 92% of the land by almost all of the farmers. In *rabi*, rice is cultivated on an average on 47% of land. In the project villages, 82% of the farmers, and in the control village, 64% of the farmers cultivate rice. Maize is grown on an average on 19% of land and is cultivated by 35% of farmers. The other crops grown in *rabi* are potato, mustard, wheat and vegetables.

Table 7.1.5 Crops cultivated in Comilla villages in different seasons in 2008-09

Season	Crop	% of Total cultivable land			% of Total farm HH		
		Project	Control	All villages	Project	Control	All villages
Kharif I	Rice	79	88	82	93	100	96
	Maize	13	0	9	29	0	19
	Jute	0.5	2	2	6	7	7
	Vegetables	8	9	7	22	100	48
Kharif II	Rice	89	94	92	93	100	95
	Vegetables	6	6	6	12	41	22
Rabi	Rice	48	45	47	82	64	76
	Maize	11	25	19	32	40	35
	Potato	20	18	19	43	23	36
	Mustard	2	2	2	6	6	6
	Wheat	2	2	2	6	13	9
	Vegetables	11	12	12	51	87	63
	Chilly	2	1	1	18	0	12

7.1.1.3: Sources of irrigation

The major sources of irrigation are tube-wells – both electric and diesel (Table 7.1.6). In Rajshahi, 77% of irrigation water was from electric tube-wells, both for small and large farmers. In Comilla too, both small and large farmers obtained around 56% of their irrigation water from electric tube-wells. In Rangpur, the larger share was of diesel tube-wells with the extent of reliance being 55% for large farmers and 63% on diesel tube wells for small farmers. Canal water was not used in any district. Some villages received a small share from rivers and other sources like ponds.

Table 7.1.6: Sources of irrigation

Source of irrigation water	Rangpur		Rajshahi		Comilla	
	Large farmers (%)	Small farmers (%)	Large farmers (%)	Small farmers (%)	Large farmers (%)	Small farmers (%)
Electric tube well	34	27	77	77	56	57
Diesel tube well	55	63	19	19	23	24
Canal	0	0	0	0	0	0
River	0	0	4	4	0	0
Others*	11	11	0	0	22	21
Total	100	100	100	100	100	100

* Other sources like ponds

7.1.1.4 Salient findings of village survey

High yielding varieties of rice and maize hybrids were used commonly across all three districts. In all the three districts, the tillage implement used in both crops was the power tiller. A few farmers in the project villages of Rajshahi used mechanized seeding in maize through the project's assistance but mechanized maize shellers were common. There was no use of mechanized seeding or harvesting in rice in any of the three districts.

Over the years, the average rice yield in *kharif*-I in Rangpur has increased consistently from 11.6 to 15.7qt acre^{-1} from 1998 to 2003, and up to 23.3qt acre^{-1} in 2008. In Rajshahi, the rice yield was 13 qt acre^{-1} in 1998, increasing to 16.4 qt acre^{-1} in 2003 but again falling to 15.2 qt acre^{-1} in 2008. In Comilla, like Rangpur, the yield has increased consistently from 9.2 qt acre^{-1} to 10.5 qt acre^{-1} to 12.6 qt acre^{-1} in 2008. In contrast, in *kharif* -II, Rajshahi reported the highest yield among the three districts. The average yield in 1998 was 14.4 qt acre^{-1} , which increased to 16 qt acre-1 in 2003 and then to 16.2 qt acre^{-1} in 2008. Rangpur also showed a consistent increase from 10qt acre^{-1} to 13 qt acre^{-1} to 14.4qt acre^{-1}. Comilla, on the other hand, showed a marginal decrease over the years from12.9 qt acre^{-1} to 12.8 qt acre^{-1} and then 11.5 qt acre^{-1} in 2008.

During the *rabi* season, rice yield was higher than in the other two seasons. The yield for the three districts ranged from 14.4 qt acre^{-1} to 19.2 qt acre^{-1} in 1998. By 2003, the yield had increased to 18.4 qt acre^{-1} in Rangpur, 21.3qt acre^{-1} in Rajshahi and 21.6 qt acre^{-1} Comilla. In 2008, the yields had reportedly increased to around 27qt acre^{-1} in both Rangpur and Rajshahi and 23.2qt acre^{-1} in Comilla.

In Rangpur, significant changes that occurred in the production practices of rice over the last few years were stated to be the use of new seeds, varietal changes and HYV introduction, yield increases, higher chemical input and micronutrient use, line planting, double transplanting, better management and better returns. Similarly, in Rajshahi, significant changes in rice cropping practices were moving from broadcasting to transplanting, line sowing, buying new seed annually, use of more chemicals and zinc and micronutrients, varietal change and introduction of hybrids and higher yields. In Comilla, similar changes were seen – adoption of high yielding varieties and hybrid rice, introduction of herbicides, use of super granular urea leading to higher yield and more area under rice due to better irrigation facilities.

In Rangpur, in *kharif*-I, the average maize yield has consistently increased from 10.6 qt acre^{-1} in 1998 to 11.8 qt acre^{-1} in 2003 to 18.8 qt acre^{-1} in 2008. In *rabi* too, yield has increased from 17.2 qt acre^{-1} in 1998 to 23.2 qt acre^{-1} in 2008. The main reasons for this yield increase were the introduction of new hybrids and the use of more fertilizers.

However, in Rajshahi, in *kharif*-I, the yield decreased from 23.4 qt acre-1 in 1998 to 20.5 qt acre^{-1} in 2003 and then to 13.7qt acre^{-1} in 2008. In *rabi* too, the maize yield decreased from 29.7 qt acre^{-1} in 1998 to 25.1 qt acre^{-1} in 2008. This was because a storm in 2008 destroyed the crop leading to lower yield. In fact, the main constraint to growing maize, apart from high costs of fertilizer and seed, was stated to be natural calamities like storms that resulted in lowered yield. In Comilla, only project villages were cultivating maize in *kharif*-I with yield of about 20qt acre^{-1}. In *rabi* 2008-09, both project and control villages in Comilla were cultivating maize for an average yield of 21 qt acre^{-1}.

Overall, the area under maize has increased over time and this is because of better hybrids and higher yields. However, in a few villages, the area under maize had decreased due to factors like high risk of climate, high costs of fertilizers and seeds. Maize is cultivated primarily for feed purposes in all villages. In a few cases, a small amount is consumed as food as well. The percentages of maize sold were higher than the percentage of rice grain sold.

New emerging cropping systems like R-M-MB, R-P-M, rice-potato-jute, rice-wheat-maize which were earlier not very common in all three districts but now had started to popularize.

7.1.2 Mid-term adoption survey:

7.1.2.1 Adoption of rice and maize:

Most of the villages surveyed in Rajshahi and Comilla, but not in Rangpur, were cultivating rice in *kharif*-I season (Table 7.1.7). In Rajshahi, area under *kharif*-I rice increased tremendously in both project and control villages. These increases were accounted to 72% and 23% for the project and control villages compared to base line village survey conducted 2 years ago. The *kharif*-1 rice area, however, slightly decreased in both the project and control villages in Comilla. Next to rice, maize has got its importance in *kharif-I* season in all of the surveyed areas except in the control village in Comilla. However, its area decreased in Paba but increased in Durgapure in Rajshahi and in Rangpur and Comilla.

In the *aman* season, rice is grown everywhere in the surveyed villages except in the control villages in Rangpur (Table 7.1.7). There is no maize cultivated in *kharif-2*. *Aman* rice is grown on around 88-94% of land in the surveyed villages. The other crops grown in *aman* season are vegetables. However, the most alarming situation is that the area coverage and percent of farmers cultivating rice in *aman* is decreasing due to increase in the area of orchards, residential areas and brick industry.

In the *rabi* season, *boro* rice is cultivated by almost all of the farmers in both the project and control villages on around 30-68% of lands in Rangpur, 37-47% in Rajshahi, and 35-36% in Comilla. The farmers involved in *boro* rice cultivation in the *rabi* season were less in Rajshahi compared to Comilla and Rangpur.

Maize is getting popularity in the *rabi* season day by day. Its area increased from 8% in 2008-09 to 16% in 2009-10 in the project villages in Rangpur and respectively from 11% to 20% in Comilla. However, in the control villages in Comilla the area under *rabi* maize cultivation increased from 24% to 35% during the same period.

Table: 7.1.7 Adoption and yield of rice and maize in different seasons in the project and non-project villages

Season	Items	Rangpur		Rajshahi		Comilla	
		PV	CV	PV	CV	PV	CV
Aus rice	Farmers involved (no.)	-	-	2194	870	730	290
	Total rice area (acre)	-	-	1543	486	527	156
	Avg rice area (acre farm^{-1})	-	-	0.70	0.56	0.72	0.54

	Avg rice yield (t ha^{-1})	-	-	4.05	3.60	2.98	2.55
Kharif-1 maize	Farmers involved (no.)	350	200	811	365	236	-
	Total maize area (acre)	170	106	406	248	198	-
	Avg maize area (acre farm^{-1})	0.49	0.53	0.50	0.68	0.83	-
	Avg maize yield (t ha^{-1})	6.90	4.75	4.50	4.20	3.43	-
Aman rice	Farmers involved (no.)	2700	-	342	700	532	290
	Total rice area (acre)	295	-	220	1112	730	163
	Avg rice area (acre farm^{-1})	0.11	-	0.64	1.59	1.37	0.56
	Avg rice yield (t ha^{-1})	4.25	-	3.60	3.60	3.33	3.17
Boro rice	Farmers involved (no.)	2700	1270	1783	1290	754	180
	Total rice area (acre)	420	449	913	986	274	67
	Avg rice area (acre farm^{-1})	0.16	0.35	0.51	0.76	0.36	0.37
	Avg rice yield (t ha^{-1})	6.00	6.15	4.20	4.95	4.83	2.50
Rabi maize	Farmers involved (no.)	350	30	110	80	324	121
	Total maize area (acre)	100	10	48	7.5	158	66.69
	Avg maize area (acre farm^{-1})	0.29	0.33	0.44	0.09	0.49	0.55
	Avg maize yield (t ha^{-1})	8.60	4.10	7.05	2.70	5.28	2.50

PV=Project villages, CV=Control villages

7.1.2.2 Yield of rice and maize:

Both rice and maize yields in *kharif*-I were always higher with the farmers living in the project villages compared to those in the control villages indicating that the farmers in project villages have managed their crops well as they received training and advice from the ACIAR R-M project staff and their collaborators. The *kharif*-1 maize yield in the project villages in Rangpur was much higher (6.9 t ha^{-1}) than in the control villages (4.74 t ha^{-1}) (Table 7.1.8).

Table:7.1.8.Yield of rice and maize in different seasons in the project and control villages

Season	Crops	Yield (t ha^{-1})					
		Rangpur		Rajshahi		Comilla	
		PV	CV	PV	CV	PV	CV
Kharif-I	Rice	-	-	4.05	3.60	2.98	2.55
	Maize	6.90	4.75	4.50	4.20	3.43	-
Aman	Rice	4.25	-	3.60	3.60	3.33	3.17
Rabi	Rice	6.00	6.15	4.20	4.95	4.83	2.50
	Maize	8.60	4.10	7.05	2.70	5.28	2.50

PV=Project villages, CV=Control villages

In *aman*, not much yield difference was observed on rice, with yield ranging from 3.2 to 4.2 t ha^{-1}.The most significant yield difference, however, was observed with *rabi*-maize in all the project villages indicating a positive impact of the project on increased yield of maize. The yield advantage of maize in the project village was about 110% higher than that in the control village. The yield advantage is 161% in Rajshahi and 111% in Comilla. The main reasons for this yield increase were introduction of hybrid seeds and use of higher doses of chemical fertilizers.

7.1.2.3 Adoption of key technologies:

7.1.2.3.1 Zero tillage:

The farmers participating in the FGDs were asked about the extent of use of the ZT technology, and if they used, the source of information, the first year of adoption, benefit derived from using it, and limitations they are facing. Almost all the participating farmers in the FGDs of all villages had heard about the ZT technology. Likewise, almost all the non-participating farmers living in the project villages in Comilla and Rajshahi but only about 55% of such farmers in Rangpur had heard about the ZT technology. In all the cases, they got information about ZT technology from the people and collaborators working in the ACIAR R-M project. On the other hand, none of the farmers living in the control villages had heard about the ZT technology. The most noticeable point is that though almost all the non-participating farmers heard and about 95% of them saw the ZT technology they did not use it in their field. This was mostly due to lack of proper training and non-availability of ZT seed drills. Though almost all the participating farmers had heard and seen the technology only 20-50% of them were practicing this.

The farmers in the group were also asked about its current level of use of ZT technology among other farmers in their village. Only very few farmers of the project villages in Rangpur (100 in *kharif*-I, 4 in *aman* and 4 in *rabi*) and Comilla (9 in both *kharif*-I and *aman*, and 10 in *rabi*) but none in Rajshahi were practicing it. The farmers who adopted the ZT technology were from the project villages in all the districts.

Irrespective of area and crop, all farmers thought that both rice and maize yields could be decreased in the ZT plots compared to the yield obtained from their conventional tillage plots. On the other hand, all farmers reported that it is a low cost technology. The participating farmers thought that water use has increased under ZT practice, while the non-participating farmers gave opposite remarks.

The most important advantages of ZT technique for maize cultivation are good root system, no or less lodging, low cost of cultivation, less weed problem, less fertilizers required when grown after potato, and enhanced moisture holding capacity of soil, etc. High weed infestation in *aman* rice plots, crop damage by people and animals while cutting grasses and grazing in the field, slower, lower, and non-uniform germination of seeds, bird damage, difficulty in sowing seeds in the fields with hard soil and crop residue, low yield, etc. were some of the disadvantages of the ZT technique. Some of the constraints of adoption of ZT technology were high weed infestation, low germination, high bird attack, and low yield, etc. The farmers of Rajshahi mentioned that the non-availability of machine is the prime constraint. The farmers in Comilla highlighted its constraints to adoption in a different way. They expressed that they don't want to give up the practices they inherited. They thought that there is high risk with this technology and they don't have much ability to bear the risk. Moreover, the clay loam or clayey soils prevalent in their fields does not allow adopting ZT practice.

7.1.2.3.2 Direct seeded rice:

Both participating and non-participating farmers of Rajshahi reported that almost all of them had heard and seen the DSR technology but only 65% of the participating and none of the non-participating farmers had used it. On the other hand, only 45-60% farmers of Rangpur and Comilla had heard about it. In Comilla, all the farmers had heard, seen, and used the DSR in deep water fields in the *aus*-season. There DSR with local *aus* varieties is a long-time practice. In Rangpur, only <50% of the participating farmers heard, seen, and used the DSR technology. Farmers mentioned that they got information about DSR technology from the people working in the ACIAR R-M project, who introduced this in aman rice in 2009.

All participating farmers except in Talukhabu of Rangpur reported that the yield of both rice and maize could be decreased in DSR compared to transplanted rice (TPR) from their conventionally-tilled fields. On the other hand, there was a mixed reaction in terms of cost of production as some farmers thought that the cost would be saved while others thought it could be increased due to more labour requirement for weeding. In Rangpur, farmers reported that it is very easy to apply fertilizers in the DSR fields. Besides, low weed infestation due to herbicide use, low cost of cultivation, good price of straw, and early harvesting is possible than from the TPR fields. This early harvest helps the labourers to get work and provides fodder for animal during the crisis *monga* period in Rangpur. In Comilla, the farmers reported that due to the earliness of DSR they can plant potato on time and the rice straw could be used as mulch in the potato fields. In Rajshahi, the farmers thought that the DSR requires less labour and lower cost of production. Due to the earliness of DSR they can plant *rabi* maize on time followed by planting of *kharif*-1 maize*, boro* rice, or mungbean on time, thus cropping intensity can be increased.

One of the disadvantages is that high weed infestation in DSR field's results in crop damage by humans and animals as they are attracted for cutting grasses or grazing in weed-infested DSR fields. Also, high bird attack just after sowing seeds results in low emergence and low plant population and reduces yield. A lot of constraints hinder farmers for wider adoption of DSR technology. In Rangpur, non-availability of machines, lack of training on the use and maintenance of machines, and lack of knowledge on DSR production hinder farmers from establishing DSR within the given short turnaround period. In Rajshahi, lack of suitable machines and skilled machine operators, added herbicide costs, and lack of knowledge on DSR cultivation practices are some of the constraints. In Comilla, flooding and excess water at the planting time of DSR in aman season, prevalence of drought during the *aus and aman* growing seasons, and lack of credit are some of the main constraints.

7.1.2.3.3 Power tiller operated seeder:

Almost all of the participating farmers of Rangpur and Rajshahi had heard and seen the power tiller operated seeder (PTOS) but only 35% and 60% of them, respectively, had used it. In Comilla, 95% of the participating farmers had heard and seen the PTOS, but only 45% of them had used it. Of non-participating farmers from the project villages respectively in Rangpur, Comilla and Rajshahi, only 35%, 60% and 85% had heard and seen it. Farmers got information about the PTOS from the people working in the ACIAR R-M project, who introduced this in 2008 in Rangpur and Rajshahi and in 2009 in Comilla.

Participating farmers in Rangpur had used the PTOS in the *aman* and *rabi* seasons but none used it in the *kharif*-1 season. In Rajshahi, only 10 participating farmers used PTOS in maize cultivation particularly in *kharif-I,* but none in *aman* rice and *rabi* maize. In Comilla, the participating farmers used PTOS in all the seasons, but the number of farmers was only 9. In Rangpur, farmers reported that the PTOS requires less tillage than conventional tillage which helps retain soil fertility, decreases water use, and reduces the cost of land preparation. It helps establish the crop earlier and also mature earlier. Farmers can grow the *rabi* crops timely as PTOS prepares land quicker and seeding becomes faster. The farmers in Rajshahi and Comilla reported that land preparation and sowing by PTOS increased their rice and maize yields as plants can get uniform air and sun light etc. They also expressed that it reduces the cost of cultivation as less labor is required for land preparation, sowing seeds, and weeding etc. However, those farmers also reported that this machine is not suitable for wet and muddy soils and for lowlands, requires more space for machinery movement, spare parts not available, and is not affordable by small farmers.

The PTOS has some constraints hindering farmers for its wider adoption. In Rangpur, the farmers reported that this machine is not affordable at the individual farmer level, unsuitable for wet land rice cultivation, and frequent attachments and detachments of parts of the machine would be required if used for strip tillage or other purposes. In addition to above constraints mentioned for Rangpur, the farmers in Comilla expressed that it is difficult to carry machine to the lands with different elevations, and is not suitable for wet/excess moisture condition and for clay soil. The farmers in Rajshahi mentioned that the machine is not easily available, and is not quite farmer friendly.

7.1.2.3.4 Bed planting:

The participating farmers of Rangpur and Rajshahi reported that almost all of them had heard and seen the bed planters but only 70% and 85% of them respectively had used it. In Comilla, 95% of the participating farmers had heard and seen the bed planters but only about 70% of them had used it. The non-participating farmers from the project villages in Rajshahi also reported that all of them had heard and seen the bed planters but only 25% and 60% of such farmers in Rangpur and Comilla, respectively, had heard and seen them. In contrast to the participating farmers, only 5% of non-participating farmers in Rangpur and Rajshahi and none in Comilla had used the bed planters. Farmers mentioned that they got information about the bed planting technology from the people working in the ACIAR R-M project and from their neighboring farmers. Surprisingly, the farmers from the control villages of Rangpur had used the bed planters much ahead of the participating farmers. The non-participating farmers from the control villages in Comilla and Rajshahi, on the other hand, did not know anything about the bed planters. In Rangpur, those farmers had started to use this machine since 1991 in contrast to the participating farmers who started to use with this since 2004 only. The participating farmers of Paba (Rajshahi) and Comilla started using bed planters since 2009 while that of Durgapure (Rajshahi) since 2003.

All participating and non-participating farmers in the project villages in all study districts (except the farmers at Goalu, Gangachara in Rangpur and Jalgaon, Barura in Comilla) reported that the yields of both rice and maize have increased and cost decreased in the bed-planted plots compared to that in the conventionally-tilled plots. Most farmers, except those of south Mohammadpur and Dekrikhola in Comilla, reported that water use was decreased with bed planting.

Farmers of Rangpur reported that it is easier to do weeding and apply irrigation and fertilizers in the bed-planted plots, and thus bed planting saves time and labour for crop management. Bed planting also allows passing of sufficient air and sunlight for successful plant growth which ultimately enhances yield. Farmers of Rajshahi reported that bed planting maintains proper plant spacing, reduces attacks by rats, saves irrigation water, and increases yield. The farmers of Comilla reported that rain-water remains for longer period in the furrows of the bed-planted plots compared to conventional plots. However, farmers also reported that the formation of beds may not be easy in wet and clay soils, leaves too much space between beds, and difficult to operate in the crop residue retained plots. Moreover, they think that seeds do not drop uniformly when planted by a bed planter.

7.1.2.3.5 HYV seeds:

Almost all the farmers of Rangpur and Rajshahi reported that they had heard, seen, and adopted the HYV seeds of rice and maize. The farmers of Comilla collected the HYV seeds from their neighbors and had adopted them earlier than the farmers of other two districts. Comilla farmers had started adopting HYV seeds since 1970 while Rajshahi farmers had started adopting since1974 and the Rangpur farmers since 1980. None of the farmers in Rangpur had adopted HYV rice seeds in *kharif-1 (aus)* season. In Rajshahi, 92% of farm households in the project villages and 38% in the control villages had adopted HYV seeds in *kharif*-1 season while in Comilla, more than 80% of farm households had adopted the HYV seeds. The farmers of the project villages in Comilla were more advanced in adopting maize in both the *kharif*-1 and *rabi* seasons compared to Rangpur and Rajshahi farmers. The farmers of the control villages of Comilla, however, did not grow any maize in the *kharif-1* season. In *aman*, farmers of Durgapure, Rajshahi were less advanced in adopting HYV seeds of rice because those farmers mostly grow *aus* rice. Only 14-30% farmers in Durgapure adopted HYV rice seeds in the *aman* season while such adoption was almost 100% in Rangpur and about 80% in Comilla.

7.1.3 Final adoption and impact survey:

This survey was conducted in April-May 2013 and the household data presented here reflect that for 2012.

7.1.3.1 Contexts and assets

7.1.3.1.1 Socio-economic characteristics of the farm households

At the time of survey, an average age of household head of the farmers interviewed was about 45 years (Table 7.1.9). Heads were slightly older in Rangpur and Comilla than Rajshahi. Across the three districts, about 2% of the households were female headed, with no female headed households in Rajshahi, where family size (4.3) was also lowest. Family size was highest in Comilla (6.0). Average literacy rate was highest in Rajshahi (73 %) followed by Rangpur (65 %) and Comilla (62 %), with average of all sites of about 67%. Thus Rajshahi was better in human capital education than the other two sites; with younger heads indicating more progressive farmers. Literacy rate of spouse of head was lower than the literacy rates of heads themselves in all 3 sites.

Table 7.1.9 Socio-economic characteristics of farm households surveyed in the study sites, 2012-13.

Characteristics	Rangpur		Rajshahi		Comilla		Total	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Age of hh head (yrs)	47.6	11.7	38.3	13.3	48.0	13.7	44.6	13.7
Female headed household (%)	3.0	17.1	0.0	0.0	2.5	15.6	1.8	13.4
Family size (no)	5.2	2.0	4.3	1.4	6.0	2.6	5.2	2.2
Household literacy rate (%)	64.7	30.6	73.1	54.9	62.2	28.2	66.7	40.0
Household illiterate heads (%)	18.9	39.3	13.8	34.6	20.8	40.7	17.8	38.3
Literacy rate spouse head (%)	75.1	43.3	83.3	37.4	77.7	41.7	78.7	41.0

SD= Standard deviation.

As heads were mostly males, the literacy rate of farming households indicated the general pattern of higher average education of men but on the otherhand female household heads had higher lieteracy rate. The data of the samples were consistent with national (rural) statistics of the country.

Number of adult male was higher in all sites (Table 7.1.10). This is also consistent with population census data where number of male population has been slightly higher than female population (Population Census 2011 of Bangladesh).

Table 7.1.10 Household composition in study sites, 2012-13

Variables	Rangpur		Rajshahi		Comilla	
	Mean	SD	Mean	SD	Mean	SD
Adult male (No)	2.0	1.1	2.0	0.9	2.4	1.3
Adult female (No)	1.7	0.9	1.5	0.7	1.8	0.9
Male children (No)	1.4	0.7	0.8	0.7	1.0	1.0
Female children (No)	1.4	0.7	0.7	0.6	1.0	1.1
Family size (No)	5.2	2.0	4.3	1.4	6.0	2.6

SD= standard deviation.

7.1.3.1.2 Ownership of assets

Housing and durable assets:

Table 7.1.11 presents data on % of farm households, which have a specific type of dwelling unit, electric connection, phone connection and have other durable type of assets. Large number of households (79.2%) lived in Katcha houses in Comilla followed by Rajshahi and then Rangpur. In this type of housing structure, roof is made of tin/CI sheet and the wall is made of either tin/CI sheet or a non-durable material like jute stalks/straw etc. The other types are Pakka and semi-Pakka. Pakka means the main bed room is fully brick made, semi-if main bed room is partially brick made or any other part of the house is brick made. The highest 35.3% of the houses were semi-Pakka in Rangpur followed by Rajshahi and then Comilla. The highest 17.2% housing structure were Pakka in Rajshahi followed by 14.4% in Comilla and the lowest 9% in Rangpur.

Largest number of households (90.6%) had electricity connection in Rajshahi, followed by 74.3% in Comilla and the lowest 62.2% in Rangpur. None of the Rangpur and Rajshahi farmers had land telephone connection. Mobile phone was the highest means of communication in the study sites, as in Bangladesh as a whole. Many farm households had more than one mobile phone in each household.

Table 7.1.11 Housing and assets of the sample households in study sites, 2012-13

Variables (%)	Rangpur		Rajshahi		Comilla	
	Mean	SD	Mean	SD	Mean	SD
Katcha houses	49.8	0.0	54.2	49.9	79.2	40.7
Semi-pakka houses	35.3	47.9	28.6	45.3	6.4	24.6
Pakka houses	9.0	28.6	17.2	37.9	14.4	35.2
Electricity connection	62.2	48.6	90.6	29.2	74.3	43.8
Land telephone	0.0	0.0	0.0	0.0	1.5	12.1
Mobile phone	87.6	33.1	96.1	19.5	94.6	22.7
Radio	3.5	18.4	7.9	27.0	4.5	20.7
TV	47.3	50.0	71.4	45.3	37.6	48.6
Electric fan	54.7	49.9	90.1	29.9	75.2	43.3
Bi-cycle	72.6	44.7	71.4	45.3	24.8	43.3
Motorbike	12.4	33.1	17.7	38.3	3.0	17.0
Other durable assets*	10.0	30.0	5.9	23.6	7.4	26.3

* Other assets are vans, rickshaws, auto rickshaws or sewing machines; vans were more common used for carrying crops and organic fertilizers (cowdung, poultry manure etc.). SD= standard deviation;

Proportionately more households owned TV, electric fan and bicycle (Table 7.1.11). Radio has the advantage of listening agricultural information while working in the agricultural field but it was not so effective source of information in the study areas as very few people were using this media.

Ownership and use of land:

On average farmers in Rangpur, Rajshahi and Comilla cultivated 1.24, 1.23 and 0.91 acres of land, respectively (Table 7.1.12). Cultivated land size was almost the same in Rangpur and Rajshahi and was lowest in Comilla. Although land ownership was higher in

Rajshahi than Rangpur, average cultivated land was almost the same. This is due to larger size tree gardens in Rajshahi. We did not include ponds and tree/bamboo gardens with cultivated land.

Table 7.1.12 Mean distribution of cultivated land according to tenancy in the study sites, 2012-13.

Land by tenancy	Rangpur		Rajshahi		Comilla	
(Acre/farm household)	Mean	SD	Mean	SD	Mean	SD
Total cultivated land	1.24	1.09	1.23	1.05	0.91	0.60
Own cultivated land	0.99	1.12	0.81	0.83	0.50	0.53
Rented in (cash) cultivated land	0.22	0.49	0.39	0.82	0.33	0.51
Crop sharing cultivated land	0.02	0.11	0.03	0.25	0.08	0.26
Gardens/ponds etc.	0.05	0.15	0.21	0.34	0.04	0.17

SD= standard deviation.

In all sites, a major part of the cultivated land is owned by the farmers themselves. The next type is land tenancy under cash rental system. Share tenancy is not so popular at present. Instead, farmers prefer cash rental tenancy system, rental prices vary mostly between regions and crop seasons. During our field trips we spoke with farmers, member of local government, school teachers, dealers, shop keepers etc. and knew that cash rental system is attractive for two reasons. The system is more flexible in terms of timing and crop choice. Tenant makes choice based on expected higher profit. For example, a tenant rents land only for a crop like potato or *Boro* rice or for a temporary nursery etc. Second, owners avoid risk by taking cash rents in advance. This helps the owner to meet their cash needs for another investment. The system may not be good for maintaing soil fertility as the tenant uses more chemical inputs to get the maximum from the land. Further analysis of this issue is beyond the scope of this study.

Considerable amount of land remains fallow only in *Kharif*-1 season, particularly in Rangpur and Rajshahi (Table 7.1.13). Late harvesting of *Boro* is a major reason for keeping land fallow in *Kharif*-1 season. Some farmers keep land fallow in the *Kharif*-1 season for fruit cultivation like papaya. Also there is a system of seasonal cash rental before the *Kharif*-1 season. During the *Kharif*-1 season land is returned to landlord. Some landlords may lack resources to cultivate land by themselves. Examining this issue was beyond our current research.

Table 7.1.13 Fallow land by season in the study sites, 2012-13.

Fallow land by season	Rangpur		Rajshahi		Comilla	
(Acre/farm household)	Mean	SD	Mean	SD	Mean	SD
Fallow land in *Rabi*	0.07	0.25	0.04	0.17	0.02	0.09
Fallow land in *Kharif-1*	0.56	0.80	0.42	0.49	0.13	0.30
Fallow land in *Kharif-2*	0.08	0.25	0.31	0.54	0.03	0.17

Note: Averages are based on all households; SD= standard deviation.

Plot characteristics:

Based on the analysis of 967 plots in Rangpur, 1095 plots in Rajshahi and 865 plots in Comilla, on average, farmers had 4, 3.7 and 3.3 plots per farm in Rajshahi, Rangpur and Comilla respectively (Table 7.1.14). Average size of a plot was around a half an acre in Rangpur, less than this size in Rajshahi and Comilla. Plot size varied from as little as 1 decimal to 2 acres. Most of the plots were owner operated followed by cash rental tenancy. The proportionate cash rental plots in Comilla were double that in Rangpur and Rajshahi. In Comilla, international migration was much higher and so rental market was dominant, because in most of the household's one or more male workers migrated temporarily. Farmers often lease out land taking a large sum of money to pay migration cost. Seasonal rental contract is more common in Rangpur and Rajshahi but uncommon in Comilla.

Soil types are almost the same in all three sites. More than 75% of the plots are sandy loam or loamy. More than 60% of the plots are medium land type where water logging is not a big problem in normal years. However Comilla site faced exceptionally harsh climatic condition, particularly in *Rabi* and *Kharif-1* in 2012. About 46% of the plots in Comilla suffered from storm and water logging problem in *Rabi* in the last 3 years. About 19% of the plots in Comilla faced water logging at maturity of Kharif-1 maize and rice.

About 98%, 97% and 81% of the plots respectively in Rangpur, Rajshahi and Comilla have access to one or another type of irrigation when necessary.

Table 7.1.14 Characteristics of all of the plots, study sites, 2012-13

Characteristics	Rangpur	Rajshahi	Comilla
Number of plots per farm hh	3.7	4.0	3.3
Average size of a plot (decimal)	30.4	27.1	24.2
Tenancy type (% of plots)			
1. Owner operated	75.4	76.5	56.9
2. Shared in (crop sharing)	1.8	0.8	6.5
3. Cash rental/mortgaged in	15.3	15.1	29.9
4. Rented/shared/mortgaged out	7.6	7.6	6.8
Total	100.0	100.0	100.0
Average distance from home (Km)	0.6	0.6	0.4
Soil type (% of plots)			
1. Sandy	8.7	4.8	12.5
2. Sandy loam/loam	80.2	76.8	77.7
3. Clay	11.2	18.4	9.9
Total	100.0	100.0	100.0
Land type			
1. Low	19.7	19.3	17.2
2. Medium	62.8	65.2	64.3
3. High	17.5	15.5	18.5
Total	100.0	100.0	100.0
Irrigated (% of plots)	97.8	97.0	81.3
Rabi crop sowing delayed due to excess moisture (% of plots)	4.1	2.6	9.9
Faced any storm and water logging in *Rabi* in 3yrs (% of plots)	6.4	3.3	45.9
Water logging issue at maturity in Kharif-1 in 3yrs (% of plots)	9.8	6.4	18.9

Agricultural machines:

In all locations, farmers hire tractor for tillage such as four wheel or two wheel power tillers and irrigation such as Deep Tube Well (DTW), Shallow Tube Well (STW) and Low Lift Pump (LLP) from private businesses. This is the usual practice and few resource rich farmers were nvolved such part-time businesses. From Only 0.5% farmers in Rajshahi owned four wheel power tillers but many farmers in all locations owned two wheel power tillers (Table 7.1.15).

More farmers engaged in businesses with irrigation machines. Those farmers who owned DTW had no full ownership, they only owned a share. Farmers rarely used traditional implements like the country plough, some farmers still used this implement for harvesting potato or harrowing. In Rangpur, we found an exceptional farmer who hired country plough for tillage. This was actually more expensive than hiring power tiller for tillage.

Sprayer is more common type of machine that farmers owned but those farmers who did not own sprayer, used it from a neighbour or a relative free of cost. Proportionately more farmers (82.3%) owned sprayers in Rajshahi. In Comilla and Rangpur, hiring a person who has a sprayer for spraying pesticides is more common. Ownership status varied between sites. There was considerable variation between sites on the ownership of machines. More farmers in Rangpur owned STW, whereas farmers in Rajshahi owned larger machines and maize sheller. Ownership of thresher is higher in Comilla and Rajshshi.

Table 7.1.15 Percent farmers owning different types of agricultural machines/implements in the study sites, 2012-13

Name of machines/implements	Rangpur	Rajshahi	Comilla	Total
Four wheel power tiller	0.0	0.5	0.0	0.2
Two wheel power tiller	1.5	4.9	1.5	2.6
Bed planter	0.5	0.0	0.0	0.2
Pump (DTW)	0.0	7.4	0.0	2.5
Pump (DTW+STW)	1.0	7.4	0.0	2.8
Pump (STW)	20.9	4.4	9.4	11.6
Pump (LLP)	0.0	0.0	2.0	0.7
Maize sheller	1.0	10.3	0.5	4.0
Country plough	12.4	3.9	9.9	8.7
Hand weeder	0.0	0.0	6.4	2.1
Thresher	7.0	25.1	35.0	22.4
Sprayer	48.3	82.3	47.3	59.4
Total number of farmers	201	202	203	606

7.1.3.1.2 Area under machine-used irrigation

The major sources of irrigation are different types of tube-wells, which lift underground water (Table 7.1.16). The prominent in Rangpur and Comilla is diesel operated STW. In Rajshahi, 76% of the irrigated area was covered by DTW, which has been operated under the Barind Multipurpose Development Authority (BMDA). The dependence on STW and DTW for irrigation indicates a large amount of ground water outflow in the study sites. In Comilla, 10.2% of the area was irrigated using the LLP, which uses surface water from sources like ponds but surface water for irrigation was rarely used in Rangpur and Rajshahi.

Table 7.1.16 Percent area under different types of irrigation machines in the study sites, 2012

Sources of irrigation	Rangpur	Rajshahi	Comilla	Total
Electricity operated shallow tube-well (STW)	23.8	9.0	37.4	21.4
Diesel operated STW	65.0	9.4	41.2	37.6

Deep tube well (DTW)	3.7	76.0	1.2	31.1
Electricity/diesel operated LLP	1.9	1.0	10.2	3.6
Mixed types of machines/other	5.5	4.4	2.7	4.4
Traditional	0.2	0.1	7.3	1.9
Total	100.0	100.0	100.0	100.0
% of total land under irrigation in *Rabi* season	98.0	97.0	88.0	95.0

7.1.3.2 Technology adoption, production & marketing

7.1.3.2.1 Rice and maize cultivation

***Rabi* season crops**

In the *Rabi* season, 60% of farmers in the study sites cultivated *Boro* rice in around 36% of cultivated land. In the project and control villages of Rangpur, *Boro* rice comprises 34-51% of cultivated land on average, with the highest average in the control village. Participant farmers (PFs) employed more land to *Rabi* maize and less to rice; however, non-participant farmers (NFs) in the same villages employed more land for potato cultivation (Table 7.1.17). This implies that without the project farmers gain from allocating land and other resources (inputs) to potato cultivation. In Rajshahi, farmers might have cut several other crop productions to gain from maize production. Particularly, wheat and boro rice producers might have switched to maize production. We found differences among PFs, NFs and CFs in proportionate allocation of land with respect to other crops including pulses and oilseeds. Also, NFs and CFs kept more land fallow.

Farmers in Rangpur and Comilla allocated proportionately more land than Rajshahi in rice cultivation in *Rabi* season. In Rajshahi, less than 30% of the land cultivated in the *Rabi* season was allocated to rice, whereas in Comilla it was more than 33%. Particularly CFs of Comilla produced *Rabi* rice in more than 56% of cultivated land. In fact, *Rabi* rice occupied more land in all control villages, but the difference between the groups was more visible in Rangpur and Comilla.

Comilla was the highest adopter of *Rabi* maize in 2012 (Table 7.1.17). Project farmers adopted *Rabi* maize in 39.4% of their land, higher than area allocated to *Rabi* rice. Lowest adopter of *Rabi* maize was the Rajshahi control village (0.6%). In all, farmers in Comilla site in 2012 adopted maize in more than 37% of cultivated land with 39.4%, 34.6% and 36. 7%, respectively, for the PF, NF and CF groups. The differences between these three groups were statistically significant. We applied Kruskal-Wallis chi-square test to find out whether the 3 groups are statistically the same with respect to maize adoption. The null hypothesis that there is no difference between the median adoption between PFs, NFs and CFs was rejected at 1% level of significance (unadjusted chi-square=45.99 and adjusted chi-square=57.58 with 2 df 2) in the full sample of 606 farmers. Only for Comilla, the difference between the median adoption between PFs, NFs and CFs was rejected at 5% level of significance (unadjusted chi-square=7.17 and adjusted chi-square=7.97 with df 2). The difference between the average adoptions between the three groups was not statistically significant (as was indicated by t test). A few NFs and CFs cultivated maize in a relatively large amount of their land may be to take advantage of buoyant markets. These NFs and CFs may be innovators.

The difference between three sites (overall) was also statistically significant at 1% level, but the difference between Rangpur and Rajshahi was not significant at 5% level. Thus we conclude that project farmers in all sites adopted more maize than other farmers and maize adoption is higher in Comilla in the *Rabi* season.

Table 7.1.17 Percent of total land area under different crops in *Rabi* season

Crops	Rangpur			Rajshahi			Comilla		
	PF	PVNF	CF	PF	PVNF	CF	PF	PVNF	CF
Boro rice	35.1	34.3	50.6	23.6	25.9	26.7	33.2	45.8	56.2
Rabi maize	13.1	5.3	5.4	13.9	5.3	0.6	39.4	34.6	36.7
Wheat	0.0	0.1	1.3	10.6	0.0	0.2	0.0	0.0	0.0
Potato	32.3	42.1	28.4	34.8	32.4	42.9	14.2	12.0	2.3
Vegetables	3.3	5.4	2.8	7.0	8.0	8.0	11.6	6.6	1.6
Other	8.0	10.9	5.5	7.0	17.7	14.5	0.7	0.2	0.2
Fallow	8.2	1.8	6.1	3.1	10.6	7.1	0.9	0.7	3.0
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

PF= participant farmer; PVNF= project village non-participant farmer; CF= control farmer.

In the *Rabi* season, *Boro* rice and potato were two dominant crops in Rangpur and Rajshahi. On the other hand, rice and maize occupied more than 70% of land in Comilla. The farmers who cultivated potato, their cropping pattern was mostly potato followed by *Kharif-1* maize or late *Boro* or another crop followed by *Kharif*-2 rice (*Aman*). The dominant pattern was potato followed by *Kharif-1* maize followed *Kharif-2* rice (*Aman*). Other cropping patterns were potato followed by late *Boro* followed *Kharif*-2 rice (*Aman)*, potato followed by *Kharif*-1 vegetable followed by *Kharif*-2 rice (*Aman*), potato followed by *Kharif*-1 vegetable followed *Kharif*-2 vegetable etc. Many farmers in Rajshahi harvest rice frequently in a year. Though they do not cultivate more than a maximum of three rice crops in the same plot but they use different plots to harvest rice frequently by using varieties which can be planted early to late. For example, in one plot a farmer uses the pattern of potato followed by late *Boro* followed *Kharif*-2 rice (*Aman*) and in another plot the same farmer uses another pattern of early *Boro* followed by *kharif*-1 Aus followed by *Kharif*-2 rice (*Aman*). The vegetable producers often harvest vegetables several times in the same season. In Comilla, some farmers reported harvest of *Rabi* vegetable before planting *Rabi* maize. Availability of early and late varieties of rice and maize made it possible for farmers in all areas to grow a short duration vegetable in the same season after harvest of rice or maize or before planting these major crops.

***Kharif*-1 season crops:**

Most of the farmers surveyed in Comilla (92.7%) and a few farmers in Rajshahi (7. 4%) cultivated *Aus* rice in *Kharif*-1 season. Farmers in Comilla grew *Aus* rice in the highest proportion (comparing three sites) of cultivated land (Table 7.1.18). *Aus* rice in Rajshahi occupied only 2.4%, but including late *Boro* (sown/transplanted in the *Rabi* season and harvested in the *Kharif*-1 season) the proportion of *Kharif*-1 rice in Rajshahi was 15%. *Aus* was not grown in Rangpur but the proportion of late *Boro* in Rangpur was much higher than Rajshahi.

Kharif-1 maize occupied the position next to rice in all of the surveyed villages. NFs in Rangpur allocated even more land to maize than rice in *Kharif*-1 season. Both PFs and NFs in Rajshahi allocated higher land to maize than rice production in the *Kharif*-1 season. Thus adoption of maize is very similar in Rangpur and Rajshahi.

Table 7.1.18 Percent of total land area under different crops in *Kharif*-1 season

Crops	Rangpur			Rajshahi			Comilla		
	PF	PVNF	CF	PF	PVNF	CF	PF	PVNF	CF
Aus rice	0.0	0.0	0.0	3.2	2.9	0.7	62.5	67.1	88.9
Late *Boro*	25.6	23.4	15.4	5.7	14.8	15.6	0.0	0.0	0.0
K1 maize	21.1	31.0	13.3	18.8	18.4	15.1	11.1	7.2	2.3
Jute	4.5	1.8	8.5	4.4	5.0	0.2	0.0	0.0	0.0

Vegetables	3.4	3.5	4.6	5.6	9.9	17.1	9.2	6.0	0.6
Other	2.9	4.6	0.5	19.8	13.2	14.6	1.3	2.6	2.7
Fallow	42.5	35.7	57.7	42.5	35.7	36.7	15.9	17.1	5.5
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

PF= participant farmer; PVNF= project village non-participant farmer; CF= control farmer; K1=*kharif*-1

In Comilla, only some farmers in project villages were cultivating maize in *Kharif-1* in 2008-09. More farmers in 2012 in project and control villages adopted maize in 2012. Thus maize area occupied 2.3% of cultivated land of CFs in *Kharif*-1 season. This is the lowest adoption of *Kharif*-1 maize but these farmers are new adopters in place of none in 2008-09. These farmers informed us that they were aware from FGDs in 2009 and then used other sources (particularly seed dealers) to learn about cultivation of maize and market opportunities and then started growing this new crop.

***Kharif*-2 season crops:**

In *Kharif-2*, *Aman* rice is grown everywhere in the surveyed villages (Table 7.1.19). In this season rice is grown in about 79% of cultivated land in the surveyed villages and cultivated by almost all (99%) farm households. The proportion of cultivated land occupied by *Aman* rice is the lowest in the control village of Rajshahi, where more than 42% of cultivated land were fallow in this season. The other crops grown in *Kharif-2* are vegetables.

Table 7.1.19 Percent of total land area under different crops in *Kharif*-2 season, study sites, 2012-13.

Crops	Rangpur			Rajshahi			Comilla		
	PF	PVNF	CF	PF	PVNF	CF	PF	PVNF	CF
Aman rice	89.2	92.1	86.6	69.9	54.9	37.5	90.6	88.7	94.3
Vegetables	1.2	3.1	3.8	3.3	8.0	15.4	7.1	5.5	0.8
Other Crops	2.3	0.5	0.5	12.7	10.0	4.9	0.3	1.6	2.6
Fallow	7.3	4.3	9.1	14.1	27.0	42.2	2.0	4.2	2.3
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

PF= participant farmer; PVNF= project village non-participant farmer; CF= control farmer.

Fallow land: We noted earlier that the highest amount of land per household remained fallow in *Kharif*-1 season in all areas. The current data also reveal that the proportion of cultivated land that remains fallow was higher in the *Kharif*-1 season in all locations except the control village in Rajshahi (Tables 7.1.17 to 19). There were various reasons such as floods, late harvesting of *Boro* and changes in cropping systems, etc. for keeping land fallow in the *Kharif*-1 season. . Usually low lying areas where it is not possible to grow *Aman* rice are kept fallow.

Often seasonal fixed cash rental system is a reason for land keeping fallow in the *Kharif*-1 season in Rangpur and Rajshahi. In case of seasonal cash rental market, owners receive land after one season rental arrangement and then wait for renting it out to another tenant and until then land remains fallow. The extent of this type of fallow land is still low.

Arguably there may be consequences of this type of cash rental on resource use, allocative efficiency, soil quality and productivity. This market helps land transfer from relatively resource poor farmers/temporary absentee owners to relatively resource rich farmers/agro-businesses. Hence this may improve the allocative efficiency of factors of production and so may improve the productivity by the use of capital intensive farm inputs like inorganic fertilisers and improved seeds. However to reap the maximum benefit agro-businesses may use tillage, fertilizer, pesticides etc. as much as possible without thinking sustainable production and maintenance of soil quality. Examining this is beyond the scope of this study but it is a fertile ground for future research.

7.1.3.2.2 Adoption of tillage and crop establishment technologies:

Technology adoption is often measured by the proportion of farmers using a technology and/or the proportion of area under the concerned technology. In this study we used mostly percentage of area, but also added percentage of farmers in some cases. Our main focus was to explain the adoption constraints.

***Rabi* rice tillage and crop establishment:**

Table 7.1.20 delineates tillage and crop establishment technologies used in the *Rabi* season rice and maize. There are no differences between participatory and non-participatory/control groups, because ZT and MT machines were made available for the project farmers (participatory adaptive trial plots and extension plots) and were not available for other farmers. Limited number of project personnel with insufficient project resources can only extend services to participating/extension farmers; around 40-50 farmers in each *Upazilla*. There was some entry exit flexibility in the project and hence we found new farmers joining the project in in this survey and some farmers exiting from the project. This posed some practical problems to interview the participatory farmers. We selected farmers such that they have experimental trials in 2012. Certainly, technology adoption in this trial period is constrained by machines such as PTOS and bed planter.

The participating farmers had access to the machines and were given training through the participatory trials on machine and manual practices. Other farmers learned from the participatory farmers and qualitative FGDs. We expect adoption of manual practices occurred beyond participatory farmers. Expansion of machines would occur up to the maximum capacity through extension of plots outside of experimental plots.

Table 7.1.20 Adoption of tillage and crop establishment technologies in *Rabi* season in study sites, 2012-13.

Technologies	% crop area			
	Rangpur	Rajshahi	Comilla	Total
rice				
CT and DSR manual	6.0	0.2	4.7	4.1
CT and line transplanting	55.0	35.8	92.7	63.1
CT and random transplanting	38.9	63.1	1.3	32.1
Other (mixed)	0.0	0.8	1.4	0.7
Total	100.0	100.0	100.0	100.0
maize				
ZT/ST and direct seeding with machine	4.5	6.6	3.8	4.5
MT and direct seeding with PTOS	2.7	17.2	2.9	5.3
MT & raised bed planter	2.0	9.4	1.7	3.1
CT and direct seeding manual	80.1	51.1	86.9	79.3
Other (mixed)	10.6	15.7	4.6	7.7
Total	100.0	100.0	100.0	100.0

Table 7.1.20 depicts the higher adoption of CA technologies in *Rabi* maize than *Rabi* rice, because the project began with maize trials; *Boro* rice was not included. Traditionally manual sowing of DSR was an important traditional farmer practice of crop establishment. Almost all *Rabi* rice farmers used conventional tillage in more than 99% of their *Rabi* rice area.

Rabi maize cultivation was dominated by conventional tillage (3 or more tillage, usually with power tiller) followed by manual direct seeding as a farmer practice. Overall, in more than 79% of the maize area, farmers used this method for growing maize in the *Rabi* season. ZT/MT was adopted in about 13% of *Rabi* maize area, with 9.2%, 23% and 8.4% respectively in Rangpur, Rajshahi and Comilla respectively. The higher adoption in Rajshahi corresponds to a better functioning of PTOS. Rangpur and Comilla experienced mechanical problem with the machine during the peak period.

The 'other' category includes mixed sort of tillage and crop establishment technologies. This proportion includes CA technologies along with conventional farmer practices. This is also the highest in Rajshahi followed by Rangpur and Comilla. This evidence indicates an incredible achievement of technology adoption in Rajshahi. Irrigation water pumping is costlier in Rajshahi and so farmers prefer to use a technology that requires less irrigation but still productive. This may be the reason for farmers in Rajshahi as more aware of alternative practices. We found that farmers prefer PTOS in all sites but the service for this machine was better in Rajshahi due to availability of technicians to handle the machine. So the adoption of MT was higher in Rajshahi. Also we noted planters in Rajshahi were available from some other service providers in addition to project support. Due to the presence of many private organizations in Rajshahi and Rangpur than Comilla, capacity building activities were also higher there.

***Kharif-1* rice tillage and crop establishment:**

In the *Kharif*-1 season, DSR with conventional tillage was used in 0.4%, 2.9% and 4.3% of land in Rangpur, Rajshahi and Comilla respectively (Table 7.1.21). The low adoption of ZT and MT was due to R-P-M system because potato harvest needs digging of the soil and tillage. Only participatory farmers who were selected for CA used ZT or MT; they are in the mixed category. Here, again Rajshahi farmers were higher adopters.

Table 7.1.21 Adoption of tillage and crop establishment technologies, *Kharif*-1 season, 2012

Technologies	% of rice area in *Kharif*-1*			
	Rangpur	Rajshahi	Comilla	Total
CT and DSR manual	0.4	2.9	4.3	3.1
CT and line transplanting	46.1	43.8	93.0	74.0
CT and random transplanting	52.8	47.5	0.8	20.7
Mixed	0.6	5.8	1.9	2.2
Total	100.0	100.0	100.0	100.0
	% of maize area in *Kharif*-1			
ZT and direct seeding manual	14.3	10.5	24.6	14.2
MT and direct seeding with PTOS	0.8	1.4	1.0	1.1
MT and direct seeding manual	5.7	0.1	3.0	3.1
MT & raised bed planter	7.7	0.9	0.0	3.9
CT and direct seeding manual	67.2	60.6	60.5	63.7
Other	4.3	26.5	10.9	14.0
Total	100.0	100.0	100.0	100.0

*includes late *Boro* in Rangpur and Rajshahi and Aus rice in Comilla

Kharif-1 maize cultivation was also dominated by conventional tillage as in *Rabi* maize with manual direct seeding. Overall, in about 64% of the maize area, farmers used this method in the Kharif-1 maize. This proportion is lower than the *Rabi* maize, because adoption of ZT with direct seeding manual is much higher in *Kharif*-1 season. Indeed, ZT/MT was adopted in more than 22.3% of the *Kharif*-1 maize area, with 28.5%, 12.9%

and 28.6% respectively in Rangpur, Rajshahi and Comilla respectively. Raised bed planter was used in the highest proportion of land in Rangpur, whilst raised bed was not used by Comilla farmers. The farmers in Comilla mentioned that stormy weather causes more damage to maize if planted in raised beds. The 'other' category includes mixed sort of tillage and crop establishment technologies, as mentioned earlier. This proportion was the highest in Rajshahi followed by Comilla and Rangpur. Including the 'other' category, Comilla is the highest adopter of CA based technologies for *Kharif*-1 maize followed by Rajshahi and Rangpur.

***Kharif*-2 rice tillage and crop establishment:**

In the *Kharif*-2 season, DSR was used by 1.6%, 1.2% and 7.4% of land in Rangpur, Rajshahi and Comilla respectively (Table 7.1.22). Hence Comilla farmers were the largest users of DSR. Overall, ZT/MT was used in 6.1% of land; Comilla appears the highest user of CA based technologies for *Kharif*-2 rice production.

Thus the adoption rate of CA technologies in rice production is the highest in Comilla in both seasons (*Kharif-1 and Kharif-2*), but the adoption rate of CA technologies in maize production is the lowest in Comilla. This indicates divergence between regions, should be taken into account in popularising technologies.

Table 7.1.22 Adoption of tillage and crop establishment technologies in *Kharif*-2 season in study sites, 2012

Technologies	% of rice area			
	Rangpur	Rajshahi	Comilla	Total
Zero tillage & direct seeding manual/machine	0.1	0.4	1.7	0.7
Zero tillage & unpuddled transplanting	0.1	0.2	0.4	0.2
Minimum tillage & unpuddled transplanting	0.2	0.3	0.3	0.2
Conventional tillage & direct seeding manual	1.5	0.8	5.7	2.7
Conventional tillage & line transplanting	41.9	41.8	88.4	57.0
Conventional tillage & random transplanting	53.3	55.6	1.0	36.9
Other	2.8	1.0	2.6	2.3
Total	100.0	100.0	100.0	100.0

7.1.3.2.3 Adoption of rice varieties:

***Rabi* varieties:**

Table 7.1.23, presents rice and maize varieties adopted by the farmers in the *Rabi* season. In general, most of the varieties, which farmers use in *Rabi* are BRRI varieties. The most popular BRRI variety in *Rabi* is BRRI Dhan 28, a medium duration, medium fine and white rice. This is a recommended variety for *Rabi* season in Bangladesh and was released in 1994. The variety was grown in about 58% of the total area of 224.38 acres under *Rabi* rice in three sites. BRRI Dhan 28 occupied the highest proportion of land in Comilla (73.74%). Next popular ones are hybrids. In Rangpur, total area under *Rabi* rice was 82.54 acres planted by 200 farmers. The highest proportion was covered by different hybrids (ACI-1, ACI-2, Hira-2, Jagoron, etc). BRRI Dhan28 is also in Rangpur.

Hybrids are less popular in Comilla. Comparing the three sites we note that higher adoption of hybrids is associated, to some extent, with relatively lower percentage use of BRRI high yielding varieties. For instance, in Rajshahi, the adoption of BRRI Dhan 28 was

54.83% and hybrid was 20.53%. Whereas in Comilla, the adoption of BRRI Dhan 28 was 75.74% and hybrid was in 7.83%. We identified the visibility of more private seed companies in Rajshahi and Rangpur from which dealers buy seed.

There were virtually no local rice varieties in Rangpur in this *Rabi* season. Some local varieties are still doing better in Rajshahi and Comilla. Examples are Guti Shwarna and Zeerashail in Rajshahi. The percentage of area occupied by local varieties was 16.01 and 14.01 in Rajshahi and Comilla, respectively. However, *Rabi* rice is not a common crop in Doudkandi *Upazilla* of Comilla. Only 2 farmers grew BRRI Dhan 29 and one farmer cultivated BRRI Dhan 28 in Doudkandi. Other *Boro* rice growers were located in Barura *Upazilla*. So local varieties in the *Boro* season was grown in Barura, mostly Mulla, a fine quality local variety. In Doudkandi farmers grow *Rabi* maize instead of *Rabi* rice.

Table 7.1.23 Adoption of rice and maize varieties in *Rabi* season in study sites, 2012

Varieties	% of rice area			
	Rangpur	Rajshahi	Comilla	Total
BR 3	0.00	1.83	0.00	0.50
BRRI Dhan 28	43.80	54.83	73.74	57.57
BRRI Dhan 29	4.79	4.92	1.55	3.66
Other HYV	3.28	1.87	2.88	2.75
Hybrid	48.13	20.53	7.83	26.12
LV	0.00	16.01	14.01	9.40
Total	100.0	100.0	100.0	100.00
Total area (acres)	82.54	61.15	80.69	224.38
	% of maize area			
NK 40	63.21	98.92	87.21	83.57
Pacific 984	11.76	1.08	0.00	2.84
900M Gold	5.14	0.00	5.43	4.52
Other hybrid	19.89	0.00	7.37	9.07
Total	100.0	100.0	100.0	100.0
Total area (acres)	25.09	17.19	68.01	110.29

In the *Rabi* season, the highest adoption of maize in all locations was NK40 (Table 7.1.23). as the popular maize hybrids are: NK40, 827K, Pacific 984, 900M Gold etc.. However, farmers prefer short duration maize hybrids with yellow grain color along with higher yield and NK40 meets such criteria. The concentration of NK40 is the highest in Rajshahi (98.92%) followed by Comilla (87.21%).

***Kharif*-1 rice and maize varieties/hybrids:**

Table 7.1.24 shows the adoption of varieties/hybrids of rice and maize in the *Kharif*-1 season. Farmers use mostly the same varieties of rice in the *Rabi* and *Kharif*-1. The same BRRI Dhan 28 is the highest adopted variety in Rangpur and Rajshahi (63.47% and 76.63% respectively). In Rangpur it is grown as late *Boro* rice, which is harvested in the *Kharif*-1 season. This late *Boro* is transplanted after the harvest of potato, or tobacco, mustard, etc. We found a farmer who grew early *Boro* and then late *Boro* in the same plot. So we recorded all late *Boro* crop in the *Kharif*-1 section of our structured questionnaire. We also identified a few farmers who transplanted late *Boro* after harvesting *Rabi* maize. So the cropping pattern is potato/another *Rabi* crop followed by late *Boro* followed by *Kharif-2* rice (*Aman* rice). *Aus* rice, which is traditionally a *Kharif*-1 rice was not grown in Rangpur.

Table 7.1.24 Adoption of rice and maize varieties in *Kharif*-1 season in study sites, 2012-13

Varieties	% of rice area			
	Rangpur	Rajshahi	Comilla	Total
BR 20			32.34	18.83
BR 22			2.02	1.18
BRRI Dhan 28	63.48	76.63	16.48	38.05
BRRI Dhan 29	9.07	2.17	0.45	3.03
BR 46			0.54	0.31
BR 48			9.79	5.70
BR 49			0.39	0.23
Other HYV	1.52	0.97	6.02	4.06
Hybrid	23.52	0.00	3.72	8.51
LV	2.41	20.24	28.26	20.10
Total	100.0	100.0	100.0	100.00
Total area (acres)	82.54	61.15	80.69	224.38
	% of maize area			
NK 40	58.58	77.98	93.54	70.69
Pacific 984	13.94	15.99	0.00	12.99
900M Gold	3.96	0.00	0.00	1.89
Other hybrid	23.52	6.03	6.46	14.43
Total	100.0	100.0	100.0	100.0
Total area (acres)	50.51	41.95	13.40	105.86

*includes Late *Boro* (also known as *Braus*) in Rangpur and Rajshahi and *Aus* rice in Comilla

In *Kharif*-1, maize area in Rangpur was double the area in *Rabi* season. In Rajshahi, the adoption in *Kharif*-1 maize was more than double the *Rabi* season, but in Comilla the adoption of maize was concentrated mainly in the *Rabi* season. The climatic condition in Comilla may be harsh for *Kharif*-1 maize. Rangpur and Rajshahi have more potential for maize expansion, partly because maize requires less irrigation, which is costlier in this belt. Of course there are other factors like awareness building activities of private organizations due to maize demand from feed sector, availability of hybrid seed etc.

NK40 was also the highest adopted variety in the *Kharif*-1 season like the Rabi maize. Varietal diversity was higher in Rangpur also in the *Kharif*-1 season. In all, NK40 occupied about 71% of *Kharif*-1 maize area.

***Kharif*-2 rice varieties:**

Table 7.1.25 depicts percentage distribution of varieties in the *Kharif*-2 season (*Aman* season). There were more differences in varietal preferences between regions. In Rangpur BR11 was adopted in about 54.2% of *Aman* area followed by hybrid in 35.2%. BR11 is a longer duration early *Aman* higher yield variety. In Rangpur and Rajshahi the *Aman* season rice has longer duration than Comilla due to climatic differences. In Rangpur BR11 as early prominent due to higher yield, it needs more growing days as compared to other varieties and there is no other constraints in Rangpur to grow this variety. In Rajshahi hybrids became the most popular followed by local varieties. BRRI Dhan 28, though not a recommended variety for the *Aman* season, more than 11% of the *Aman* area in Rajshahi is occupied by this variety.

In Comilla, BR22, a photosensitive variety, was the most accepted *Aman* variety followed by BRRI Dhan 32 and hybrids. , Both these varieties are of short duration as compared to BR11. In Comilla, farmers generally grow three rice crops in a year. They plant *Aman* rice in the last week of August or in September so window for *Aman* rice is short. The productivity of both of these varieties is lower than BR11 but farmers of Comilla prefer them due to short duration, which they require to plant rice three times a year in the same plot of land. Site specific climatic issues play important role on the choice of variety. Farmers adopt varieties of particular features to adapt climatic situation.

Proportionately more land is allocated to local varieties in the *Aman* season in Rajshahi. The varieties are Shorna and Zeerashail (fine quality rice with higher yield). Only one farmer reported growing Basmoti (aromatic fine quality rice) in Rajshahi.

Table 7.1.25 Adoption of varieties in *Kharif-2 (Aman*) season in study sites, 2012

Varieties	% of rice area			
	Rangpur	Rajshahi	Comilla	Total
BINA 7	2.69	0.00	1.90	1.77
BR 3	0.00	4.11	0.00	1.02
BR 11	54.16	0.28	1.18	23.61
BR 20	0.00	0.00	1.71	0.55
BR 22	0.00	0.00	27.31	8.87
BRRI Dhan 28	1.63	11.12	3.83	4.70
BRRI Dhan 29	0.80	0.00	0.09	0.37
BRRI dhan 32	0.00	0.99	25.60	8.56
BRRI dhan 46	0.00	0.00	9.98	3.24
BRRI dhan 49	0.00	2.29	2.02	1.22
Other HYV	1.80	12.55	1.67	4.43
Hybrid	35.22	51.28	18.45	33.75
LV	3.69	17.38	0.58	6.07
Pajam	0.00	0.00	5.68	1.84
Total	100.0	100.0	100.0	100.00
Total area (acres)	216.15	125.27	164.21	505.63

7.1.3.2.4 Rice productivity (yield):

Productivity (yield) of rice by technology:

For *Rabi (boro)* rice in Rangpur, DSR yield was lower than TPR, but there was very little difference in Comilla (Table 7.1.26). We had insufficient observations to examine the differences in Rajshahi. Line transplanting was better than random transplanting in term of yield. For *Kharif-1 (Aus)* rice, DSR produced the lowest yield in Comilla.

For *Kharif-2 (Aman)* rice, yield differences between CA technologies are not so prominent. In Rajshahi and Comilla, CA technologies appeared better than conventional tillage. Under the conventional tillage system DSR resulted in lower yield than transplanted in Comilla in this *Kharif*-2 season as well. The low adoption of DSR indicates that individual farmers were interested in immediate and tangible benefit offered by higher yield.

Table 7.1.26 Yield (t ha^{-1}) of rice by technology in the study sites, 2012-13

Crop	Technologies	Rangpur		Rajshahi		Comilla	
		Mean	SD	Mean	SD	Mean	SD
Early	Conventional tillage & direct seeding	5.2	1.9	-	-	5.5	2.1

Boro	manual						
	Conventional tillage & line transplanting	6.1	1.7	6.0	1.3	5.2	1.3
	Conventional tillage & random transplanting	5.9	1.3	6.0	1.6	-	-
	Overall	6.0	1.5	6.0	1.5	5.3	1.3
Late *Boro*	Conventional tillage & line transplanting	5.3	1.8	5.9	1.3	-	-
	Conventional tillage & random transplanting	5.1	2.1	5.5	1.0	-	-
	Overall	5.1	2.0	5.6	1.2	-	-
Aus rice	Zero tillage & direct seeding machine	-	-	-	-	2.7	0.3
	Zero tillage & unpuddled transplanting	-	-	-	-	3.1	0.5
	Minimum tillage & unpuddled transplanting	-	-	-	-	3.8	0.5
	Minimum tillage & raised bed manual	-	-	-	-	3.4	0.8
	Minimum tillage & raised bed planter	-	-	-	-	3.5	0.3
	Conventional tillage & line transplanting	-	-	3.8	1.5	3.3	1.1
	Conventional tillage & random transplanting	-	-	3.8	0.4	-	-
	Conventional tillage & raised bed manual	-	-	-	-	3.2	0.6
	Overall	-	-	3.8	1.2	3.3	1.0
Kharif-2 rice	Zero tillage & direct seeding machine	4.7	2.9	5.5	1.4	3.6	0.8
	Zero tillage & unpuddled transplanting	5.0	0.3	5.4	2.5	-	-
	Minimum tillage & direct seeding machine	5.5	2.8	5.7	1.3	-	-
	Minimum tillage & unpuddled transplanting	4.5	1.3	5.1	0.6	3.8	1.0
	Minimum tillage & line transplanting	4.5	1.1	-	-	-	-
	Conventional tillage & direct seeding manual	4.6	1.1	-	-	2.7	0.7
	Conventional tillage & unpuddled transplanting	-	-	-	-	4.9	1.0
	Conventional tillage & line transplanting	4.1	1.3	4.6	1.0	3.9	1.2
	Conventional tillage & random transplanting	4.1	1.2	4.4	1.2	-	-
	Overall	4.3	1.4	4.7	1.3	3.8	1.2

yield was not reported due to very small sample size (observation<5); there was no Aus rice in Rangpur.

Table 7.1.27 reveals differences in maize yield by CA and crop establishment technologies. In case of *Rabi* maize, CA technologies were better than conventional tillage. Zero tillage and direct seeding with machine produced 8 t ha^{-1} of maize yield in Rangpur. This was the highest average yield obtained in the *Rabi* season.

In general, *Rabi* maize yield in Comilla was lower than Rajshahi and Rangpur. Farmers mentioned that due to unfavourable stormy weather *Rabi* maize in 2012 was badly damaged everywhere in Comilla. This was the main reason for lower yield in Comilla in the *Rabi* season. In *Kharif*-1 season, minimum tillage outperformed zero (ZT) and conventional tillage.

Table 7.1.27 Yield (t ha^{-1}) of maize by technology in the study sites, 2012

Crop	Technologies	Rangpur		Rajshahi		Comilla	
		Mean	SD	Mean	SD	Mean	SD
Rabi maize	Zero tillage & direct seeding machine	8.0	1.3	7.3	1.5	6.7	1.5
	Minimum tillage & direct seeding machine	6.6	1.3	7.2	1.6	6.5	0.8
	Minimum tillage & raised bed planter	7.6	1.0	7.5	1.6	5.8	1.3

	Minimum tillage & direct seeding manual	-	-	-	-	6.1	1.6
	Conventional tillage & direct seeding manual	6.7	2.2	6.8	2.1	5.7	1.4
	Overall	7.0	2.0	7.1	1.9	5.9	1.5
Kharif-1 maize	Zero tillage & direct seeding manual	6.0	2.5	4.7	1.3	5.4	0.9
	Minimum tillage & raised bed planter	6.5	2.2	-	-	-	-
	Minimum tillage & direct seeding manual/machine	6.6	2.5	5.5	1.8	-	-
	Conventional tillage & direct seeding manual	6.2	2.1	5.2	1.8	6.1	1.0
	Overall	6.2	2.3	5.1	1.7	5.6	1.4

- Yield was not reported due to very small sample size (observation<5); SD=standard deviation.

Yield comparison with baseline:

Figure 7.1.2 shows the maize yield advantage gained in 2012 over the yield obtained in 2008. Maize yield had consistently increased across sites and villages except *Rabi* maize in Comilla. An exceptionally damaging storm hit all villages in Comilla in 2012 causing the observed lower yields of an otherwise increasing trend. There was no *Kharif*-1 maize in the control village of Comilla in 2008 but we found a few farmers adopting *Kharif-1* maize in this village in 2012.

In general, yield advantage was higher in case of *Kharif*-1 maize across all villages. In the baseline survey, yield of *Rabi* maize was much higher than *Kharif-1* maize except for project villages in Comilla, but in 2012 yield gap between *Rabi and Kharif-1* reduced considerably.

During the baseline in 2008, the difference in average yield between project villages and

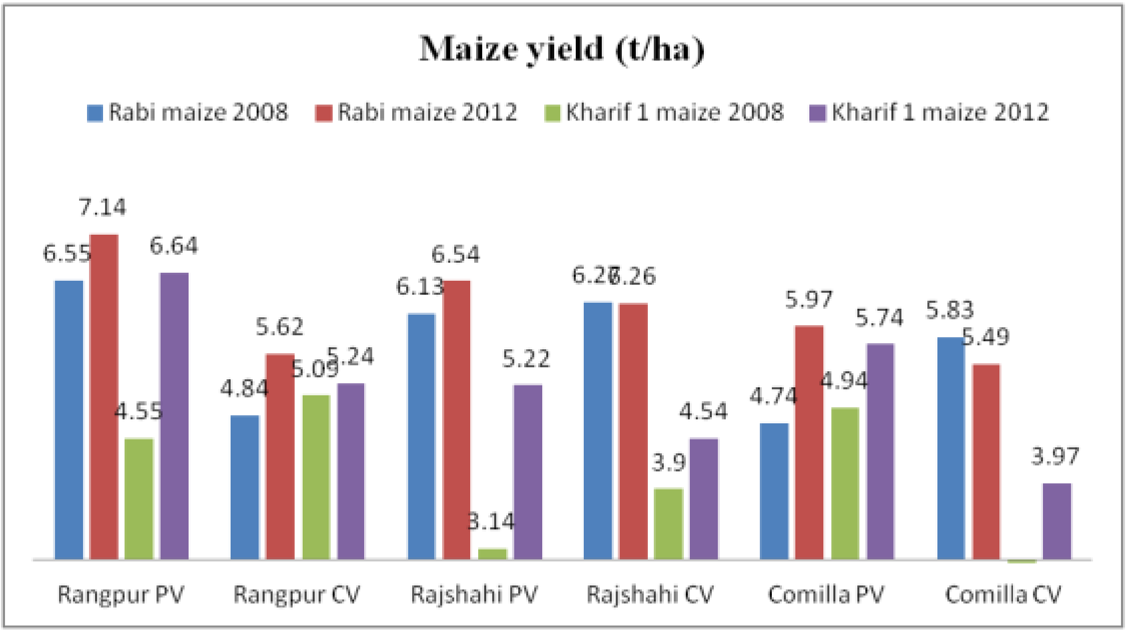


Figure 7.1.2 Yield advantages of maize as obtained by the farmers in study villages

control villages was statistically insignificant. In 2012, the difference in average yield was significant at 5%. This indicates that the project contributed positively to yield advantage. This means that CA and NM as well as advices of project staffs helped farmers enhance yield. This study is not for impact assessment and so measuring actual impact due to project is beyond our scope. However we explain potential reasons for yield advantage in the following sections.

7.1.3.2.5 Adoption comparison of crops with the baseline:

Crops considered for current adoptions compared to the baseline are are rice, maize, wheat, potato and others for the *Rabi* season (Table 7.1.28). One farmer has a maximum of 5 counts in this case. We got that rice counts 55% in 2008 in Rangpur and this reduced to 27% in 2012. On the other hand maize counts 5% in 2008 and increased to 33% in 2012. Wheat counts 0% in 2012 compared to 1% in 2008. So maize is getting much popularity in Rangpur. Similar trend is observed in Rajshahi and Comilla. This implies that maize adoption in rising rapidly. Farmers gave up wheat production in Rangpur and Comilla but counts increased in Rajshahi. In case of potato, adoption decreased in all locations but the decrease is higher in Rajshahi and Comilla. The other category comprises mainly different types of vegetables, and some spices, pulses and oilseeds. Some farmers in Rangpur mentioned about growing tobacco and in Rajshahi betel leaf.

Table 7.1.28 Adoption comparison of crops in the *Rabi* season, 2008 and 2012, R-M project sites in Bangladesh.

Crops	% of crop types in *Rabi*					
	Rangpur		Rajshahi		Comilla	
	2008	2012	2008	2012	2008	2012
Rice	55	27	39	21	46	23
Maize	5	33	2	23	19	61
Wheat	1	0	4	11	2	0
Potato	27	26	36	19	19	7
Other	12	13	19	27	14	8
Total	100	100	100	100	100	100

In *Kharif*-1 we used rice, maize and others (Table 7.1.29). In this category one farmer has maximum of 3 counts. We got that rice counts 47% in 2008 in Rangpur and this declined to 28% in 2012. On the other hand maize counts 11% in 2008 and increased to 43% in 2012. It means maize adoption is rising in Rangpur in *Kharif*-1 too. Trend, however, is different for Rajshahi and Comilla. In Rajshahi, *Kharif*-1 maize adoption is declining and there is no change in Comilla.

Others in *Kharif*-1 in Rangpur comprise mainly different types of vegetables and jute while in Rajshahi are sesame, jute, betel leaf and vegetables and in Comilla vegetables and spices. Vegetable production in *Kharif*-1 is growing through intensive cultivation in all study villages.

Table 7.1.29 Adoption comparison of crops in the *Kharif*-1 season, 2008 and 2012, R-M project sites in Bangladesh.

Crops	% of crop types in *Kharif*-1					
	Rangpur		Rajshahi		Comilla	
	2008	2012	2008	2012	2008	2012
Rice	47	28	10	15	82	83
Maize	11	43	62	30	9	9
Others	42	29	28	55	9	8
Total	100	100	100	100	100	100

In *Kharif*-2 there is rice and othersonly (Table 7.1.30). In this one farmer has a maximum of 2 counts. We obtained rice counted 96% in 2008 in Rangpur and this declined slightly to 94% in 2012. Similar situation is also observed in Comilla, where rice counted 94% in 2008 and 93% in 2012. The pattern is different in Rajshahi where rice counted 92% in 2008 and declined remarkably to74% in 2012. On the other hand in Rajshahi, other crops counted 8% in 2008 and increased amazingly to 26% in 2012. Others comprise mainly vegetables and betel leaf. In Rangpur and Comilla, the other crops remained the same and dominated by rice mono crop.

Table 7.1.30 Adoption comparison of crops in the *Kharif*-2 season, 2008 and 2012, R-M project sites in Bangladesh

Crops	% of crop types in *Kharif*-2					
	Rangpur		Rajshahi		Comilla	
	2008	2012	2008	2012	2008	2012
Rice	96	94	92	74	94	93
Others	4	6	8	26	6	7
Total	100	100	100	100	100	100

The variation between the regions indicates that the capacity to adopt innovative technologies would vary substantially between regions. Failing to capture region specific differences in innovation would not produce desired impact.

7.1.3.2.6 Market sales of rice and maize:

In *Rabi*, on an average 30.9% to 67.9% of the rice grain produced was sold in the market in 2012. The lowest amount (30.9%)sold was by the non-participatory farmers in the project village of Rajshahi while the highest amount (67.9%) was sold by the participatory farmers in the project village of Rangpur. On an average, around 36.6% to 66.7% of the rice grain was sold in the *Kharif-1* season. In most of the villages farmers sold higher proportion of rice grain in *Kharif-1* in relation to *Rabi* andthe proportion rice grain sold was lower in Rajshahi than Rangpur and Comilla. A larger proportion of the maize was sold compared to rice. In fact, almost all the harvested maize was sold. and very little was kept for home consumption . So maize appears o be a commercial crop.

Table 7.1.31 Rice and maize marketed in different seasons in study sites, 2012-13

Commodities	% of rice and maize marketed								
	Rangpur			Rajshahi			Comilla		
	PF	PVNF	CF	PF	PVNF	CF	PF	PVNF	CF
Rabi rice	67.9	58.9	64.3	41.4	30.9	37.3	39.8	33.8	44.5
Kharif-1 rice	48.3	46.3	66.7	43.1	40.2	40.7	56.3	36.6	57.4
Kharif-2 rice	51.8	51.1	61.1	38.8	44.0	52.5	43.4	34.5	52.9
Total annual rice	55.1	52.4	63.3	39.9	39.2	44.1	46.8	35.0	52.7
Rabi maize	94.8	96.2	97.0	98.8	92.9	100.0	91.5	93.3	98.2
Kharif-1 maize	98.6	95.6	100.0	97.1	99.6	97.9	91.1	99.8	100.0
Total annual maize	96.5	95.9	98.0	98.0	97.3	93.4	93.7	94.2	98.3

PF=participant farmers; PVNF=project village non-partcipant farmers; CF=control farmers

7.1.3.3 Adoption and constraints:

Though the use of CA technologies and the area under maize cultivation increased in some areas in 2012 compared to 2008, some farmers exited from the project as well as from maize cultivation. The reasons need to be identified for further action in relation to interventions for the participatory projects such as the R-M project.

The FGDs identified some important constraints to the adoption of technologies. Other than through the participatory trials, technology adoption had been rising through extension, meaning some farmers were extending the use of the technologies beyond their trial plots. However non-participatory farmers, although had shown interest to use some of the technologies like PTOS for maize cultivation, were unable to use the machine because it was not locally available. Farmers mentioned a number of constraints for the wider adoption of ZT technology in addition to non-availability of machine, which appears the primary constraint. The farmers in Rangpur identified high weed infestation, low germination, high bird attack, and low yield, etc. The farmers of Rajshahi, on the other hand, mentioned that the ZT technology is not friendly and/or suitable for all types of soil while the farmers in Comilla were reluctant to give up the practices they inherited. They were worried about the associated risk with ZT technology in absence of reasonable coping strategies. They mentioned that soil in Comilla site is not suitable for ZT practice. Farmers also mentioned about people and the animals also damage the crops as they are attracted by grasses and weeds in the ZT fields.

Regarding impact of ZT on water use, FGD results were inconclusive; participating farmers reported that water use has increased under ZT practice, while the non-participating farmers gave opposite remarks. Farmers also reported that both rice and maize yields as well as cost of production decreased in the ZT plots compared to that in the CT plots.

Main constraints to growing maize were stated to be natural calamities like storms lowering the yield and the high costs of fertilizer, seeds and irrigation. Some farmers mentioned about difficultis for post-harvest processing (shelling-threshing), drying and storage facilities.

We did not find any systematic evidence of lower yield in CA technologies compared to conventional farmer practices. Instead we found MT better than ZT and CT (Table 7.1.26 and 27). For Kharif-1 rice in Comilla yield under ZT was lowest, MT highest and CT intermediate. In Kharif-2, both ZT and MT resulted in higher yield than CT.

Constraints as mentioned by farmers varied between locations (Table 7.1.32). In Comilla, the highest proportion of land suffered from climatic problems such as crop damaged due to storm and water logging (sowing delayed in the *Rabi* season and *Kharif*-1 crop damaged due to water logging at maturity). ZT/ST/PTOS/bed planter machine was supplied by the project only to the participatory farmers and a large proportion of farmers mentioned about the unavailability of the machine on time due to lack of machines as well as delay in repairing them. Actual demand of the machines was much higher than what was supplied by theproject.

Table 7.1.32 Constraints to rice and maize production in R-M project sites in Bangladesh, 2012

Constraints	Rangpur			Rajshahi			Comilla		
	PF	PVNF	CF	PF	PVNF	CF	PF	PVNF	CF
Climate shock (*Rabi*) % of area	8.4	5.1	25.0	8.3	4.5	3.8	58.0	70.5	35.3
Climate shock (*Kharif*-1) % of area	7.1	5.2	11.6	4.3	4.6	1.7	18.0	16.9	20.8
ZT/ST machine was not available on time (% of farmers)	13.0	-	-	40.9	-	-	38.2	-	-
PTOS was not available on time (% of farmers)	35.7	-	-	11.1	-	-	54.2	-	-
FB/PB planters were not available on time (% of	20.9	-	-	32.4	-	-	27.3	-	-

farmers)									
Machine for DSR was not available	20.8	-	-	33.3	-	-	50.0	-	-
UT not possible	10.0	-	-	33.3	-	-	14.3	-	-
Seed was not available on time (% of farmers)	0.3	1.6	6.0	1.4	0.0	1.6	1.0	1.4	0.9
Constraints on fertilizer (% of farmers said yes)	29.2	39.5	34.2	18.8	21.9	72.7	64.1	83.8	37.5
High constraints on fertilizer (% of farmers said yes)	4.9	4.7	5.0	0.4	2.9	0.0	8.3	11.8	16.6
Constrained to weeding	1.7	3.0	8.5	17.4	15.8	7.4	25.4	15.0	12.7
Constraint to pest management	5.7	6.7	12.9	19.0	28.3	20.8	35.9	27.2	25.0
Market constraint (% said yes in Rabi)	14.0	0.0	7.9	6.0	0.0	0.0	13.4	1.8	2.1
Market constraint (% said yes in K1 season)	12.5	10.5	13.6	0.0	0.0	0.0	13.0	2.5	2.6
Market constraint (% said yes in K2 season)	11.5	4.6	8.3	8.7	5.9	0.0	8.5	2.9	3.0

7.1.3.3.1 Information constraint:

We asked farmers about the sources from which they received recommendation on the use of fertilizer and seed, weed control, pest management, etc. In all cases, we found very little involvement of government sources including extension personnel. In all situations most farmers either used their experiential knowledge or sought advice from the private dealers who have relevant

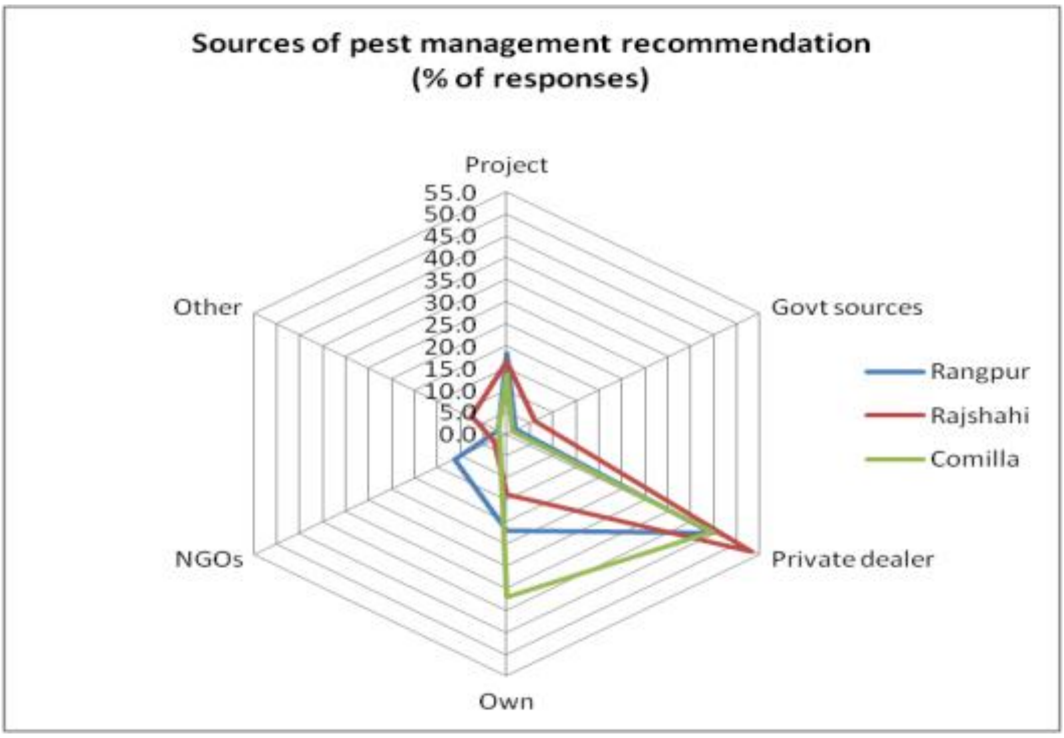


Figure 7.1.3 Percentage of responses on the sources of weed/pest management recommendation

businesses. For example, the radar diagram shows that for use for pest management recommendation, some farmers used more than one sources. Nearly 55% of the responses in Rajshahi and around 45% in Rangpur and Comilla were in favor of private dealers followed by farmers themselves and then by the R-M project personnel (Figure 7.1.3).

Mobile phone is a major means of communication of the sample farmers (Tables 7.1.11 and 7.1.12). Mobile phones have opened up new opportunities in communicating new ideas quickly in remote places. Some technical innovation with minimum effort is possible to transfer images from remote areas to experts to better inform problems like the type of disease/pest infestation level, color of leaf, plant growth etc. Farmers easily get the required inputs and use information from the dealers but the danger of inappropriate use of inputs like pesticides cannot be over ruled. Mobile phone-based technologies can be used for transferring images of insects/diseases to agricultural experts who can provide farmers with appropriate advices.

7.2 Objective 2: To evaluate elite maize germplasm for tolerance of excess moisture during emergence and at flowering stage for the *rabi* and *kharif-1* seasons.

7.2.1 Cup screening of promising inbreeds and hybrids against water logging stress:

In 2009, seedlings of two sets of maize inbreds and hybrids (108 and 160 inbreds and public/private sector hybrids from BARI and CIMMYT) were screened for emergence-stage high moisture tolerance using “cup method” in control conditions. Among the hybrids, eight (Pinnacle, 900MGold, Uttaran-2, PG-1000, BHM-5, BHM-8 and BHM-9) showed comparatively less susceptibility to excess water at the seedling stage. However none of the hybrids showed significantly high emergence-stage high-moisture tolerance for taking them forward to on-farm trials. Overall, only six lines showed relatively less susceptible and most of other lines highly susceptible to emergence-stage waterlogging, and the latter were unable to survive under high moisture condition.

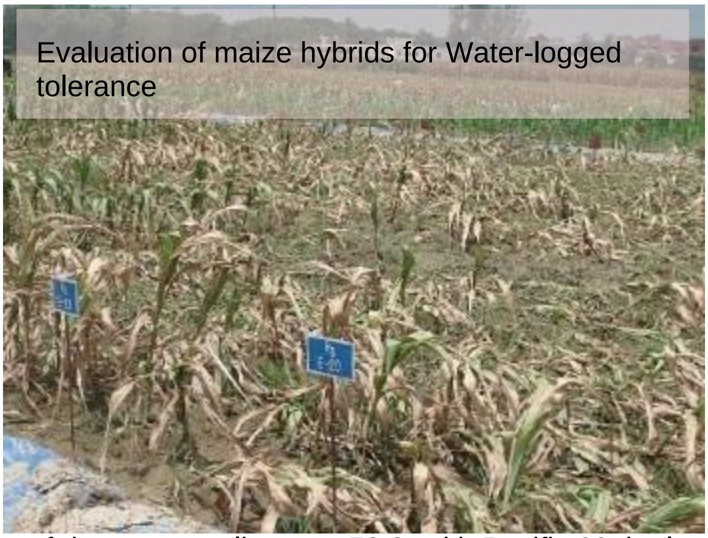
Similarly, 250,180 and 60 inbreds and hybrids were screened respectively in 2010, 2011 and 2012. In 2010, all inbreds were dead at emergence-stage and thus none of them were tolerant. In addition to these trials, CIMMYT program in Hyderabad also conducted similar experiment with 301 CIMMYT inbreds. Out of the total lines screened, only 14 lines with more than 50% germination and 7 lines with more than 80% germination under anaerobic conditions were selected, and they were further taken-up for next generation for confirmation.

In 2012, based on the number of leaves, plant height, root and shoot biomass and survival percentage at 7, 14 and 21 days after emergence, 10 inbreds were found relatively less susceptible to excess water at seedling stage. Considering the survival percentage six inbred lines viz. E15, E298, E47, E50, E55 and E57 and one susceptible line were selected for crossing in diallel fashion.

Results suggest thatnone of the existing hybrids in Bangladesh possess targeted/acceptable high-moisture/waterlogging tolerance. However, based on the four years of study, a few hybrids and inbred lines were identified with comparatively less susceptible to the excess moisture stress though none of them were found worth advancing for demonstration or on-farm trials. Thus, there is a need for a planned and systematic breeding initiative for both emergence-stage high-moisture and late-vegetative-stage waterlogging tolerance in maize in Bangladesh.

7.2.2 Field evaluation of maize hybrids for water logging tolerance at multiple locations:

In the multi-location trials in 2011, there was large climatic variation across locations during the season, so the experiment could not be set up at the same time in all locations. Due to heavy showers throughout the season the hybrids at all locations experienced severe excess water stress. There were highly significant variations in days to maturity, plant height, ear height, and yield over locations (Table 7.2.1). In addition to above four characters, significant variation was also noted for number of days to tasseling. There were also significant location-genotype and location-genotype-replication interactions effects. Mean number of days to tasseling was 50.2, with Pacific 60 the lowest (49.2 days) and CML254XCML247 the highest (51.7 days). The number of days to maturity was lowest for Pinnacle (95.2 days) and highest for 900M Gold (98.2 days). Uttaran-2 was tallest (222.8 cm) and Pacific 60 shortest (185.9 cm) hybrid. Uttaran-2 was the highest yielder (7.1 t ha^{-1}) followed by 900M Gold (6.8 tha^{-1}) and Pinnacle (6.4 tha^{-1}) (Table 7.2.2).



Burirhat (Rangpur) produced the highest yield (7.23 tha^{-1}) followed by Barisal (6.97 tha^{-1}) and Jamalpur (6.53 tha^{-1}) and least Gazipur produced only 5.33 t ha^{-1}. Uttaran produced highest yield in Jamalpur (8.18 t ha^{-1}) and lowest in Satkhira (5.88 t ha^{-1}). 900M Gold had the highest yield in Burirhat (8.11 t ha^{-1}) and the lowest in Gazipur (5.51 t ha^{-1}). Pinnacle performed best in Burirhat (7.90 tha^{-1}) and worst in Barisal (5.48 t ha^{-1}) (Table 7.2.3).

Table:7.2.1 Combined analysis of variance for different characters of maize over five locations

Sources of variation	df	Mean sum of squares					
		Days to tasseling	Days to silking	Days to maturity	Plant height (cm)	Ear height (cm)	Yield (tha^{-1})
Location	4	29.7	63.7	199.5**	4387.6**	4226.1**	39.3**
Genotype	4	53.5*	56.9	99.3**	13431.0**	1264.1**	23.7**
Loc*Geno	16	139.9	118.4	127.7*	8861.3**	3563.0**	51.5**
Loc*Geno*Rep	50	264.0	275.3	191.3*	810.0*	709.7*	44.4*

**Significance level at $p<0.01$,*Significance level at $p<0.05$

Table: 7.2.2 Mean performance for different characters of the tested hybrids, 2011.

Genotype	Days to tasseling	Days to silking	Days to maturity	Plant height (cm)	Ear height (cm)	Yield (t ha^{-1})
Pacific 60	49.2	52.1	95.3	185.9	89.2	5.97
Pinnacle	49.7	52.9	95.2	214.6	101.0	6.43
CML254XCML247	51.7	54.7	97.2	209.0	95.9	5.51
900M Gold	50.2	52.7	98.2	221.4	98.2	6.77
Uttaran-2	50.3	52.9	96.0	222.8	99.3	7.10
Overall mean	50.2	53.1	96.4	210.7	96.7	6.35
LSD (5%)	1.68	1.72	1.43	2.95	2.76	0.69

Table:7.2.3 Location wise yield (t ha^{-1}) of five hybrids, 2011.

Hybrid	Grain yield (t ha^{-1})				
	Barisal	Rangpur	Gazipur	Jamalpur	Satkhira
Pacific 60	7.07	5.85	4.38	5.07	7.55
Pinnacle	5.48	7.90	5.89	6.90	6.0
CML254XCML247	7.53	6.29	4.82	5.71	3.22
900M Gold	7.43	8.11	5.51	6.79	5.99
Uttaran-2	7.38	8.0	6.04	8.18	5.88
Overall mean	6.97	7.23	5.33	6.53	5.73
LSD (5%)	0.27	0.84	2.09	3.0	0.93

Qualitative characters like leaf rolling, leaf yellowing and leaf senescence were not observed in Uttaran-2 in any of the locations except Satkhira. Considering all the qualitative characters Uttaran-2 was found stable across the locations followed by 900M Gold and Pinnacle. The cross of CML254 and CML247 was responsive to all the locations. Uttaran-2 produced large number of brace roots and brace root producing nodes, which are the most important characters to survive under excess water stress (Table 7.2.4).

Considering all the yield contributing characters and excess water tolerant parameters Uttaran-2, 900M Gold, and Pinnacle can be recommended as these are less susceptible (or moderately tolerant) to waterlogging. Similar experiment needs to be conducted with these and other promisinghybrids in the *rabi and kharif-1* season in these and a few other locations.

Table:7.2.4 Qualitative characters of five maize hybrids under excess water stress

Location	Variety	Qualitative characters						
		LR	LY	LS	#BR	#NBR	RL (%)	SL (%)
Barisal	Pacific 60	0	2	0	2	4	9.84	18.14
	Pinnacle	1	1	0	1	4	9.3	14.89
	CML254XCML247	1	2	1	2	2	11.54	9.54
	900M Gold	1	0	0	2	3	15.1	11.3
	Uttaran-2	0	0	0	1	3	10.56	8.03
Rangpur	Pacific 60	0	2	0	2	4	9.3	12.2
	Pinnacle	1	1	0	2	4	8.6	10.3
	CML254XCML247	1	2	1	2	2	10.75	10.6
	900M Gold	1	0	0	2	3	14.3	12.3
	Uttaran-2	0	0	0	2	3	9.3	5.8
Gazipur	Pacific 60	0	1	0	1	4	7.5	5.2
	Pinnacle	0	1	0	2	3	8.2	6.4
	CML254XCML247	1	2	0	1	2	12.3	7.8
	900M Gold	1	0	0	2	3	9.5	5.5

	Uttaran-2	0	0	0	1	3	7.6	4.8
Jamalpur	Pacific 60	1	1	0	1	3	10.9	6.5
	Pinnacle	0	1	0	2	3	9.6	7.4
	CML254XCML247	2	2	1	2	2	11.3	8.3
	900M Gold	1	1	0	2	3	8.6	5.8
	Uttaran-2	0	0	0	1	4	8.2	6.2
Satkhira	Pacific 60	1	1	0	2	4	12.4	5.8
	Pinnacle	0	2	1	3	3	10.6	9.2
	CML254XCML247	1	1	0	2	3	15	10.2
	900M Gold	1	1	0	1	4	8.3	6.2
	Uttaran-2	1	1	0	1	4	6.2	6.4

Leaf rolling (LR): 0 - no rolling, 5 - 100% rolling; leaf yellowing (LY): 0 - no yellowing, 5 - 100% yellowing; leaf senescence (LS): 0 - no senescence, 10 - 100% senescence; brace root (#BR): 1 - large number of brace roots, 5 - no brace roots; nodes for brace roots (#NBR): 1 - 1st node, 5 - up to 5th; root lodging (RL): Root lodging (%); stalk lodging (SL) : Stalk lodging (%)

7.2.3 Advancing S1 to S2 generation of excess water tolerant maize inbred lines:

Inbred lines of maize are a prerequisite for development of maize hybrids. Thus, superior inbred lines are desirable for the development of excess water tolerance commercial maize hybrids also. Extraction of superior lines from the available inbred lines is a common technique in maize breeding program. In this project, the materials were advanced from S_0 to S_1 generationin *kharif*-1 season 2009 and from from S_1 to S_2 generation in 2010. The experiments were conducted at Joydebpur, Gazipur. The materials consisted of two sets of S_1 lines (set 1 with5 excess water tolerance inbred lines, and set 2 with 6 excess water tolerance inbred lines). In 2010, seeds of both sets were sown on 20 February and 29 March. Each S_1 material was sown in single row of 5 m long. Spacing was 75x20 cm (one plant/hill). After earthing-up at V_8 stage, water was applied continuously for 6 days at 15 cm height from the soil surface. Plants were kept under observation for 2 to 3 weeks without any cultural operations. Selected plants were selfed by hand pollination. A total of 50 plants were selfed. The selfed plants were harvested individually and dried properly. Finally 20 ears of both the sets were selected and were preserved separately for advancing from S_2 to S_3 generation during 2011 as ear to row method. Mean performance of the materials is summarised in Table 7.2.5.

Table:7.2.5. Mean performance of 11 S_1 lines of excess water tolerant maize lines, *kharif*-1, 2010.

Material	Plant height (cm)	Ear height (cm)	Cob length (cm)	Cob diameter (cm)	Row/cob	Grain/row	Amount of sefled seed (g)
E-38	115.0	54.0	10.8	10.8	10.0	18.0	230
E-64	133.7	71.7	11.0	12.3	12.0	19.7	155
E-31	132.7	78.3	11.0	14.0	16.0	19.2	340
E-80	145.3	74.7	11.2	10.8	10.8	17.8	142
E-58	102.0	64.3	8.5	10.0	10.0	16.0	60
E-40	124.3	60.7	5.7	8.3	8.7	10.0	35
E-61	84.8	70.3	12.0	13.6	13.2	22.8	490
E-79	138.3	62.3	12.6	9.0	9.2	19.8	140
E-63	138.7	62.7	9.4	9.6	7.6	10.0	70
E-37	145.3	85.0	9.8	8.5	7.0	16.3	80
E-71	83.7	38.7	10.0	7.0	6.0	14.0	20

7.3 Objective 3: To develop locally adapted integrated management solutions for high-yielding, profitable, resource-efficient, and sustainable R-M systems.

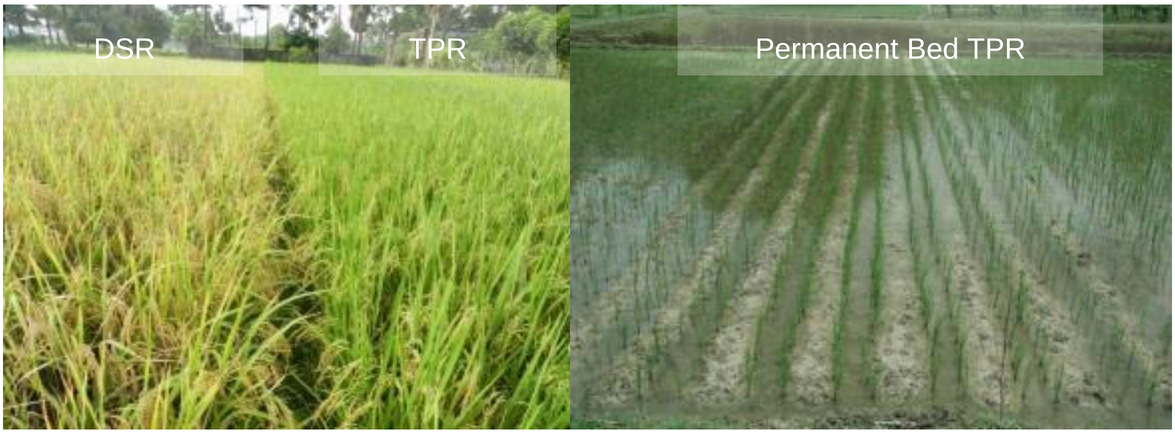
7.3.1 On-farm participatory research trials:

7.3.1.1 Conservation agricultural (CA) based crop management practices:

In this section,the key results are presented for individual crops in each district but also summarized to see overall performance by combining the data of all five years from all the three districts. Further, results are also summarized on a system basis for both R-M-MB and R-M-R system. Under the R-M-MB system, mungbean economic yield was not considered because in initial years seeds were not harvested due to heavy rains at the time of maturity and biomass was recycled to restore the soil fertility but in later years some farmers received economic yield and it was possible to advance mungbean sowing through relay planting into standing maize, but we didn't consider those farmers in analysis.

7.3.1.1.1 Effect of CA-based crop management practices on Aman rice:

Aman rice performance was evaluated under different tillage/crop establishment options during 2009 to 2013 (5-yr pooled data) in Rangpur, Rajshahi and Comilla. The ANOVA by year, farmer, treatment, and year*treatment and the adjusted mean values for all yield parameters (grain, straw, biomass and HI) reveal that these characters are significantly



different for different tillage options at various levels of probabilities (Table 7.3.1). A total of 50, 74 and 61on-farm trials on aman rice were conducted in Rangpur, Rajshahi and Comilla, respectively, during 2009-2013. Out of 6-tillage options tested, 4 options (FB, PB, MT, ST) were maintained in each replicate (farmers' field) but conventional tillage was maintained as a control in all trials. The results indicated that year was non-significant and hence across the three districts, all yield parameters performed similarly in all the years. It might be due to the fact that all farmers were using the aman rice varieties with similar yield potential and were growing aman rice under rainfed situation with similar water regime. In all three districts, all crop parameters behaved differently among the farmers which could be due to different agronomic management practices (except fertilizer management), including irrigation and use of *aman* rice varieties, adopted by individual farmers. Year * treatment interactions in all sites and for all parameters were found non-significant which allowed us to combine (pool) together all 5-yr data. Different tillage/crop establishment options produced similar crop yield and biomass including HI across all sites. The straw yield ranged from. 4.70-5.26, 5.11-5.34 and 4.34-5.57 t ha^{-1} in Rangpur, Rajshahi and Comilla, respectively. Similarly the grain yield ranged from 4.36-4.97, 4.47-4.82 and 3.60-4.01 t ha^{-1} in Rangpur, Rajshahi and Comillla, respectively. Rajshahi produced rice grain yield (4.67 t ha^{-1}) followed by Rangpur (4.56 t ha^{-1}) and Comilla (3.80 t ha^{-1}). The HI varied from 0.45 to 0.48 in all three districts.

Table 7.3.1 *Aman* rice performance (5-yr pooled data; t ha^{-1}) under different tillage options in three districts of Bangladesh during 2009 to 2013

Treatment	Adjusted pooled mean			HI
	straw	Grain	Biomass	
		Rangpur		
CT(50)¥	5.16	† 4.37	9.50	0.46
FB(32)	5.03	4.46	9.50	0.47
MT(25)	5.08	4.58	9.65	0.48
PB(31)	5.26	4.97	10.22	0.49
ST(37)	5.13	4.63	9.74	0.48
ZT(12)	4.70	4.36	9.05	0.48
ANOVA		Probability		
Year	0.097	0.136	0.105	0.100
Farmer	0.019	0.069	0.024	0.049
Treatment	0.787	0.173	0.488	0.542
Yr*Trt	0.065	0.230	0.107	0.117
		Rajshahi		
CT(74)	5.29	4.76	10.05	0.47
FB(54)	5.34	4.71	10.09	0.47
MT(46)	5.25	4.65	9.81	0.47
PB(41)	5.36	4.82	10.18	0.47
ST(57)	5.11	4.47	9.58	0.47
ZT(23)	5.16	4.61	9.77	0.47
ANOVA		Probability		
Year	0.086	0.081	0.083	0.823
Farmer	0.001	0.001	0.001	0.001
Treatment	0.231	0.153	0.172	0.703
Yr*Trt	0.404	0.409	0.329	0.477
		Comilla		
CT(61)	5.57	3.84	8.40	0.46
FB(23)	4.68	4.01	8.70	0.46
MT(31)	4.55	3.71	8.26	0.45
PB(58)	4.60	3.87	8.45	0.46
ST(50)	4.61	3.80	8.40	0.45
ZT(21)	4.34	3.60	7.93	0.45
ANOVA		Probability		
Year	0.119	0.148	0.123	0.126
Farmer	0.021	0.014	0.028	0.005
Treatment	0.800	0.377	0.544	0.694
Yr*Trt	0.241	0.269	0.366	0.132

¥ () represents the number of farmer replicates; †Within a column, means followed by the same letter are not different at the 0.05 level of probability by Tukey's HST test

Table 7.3.2 Effect of tillage on *aman* rice performance (combined pool for 3 districts for 5 years) in Bangladesh during 2009-2013

Treatment	Yield (t ha^{-1})			HI
	Straw	Grain	Biomass	
CT(185)¥	5.02 †	4.34	9.36	0.46
FB(109)	5.10	4.44	9.54	0.47
MT(102)	5.01	4.32	9.33	0.46
PB(130)	5.06	4.57	9.51	0.47
ST(144)	4.95	4.28	9.24	0.46
ZT(56)	4.79	4.18	8.98	0.47
ANOVA			Probability	
District	0.155	0.165	0.168	0.244
Year	0.088	0.088	0.087	0.123
Farmer	0.001	0.001	0.001	0.001
Treatment	0.430	0.333	0.342	0.664
Yr*Trt	0.188	0.163	0.114	0.153

¥() Represents total number of farmer replicates; †Within a column, means followed by the same letter are not different at the 0.05 level of probability by Tukey's HST test

Combined pooled data of all three districts (Table 7.3.2) showed that a total of 185 on-farm trials were conducted in three districts during 2009-2013. CT was executed in all trials (farmers) as a control, while only 109, 102, 130, 144, and 56 farmers implemented FB, MT, PB, ST, and ZT tillage treatments respectively. All three districts behaved similarly for straw, grain, and biomass yield as district was not significant. Combined results further confirmed that the individual district was significant for farmer and non-significant for year, treatment, and year*treatment. Straw yield varied from 4.79-5.10 t ha^{-1}, grain yield from 4.18-4.57 t ha^{-1} and biomass from 8.98-9.54 t ha^{-1} .Almost similar HI was recorded for all tillage-options. A little penalty in grain yield was observed under zero-tillage but it was non-significant between other tillage-options. Similar patterns were also reflected in straw and biomass production.

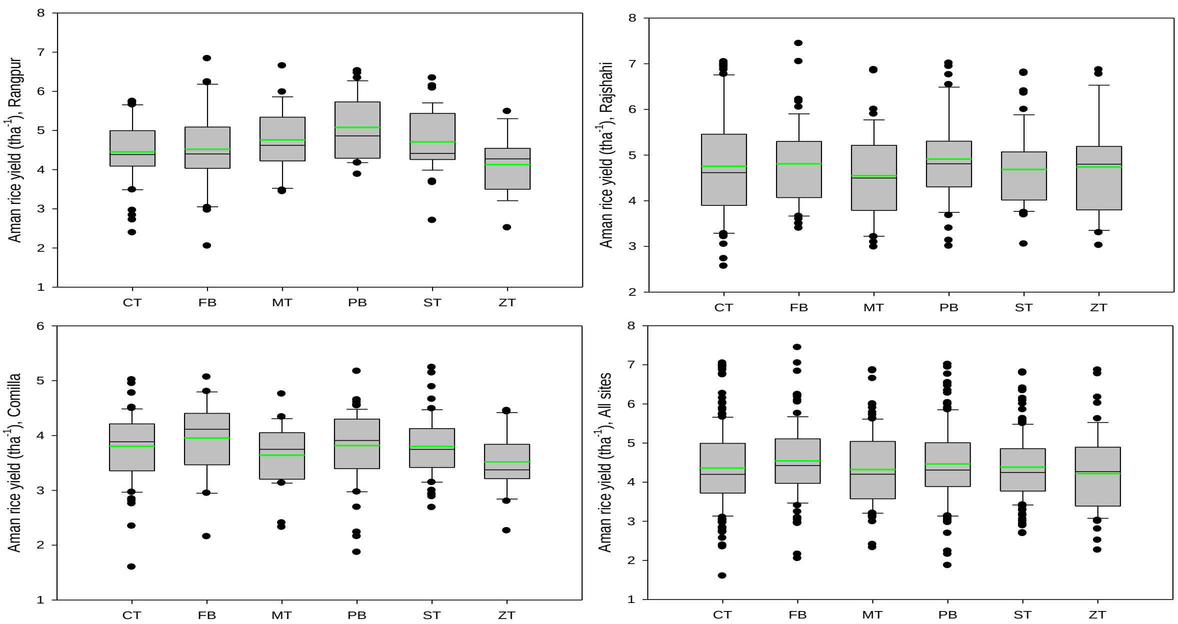


Figure 7.3.1 Box plots showing variation in *aman* rice grain yield under different tillage options in all sites

There was variability in *aman* rice grain yield among the farmers within tillage options in all three districts (Figure 7.3.1). In Rangpur, the farmers' yield distributed well under CT, FB, MT and PB but all were slightly positively skewed towards quartile 1 (Q1). It means more farmers were closely grouped on the side of 25% of interquartile range (IQR) than upper IQR. Farmers yield highly positively skewed toward Q1 in ST but an opposite pattern was found in ZT. The farmers skewed negatively towards Q3. Farmers were grouped more under whisker in FB than other in tillage options. In Rangpur, overall ZT was least performer in terms of rice grain yield than the other tillage options.

In Rajshahi, all tillage options produced similar yield levels. The farmers' yield in all tillage options was well distributed and more consistent than in Rangpur. Farmers' performance in FB and MT was well representative in IQR and also equally lying in both upper and lower whiskers. Under CT, PB, ST and ZT the wide range in yield was grouped in upper whisker than lower whisker but in ST and ZT the median showed more negatively skewed towards Q3 and in CT data were spread around neutral (Q2). Numbers of outliers were highest in CT and least in ZT, but it could be due to the fact that the numbers of participatory farmers were also more in CT than ZT.

Comilla box plot results showed that more or less the IQR of data was similar in all tillage options. The meadin for CT, FB, and MT were more negatively skewed towards Q3, meaning more consistent results were achieved on 75 percentile side and more variability was found on 25 percentile side. In contrast to these tillage options the median for ZT was skewed towards Q1. The PB and ST were performing more consistently than the other tillage options. The highest numbers of outliers were observed under ST and CT.

Overall, when box plot results for all districts combined, it showed similar yield patterns in all tillage options. Surprisingly, in all tillage options, the rice grain yield was well distributed among the farmers and showed more consistent results as compared to individual districts. In CT, FB, MT and PB, median values were skewed towards positive but in ZT it was skewed towards negative.

For partial economic analysis, all input and output information for each tillage options at each farm was collected by the project team during the implementation of on-farm trials. In Rangpur, year and year* treatment interaction were found non-significant for all economic parameters but labor use behaved differently and was hghly significant for year*tillage interactions (p=0.003) (Table 7.3.3), which could be due to the refinement of the technologies with time. Farmers were found significant for all parameters but very close to significance for gross return (p=0.055) Cost of production and labor use were significantly different between the tillage options but the gross return and net income were non-significant. The farmers had to invest 5% more in CT (43922 BDT ha^{-1}) than ST (41807 BDT ha^{-1}) but other tillage options required intermediate investment. Labor use was highest for CT than all other tillage options except FB. The gross return ranged from 84324-96024 BDT ha^{-1} while net income ranged 41318-51929 BDT ha^{-1}.

In Rajshahi, the year did not show any significant effect for any of the economic parameters. Year*treatment interaction showed the significant difference for all parameters except gross return. It might be due to the variable input prices in different years and technology improvement with time. Farmer effect showed different patterns for all economic parameters except labor use, which was probably due to the adoption of more mechanization in Rajshahi from the beginning of the project. Labor use under CT (83 person days ha^{-1}) and ZT (87 person days ha^{-1}) were higher than MT, PB and ST. More labor was used under ZT due to the un-puddled transplanting and more weed infested which require more weeding manually. The cost of production ranged from 57155-68952 BDT ha^{-1}, and net income ranged from 32400-46377 BDT ha^{-1}.

In Comilla, both year and year*treatment effects showed similar patterns as for Rajshahi. Farmers were highly variable in terms of economic parameters and it could probably be due to the fact that farmers generally buy the inputs from different sources and also sell their product to different brokers. Except for labor use, other parameters were non-significant between different tillage options. The cost of production ranged from 48545-51923 BDT ha^{-1} and net income ranged from 33772-42001 BDT ha^{-1} .Labor use was highest in CT and ST than MT, FB, PB but intermediate for ZT.

Table 7.3.3 Partial budgeting (BDT ha^{-1}) for *aman* rice (adjusted pooled mean) under different tillage options in three districts of Bangladesh during 2009-13

Treatment	Adjusted pooled mean				Labor use (person days ha^{-1})	
	Cost of production		Gross return	Net profit		
			Rangpur			
CT(50)¥	43922	a†	85283	41318	79	a
FB(32)	42559	ab	87207	44654	71	ab
MT(25)	41363	b	89051	47552	65	b
PB(31)	43882	ab	96024	51929	68	b
ST(37)	41807	b	89825	48134	68	b
ZT(12)	41931	ab	84324	42199	68	b
ANOVA			Probability			
Year	0.080		0.123	0.091	0.083	
Farmer	0.003		0.055	0.047	0.003	
Treatment	0.009		0.208	0.217	0.003	
Yr*Trt	0.108		0.184	0.126	0.039	
			Rajshahi			
CT(74)	58218		103526	45313	83	a
FB(54)	55285		102578	46377	79	ab
MT(46)	57155		100165	43159	51	b
PB(41)	61796		104493	42461	47	b
ST(57)	59536		97295	38043	60	b
ZT(23)	68952		100495	32400	87	a
ANOVA			Probability			
Year	0.083		0.079	0.082	0.129	
Farmer	0.002		0.001	0.001	0.309	
Treatment	0.299		0.187	0.431	0.001	
Yr*Trt	0.004		0.223	0.004	0.005	
			Comilla			
CT(61)	51923		87085	35461	59	a
FB(23)	49697		91406	42001	57	b
MT(31)	50591		85317	35511	57	b
PB(58)	48659		87412	38983	57	b
ST(50)	48748		85096	76588	60	a
ZT(21)	48545		82425	33772	58	ab
ANOVA			Probability			
Year	0.119		0.112	0.113	0.115	
Farmer	0.001		0.003	0.008	0.006	
Treatment	0.131		0.160	0.126	0.001	
Yr*Trt	0.212		0.112	0.145	0.425	

¥() Represents total number of farmer replicates; †Within a column, means followed by the same letter are not different at the 0.05 level of probability by Tukey's HST test

Data for the overall economic analysis across districts (Table 7.3.4) reveal that district effect was similar for year and for all economic parameters including labor use. Treatment and year*treatment effects were non-significant for cost of production, gross return and net income but were different for labor use. The maximum number of labour was used for

CT (74 person day's ha^{-1}) and ZT (72 person day's ha^{-1}) than the other tillage options. The MT and PB used fewer numbers of labours than FB but were non-significant with ST.

Table 7.3.4 Partial budgeting (BDT ha^{-1}) for *aman* rice (adjusted pooled mean across districts) under different tillage options in Bangladesh during 2009-13

Treatment	Adjusted pooled mean			Labor use (person days ha^{-1})	
	Cost of production	Gross return	Net profit		
CT(185)¥	50061	92738	42501	74	a†
FB(109)	48832	95105	46279	69	bc
MT(102)	47675	91758	43745	56	c
PB(130)	49687	94313	44227	57	c
ST(144)	48830	90563	42428	61	bc
ZT(56)	52002	89146	37302	72	a
ANOVA	Probability				
District	0.170	0.172	0.194	0.166	
Year	0.082	0.080	0.128	0.102	
Farmer	0.001	0.001	0.001	0.006	
Treatment	0.586	0.247	0.414	0.001	
Yr*Trt	0.065	0.250	0.029	0.010	

¥() Represents total number of farmer replicates; †Within a column, means followed by the same letter are not different at the 0.05 level of probability by Tukey's HST test


ZT DSR field

The profit margin risk for individual tillage options for *aman* rice were assessed by using the descending cumulative distribution functions (CDFs). Descending CDFs describe the potential (y-axis) of obtaining the profit (BDT ha^{-1}) greater than or equal to value on the x-axis at probability levels from 0 to 100%. A no-risk, high profit scenario would thus be depicted as a vertical-learning line shifted as far as the right as possible (Krupnik et al. 2012). In Rangpur, all tillage options provide the 100% assurance of minimum profit margin of BDT12444, 11334, 28707, 25579, 18681, and 24261 in CT, FB, MT, PB, ST and ZT, respectively. The profit margins under CT and FB were less than the other three tillage options. The PB and MT provided higher profit margins at 10-100% probability level, meaning less risk under both of these tillage options (Fig. 7.3.2). In Rajshahi, the minimum risk was with FB followed by PB and both options provided at least 100% assurance for getting 19850 and 9794 BDT ha^{-1} but high risk under ZT which provided 100% assurance for getting only 551 BDT ha^{-1} profit margin. The FB gave higher assurance of 50-100% farmers but after that not much difference was found between the tillage options. Similarly, in Comilla, the FB provided 100% profit margin assurance at minimum probability level as compared to other tillage options. Overall profit margin for all districts revealed that FB can provide the highest profit margin assurance. The CT provided less profit margin assurance at all levels from 0-100% probability as compared other tillage options. Overall, in the profit margin analysis aman rice, we didn't find very strong risk cover by any of the tillage options due to inconsistent yield patterns in all tillage options. Overall, Rangpur farmers had more consistent profit margin with less risk as compared to other two districts. In Rajshahi the farmers face more risk in-terms of profit margin in aman rice which could be due to less rainfall with more drought spells than other two districts.

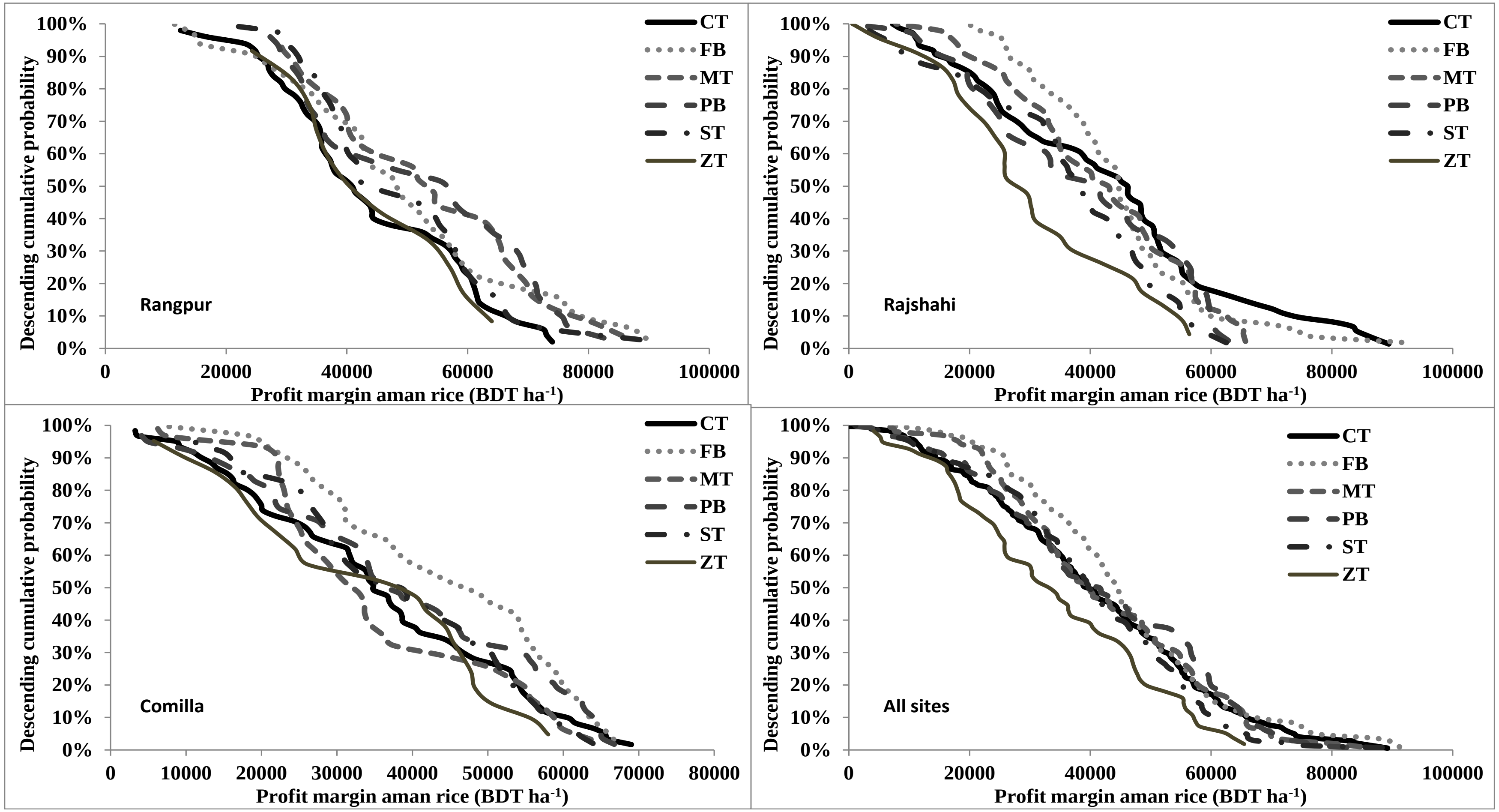


Figure 7.3.2 Descending cumulative probability for profit margin from different tillage options in *aman* rice during 2009-2013

7.3.1.1.2 Effect of CA-based crop management practices on rabi maize:

Rabi maize was also evaluated under different tillage options in six-*upazillas* of three districts during 2009-13. The same plots were maintained by farmers after aman harvest for rabi maize planting as much as possible and as the project progressed new farmers were also included. The same plots CT, FB, MT, PB, ST and ZT were used to evaluate rabi maize in all six tillage options. The numbers of on-farm trials conducted in Rangpur, Rajshahi and Comilla were 56, 62 and 66, respectively (Table 7.3.5). Year was found non-significant for all crop parameters yield (stover, grain, biomass and HI) at all sites, indicating that there was similar crop performance in all years. The stover, grain, biomass and HI performance among the farmers in all three districts was significantly different, except biomass in Rangpur and stover and HI in Rajshahi. Year*treatment interactions were unable to show the significance differences in all parameters at all three sites. Stover yield and HI were found non-significant among the six tillage options in all sites.


Farmer looking maize plant in zero till field at Rangpur


Maize planted by bed planter

In Rangpur, PB produced highest grain yield (9.01 t ha^{-1}) followed by ST (8.66 t ha^{-1}), ZT (8.5 t ha^{-1}), FB (8.42 t ha^{-1}), and MT (8.18 t ha^{-1}), though the latter was not significantly different from CT (7.33 t ha^{-1}). All the alternative tillage options were not significantly different from each other. Biomass production was maximum under PB and significantly higher than CT but other tillage options (FB, MT, ST and ZT) were non-significant with each other. In Rangpur the stover yield varied from 6.43-6.99 t ha^{-1} and harvest index from 0.52-0.55.

In Rajshahi, only grain yield showed significant differences between different tillage options but not other parameters. Both bed planting systems, PB and FB, produced higher grain yield as compared CT. PB and FB produced 12% higher grain yield than CT. Other tillage options (MT, ST, ZT) were unable to show superior to CT. Other crop parameters - stover, biomass and HI ranged from 8.32-8.81, 16.75-18.09 t ha^{-1} and 0.46-0.48, respectively.

Table 7.3.5 *Rabi* maize performance (t ha^{-1}) under different tillage options in three districts of Bangladesh during 2009-13

Treatment	Adjusted pooled mean					HI
	Stover	Grain		Biomass		
Rangpur						
CT(56) ¥	6.45	7.33	b†	14.45	b	0.52
FB(51)	6.75	8.42	a	15.70	ab	0.54
MT(33)	6.63	8.18	ab	15.45	ab	0.54
PB(27)	6.99	9.01	a	16.72	a	0.55
ST(42)	6.76	8.66	a	16.12	ab	0.54
ZT(13)	6.43	8.50	a	15.61	ab	0.54
ANOVA	Probability					
Year	0.083	0.081		0.080		0.082
Farmer	0.032	0.001		0.068		0.008
Treatment	0.771	0.003		0.049		0.278
Yr*Trt	0.090	0.052		0.065		0.119
Rajshahi						
CT(62)	8.46	7.93	b	16.75		0.47
FB(36)	8.81	8.87	a	18.08		0.47
MT(36)	8.62	8.69	ab	17.66		0.46
PB(54)	8.72	8.87	a	18.09		0.48
ST(51)	8.32	8.18	ab	16.99		0.47
ZT(30)	8.40	8.62	ab	17.42		0.48
ANOVA	Probability					
Year	0.091	0.091		0.116		0.101
Farmer	0.083	0.005		0.039		0.071
Treatment	0.814	0.006		0.129		0.515
Yr*Trt	0.480	0.091		0.234		0.413
Comilla						
CT(66)	9.14	8.04		17.43		0.47
FB(38)	9.15	8.15		17.53		0.47
MT (35)	9.12	8.18		17.56		0.48
PB(52)	9.18	8.09		17.53		0.47
ST(54)	8.96	8.41		17.63		0.49
ZT(18)	9.28	8.47		17.98		0.48
ANOVA	Probability					
Year	0.125	0.114		0.120		0.114
Farmer	0.012	0.021		0.006		0.013
Treatment	0.994	0.280		0.980		0.556
Yr*Trt	0.412	0.489		0.562		0.328

¥() Represents total number of farmer replicates; †Within a column, means followed by the same letter are not different at the 0.05 level of probability by Tukey's HST test

In Comilla all crop yield parameters hardly produced any significant differences among six tillage options. The stover yield ranged from 8.96-9.28, grain yield from 8.04-8.47 and biomass from 17.43-17.98 t ha^{-1}. The HI ranged from 0.47 to 0.49. On an average, higher

HI was noticed in Rangpur than Rajshahi and Comilla. Higher HI was due to the fact that farmers harvested maize green leaves for animal fodder in Rangpur.

A total of 184 on-farm trials were conducted across all sites during 2009-2013. Overall, combined pooled results showed site/district as non-significant and also year and year* treatment were in same line for all four parameters (Table 7.3.6). As in individual sites, farmer effect was behaving differently for all four parameters which could be due different field management history such as irrigation, land type and other local socio-economic factors as well. Stover yield and HI were non-significant. PB, ZT and ST produced higher maize grain yield than CT but FB and MT were non-significant with CT. Biomass production was higher in PB than CT but rest of tillage options showed similar response.

Table 7.3.6 Effect of tillage on *rabi* maize performance (all sites pooled analysis; t ha^{-1}) in Bangladesh

Treatment	Adjusted pooled mean					HI
	Stover	Grain		Biomass		
CT(184)¥	8.06	7.86	b†	16.40	b	0.49
FB(125)	8.13	8.38	ab	16.38	ab	0.51
MT(104)	8.13	8.36	ab	16.79	ab	0.50
PB(133)	8.47	8.74	a	18.35	a	0.49
ST(147)	8.08	8.51	a	17.47	ab	0.50
ZT(61)	8.09	8.70	a	17.67	ab	0.50
ANOVA			Probability			
District	0.167	0.357		0.215		0.166
Year	0.156	0.083		0.086		0.135
Farmer	0.001	0.001		0.001		0.001
Treatment	0.582	0.001		0.003		0.447
Yr*Trt	0.263	0.211		0.263		0.328

¥() Represents total number of farmer replicates; †Within a column, means followed by the same letter are not different at the 0.05 level of probability by Tukey's HST test

Figure 7.3.3 shows variability of maize yield among farmers'plots in different tillage options in different districts and for overall plots. In Rangpur, the PB and ST/ZT performed better than other tillage options. In general, the maize performance was consistently, well distributed among famers. Under CT and PB the farmers' yields were more stable and well distributed in IQRs and whiskers. The FB median slightly skewed towards Q3 (75th percentile) but MT, ST and ZT skewed positively towards Q1 (25th percentile). The whiskers were more wider towards upper quartile in FB, MT, ST and ZT.

In Rajshahi, box plots showed different variability than Rangpur. Farmer performance under FB and PB were more stable and equally distributed among the farmers than under other tillage options. The median under CT was sitting more towards negative IQR (75th Percentile) and similar responses were also shown for MT, ST and ZT. It means more farmers grouped towards higher maize grain yield but more variability towards positive site of the Q1 and lower whisker.

In Comilla, all tillage options showed similar yield trends. The grain yield variability was less among the farmers compared to Rangpur and Rajshahi. The performance of maize was more stable for all tillage options except FB and ZT. FB median favoured more the higher maize grain producers (toward Q3) but in ZT, it was just opposite.

Overall, the grain yield of maize showed similar trend for all tillage options. The variability in maize grain yield was less with showing similar interquartile range (IQR) among all the tillage options. In all tillage options the yield showed more consistent and well distributed except for ZT where, yields grouped toward Q3. In all tillage options there were outliers

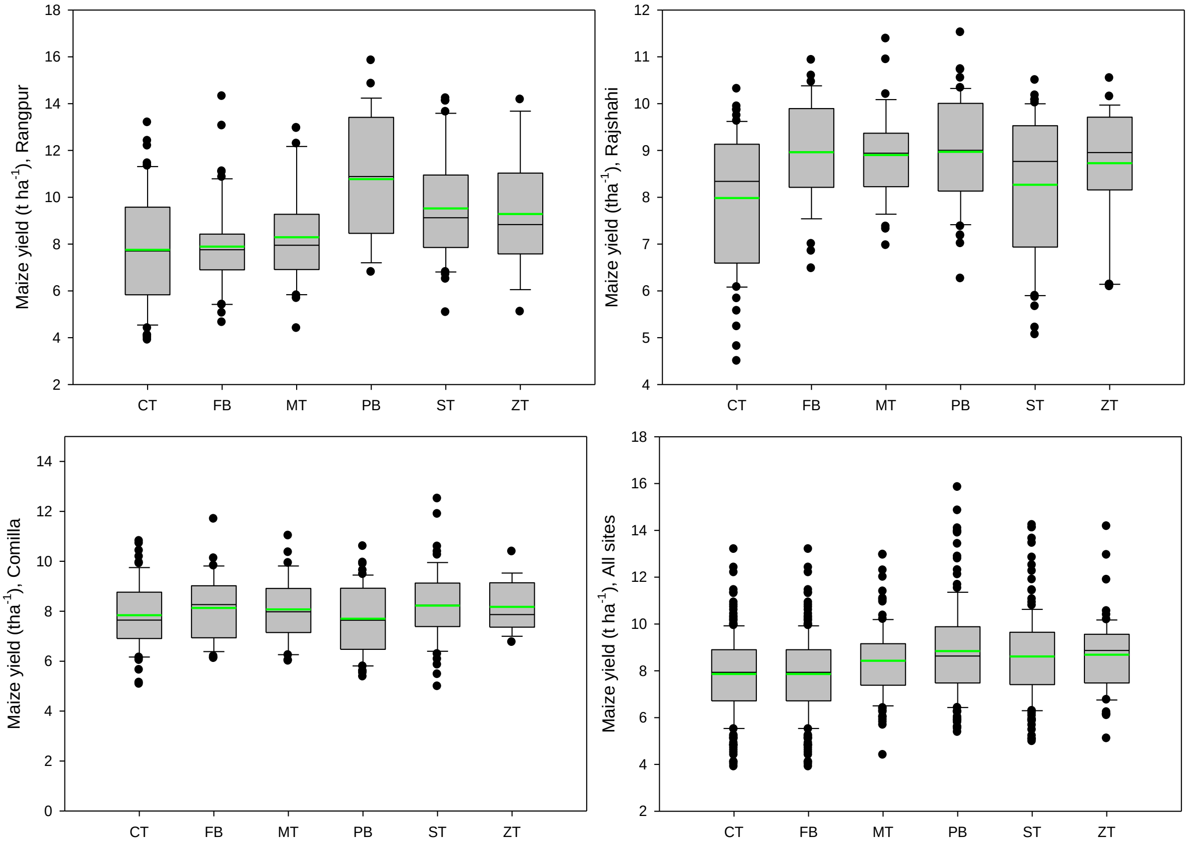


Figure 7.3.3 Box plots showing maize grain yield variability in on-farm trials across three districts during 2009-13

which were outside the 1.5 x IQR of – Q1 and + Q3.

Partial economic analysis was carried out after collecting all input and output data from the individual farmers in each tillage options during the implementation of the on-farm trials 2009-13. The partial economic results showed that year was non-significant for all economic parameters in all three districts (Table 7.3.7). However, unlike year, farmer effect showed difference among farmers for all parameters in all three sites. Year* treatment interaction showed significant difference for cost of production and labor in Rangpur, gross return and labour in Rajshahi, and cost of production and labor in Comilla, respectively. Cost of production in Rangpur and Rajshahi and gross return in Comilla showed the non-significant trends for different tillage options. In Rangpur lowest gross return was received in CT (144207 BDT ha^{-1}) and highest was in PB (176771 BDT ha^{-1}) with FB and ST but these were non-significant with MT and ZT. The highest net income was achieved with PB (99621 BDT ha^{-1}) which was 65% and 21% higher than CT and MT. PB was non-significant with ST, ZT and PB. MT also gave higher net income than CT. aximum number of labor (63 person days ha^{-1}) was used for CT than the alternative tillage options (34-37 person days ha^{-1}). More labour was required in CT due to manual planting, more tillage operations and more number of weeding, and also earthing-up at V5-V8 stage.

In Rajshahi, lowest gross return was received from CT (159932 BDT ha^{-1}) and highest from FB (180019 BDT ha^{-1}) than PB and MT. ST and ZT provided intermediate gross return. FB gave 30843 and 15624 BDT ha^{-1} higher return than CT and ST, respectively. ST also gave more net income (95304 BDT ha^{-1}) than CT (80085 BDT ha^{-1}). FB was non-significant with other three tillage options, MT, PB and ZT. Labor use was similar to Rangpur withthe maximum number of labor used in CT than other tillage options due to the reasons explained previously.

In Comilla, the maximum cost of production was for CT (78860 BDT ha^{-1}) than rest of the tillage options. Higher cost of production for CT was due to more number of tillage operations, labor for manual planting and earthing up in the mid-season of maize crop. The highest net income was achieved in ZT (88393 BDT ha^{-1}) than CT but non-significant with rest of the tillage options. Labor use was in line with two previous sites. In general, more labor was used in Comilla than the other two sites across the tillage options.

Table 7.3.7 Partial budgeting for *rabi* maize (BDT ha^{-1}) under different tillage options in three districts of Bangladesh during 2009-13

Treatment	Adjusted pooled mean						Labor use (person days ha^{-1})	
	Cost of production		Gross return		Net profit			
Rangpur								
CT(56)	78689		144207	b†	65718	c	63	a
FB(51)	75413		166063	a	90957	ab	37	b
MT(33)	74465		157163	ab	82707	b	36	b
PB(27)	77151		176771	a	99621	a	34	b
ST(42)	75323		171366	a	96621	ab	34	b
ZT(13)	74432		164877	ab	90629	ab	34	b
ANOVA	Probability							
Year	0.079		0.080		0.081		0.084	
Farmer	0.001		0.001		0.001		0.001	
Treatment	0.281		0.003		0.001		0.001	
Yr*Trt	0.001		0.072		0.165		0.003	
Rajshahi								
CT(62)	79579		159932	b	80085	c	85	a
FB(36)	69203		180019	a	110928	a	56	b
MT(36)	71015		176728	a	105134	ab	53	b
PB(54)	71026		179437	a	108184	ab	53	b
ST(51)	70960		165663	ab	95304	b	55	b
ZT(30)	72178		174103	ab	101896	ab	56	b
ANOVA	Probability							
Year	-		0.115		0.135		0.155	
Farmer	-		0.005		0.004		0.002	
Treatment	-		0.007		0.001		0.001	
Yr*Trt	-		0.049		0.060		0.017	
Comilla								
CT(66)	78860	a	151229		72113	b	98	a
FB(38)	71193	b	153408		82239	ab	69	b
MT (35)	70732	b	147398		76631	ab	67	b
PB(52)	69697	b	150612		80224	ab	65	b
ST(54)	70192	b	155445		85112	a	68	b
ZT(18)	71107	b	159510		88393	a	68	

ANOVA	Probability			
Year	0.165	0.112	0.112	0.164
Farmer	0.002	0.009	0.019	0.095
Treatment	0.002	0.247	0.002	0.001
Yr*Trt	0.014	0.084	0.231	0.008

¥() Represents total number of farmer replicates; †Within a column, means followed by the same letter are not different at the 0.05 level of probability by Tukey's HST test

Table 7.3.8 depicts that district, year and year*treatment was non-significant for all parameters except for cost of production and labor use. The cost of production, gross return and labor use showed that CT had more cost of production with minimum gross return and higher number of labor use compared to rest of the tillage options. The highest net income achieved was from PB which was 32 and 12% higher than CT and MT, respectively. MT also provided higher net income than CT. FB, ST and ZT were non-significant with PB and MT.

7.3.8 Partial budgeting for *rabi* maize (BDT ha^{-1}) under different tillage options in Bangladesh during 2009-13

Treatment	Adjusted pooled mean						Labor use (person days ha^{-1})	
	Cost of production		Gross return		Net profit			
CT(184)¥	78927	a†	155527	b	76159	c	80	a
FB(125)	71111	b	165237	a	93860	ab	51	b
MT(104)	71835	b	161707	a	89525	b	50	b
PB(133)	72419	b	173145	a	100182	a	50	b
ST(147)	71687	b	167786	a	95900	ab	51	b
ZT(61)	72636	b	171769	a	98809	ab	52	b
ANOVA	Probability							
District	0.181		0.211		0.212		0.166	
Year	0.086		0.086		0.093		0.101	
Farmer	0.001		0.001		0.001		0.001	
Treatment	0.001		0.001		0.001		0.001	
Yr*Trt	0.045		0.232		0.253		0.005	

¥() Represents total number of farmer replicates; †Within a column, means followed by the same letter are not different at the 0.05 level of probability by Tukey's HST test

The profit margin assessment for rabi maize for different tillage options are presented in figure 7.3.4. Risk for farmer profit margin was much lower for maize than *aman* rice profit margin. In Rangpur, profit margin with 100% assurance with lowest risk was recorded for PB and ST with profit of BDT 63186 and 55364 ha^{-1}, respectively, and lowest assurance was for CT with profit of only BDT 6317 ha^{-1}. PB and ST provided more risk at all 0-100 % probability levels than CT but PB showed more profit margin below 50% probability than ST and ZT. FB and MT provided better assurance at 100% probability than CT but below 30% assurance both were similar to CT.

In Rajshahi, other than CT, all tillage options provided better assurance for higher profit margin at all probability levels. The 100% assurance was highest with FB (69193 BDT ha^{-1}) followed by PB (64435 BDT ha^{-1}) and ST (53520 BDT ha^{-1}), and was lowest with CT (17093 BDT ha^{-1}). Profit margin was more consistent at 0-100% assurance for all tillage options except CT.

In Comilla, the CA-based tillage options were not able to provide much profit margin assurances as compared to other two districts because in Comilla maize was generally planted in late December and January which exposed the crop to very bad weather and natural calamity,, especially storms and water logging in late season. The CA-based tillage options provided more profit margin assurance up to 100 to 70% probability but below that they were unable to provide better assurance than CT. In overall, profit margin assurance was least for CT among all tillage options at all probability levels. CA-based tillage options had more risk coverage than CT.

Cost comparison studies were undertaken during promotion of an inclined plate fixed in the 2-wheel tractor attached bed planter for seeding of maize after potato in *kharif*-1 with farmers of different villages of Rangpur (Table7.3.9). The project staff advocated to the farmers to maintain the records of labor use, ploughing, seed cost, etc. at the time of seeding maize. Data were synthesized and analysed to show the benefits of machine planting of maize to farmers. Results were highly appreciated by farmers and instantly they realized that they can save at least 10,000 BDT ha^{-1} by using the machine seeding compared to manual seeding. The benefit mainly came through saving labor and ploughing because in the conventional system maize is planted by hand through dibbling after heavy tillage and by manually bed formation.

Table 7.3.9: Cost comparison between manual seeding and seeding by bed planter with incline plates for *kharif*-1 maize after potato in different villages of Rangpur

Seeding method	No. of land ploughing	Ploughing cost	Labor for bed formation	Labor for seeding	Bed formation and seeding cost (BDT)	Seed cost (BDT)	Total cost (BDT)	Saving over farmer practice (BDT)
Manual seeding	2	4500	20	25	9000	3750	17250	
Seeding by bed planter	0	0	5	3	3750	3750	7500	9750

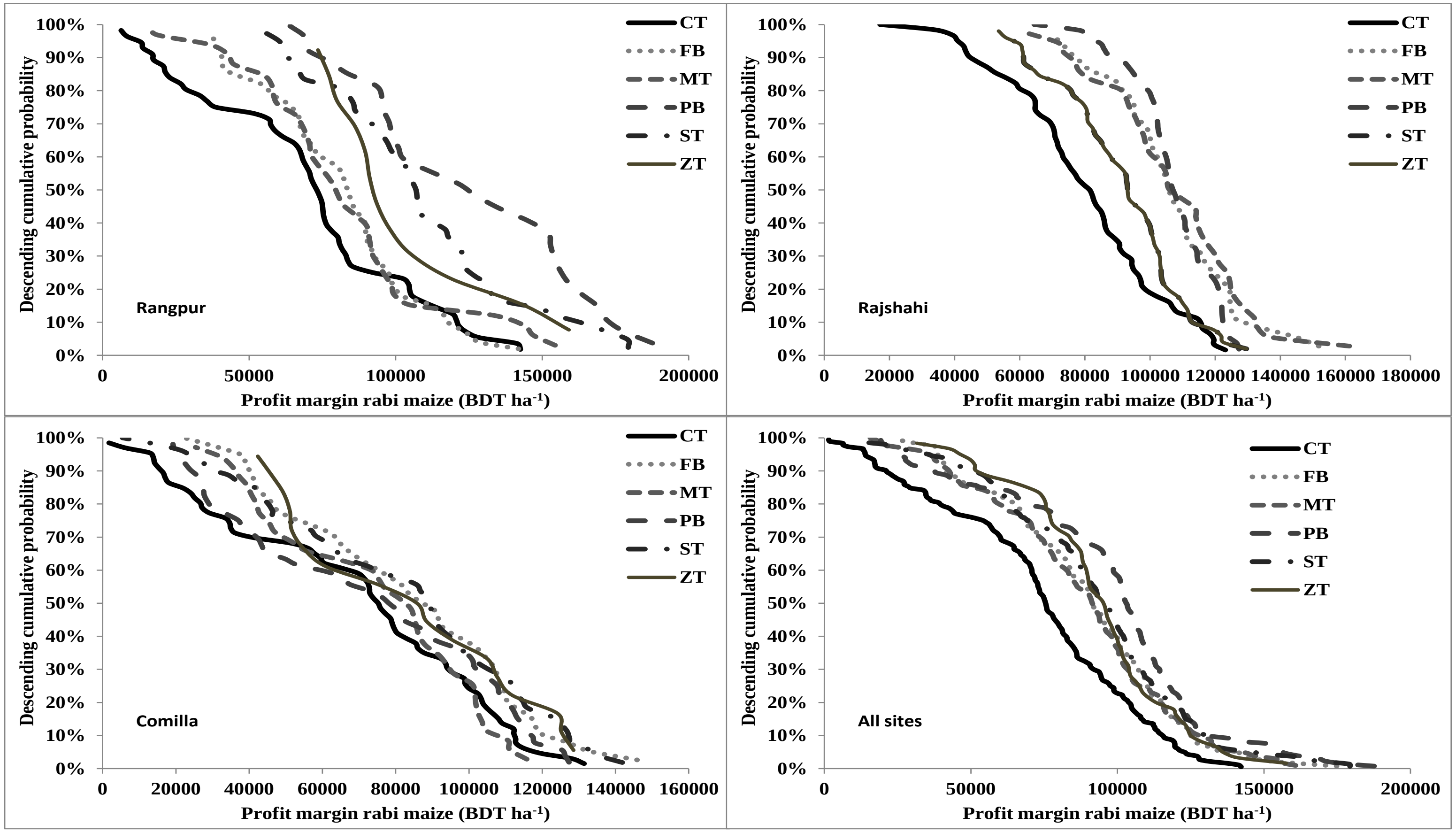


Figure 7.3.4 Descending cumulative probability for profit margin from different tillage options in *rabi* maize during 2009-2013

7.3.1.1.3 Effect of CA-based crop management practices on Aus rice:

The *Aus* rice was experimented in Comillla, only in R-M-R system. Fifty-one on-farm trials on Aus rice were conducted during 2009-13. All crop parameters (straw, grain, biomass and HI) for *Aus* rice were found non-significant among the tillage options (Table 7.3.10). The straw yield ranged from 4.19-4.81, grain yield ranged from 3.23-3.49, biomass yield from ranged from 7.42-8.35 and the HI from 0.45-0.47.

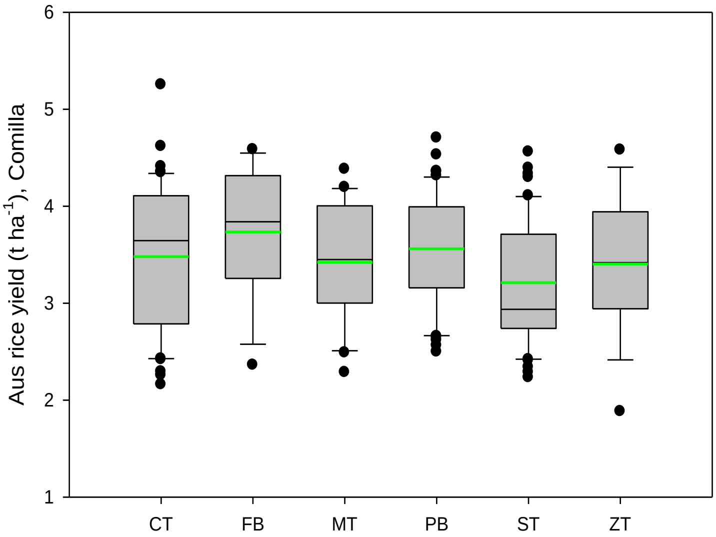


Figure 7.3.5 Aus rice grain yield variability through box plot

The total cost of production was highest under CT (45002 BDT ha^{-1}) and lowest under FB (36017 BDT ha^{-1}) and these two tillage options were significantly different from each other. All the alternative tillage options were non-significant from each other. The higher cost of production under CT was due to more tillage operations, labor, and inputs cost. The gross return and net income were non-significant among the different tillage options. The net income ranged from BDT 20045-33219 ha^{-1}. Labor use was highest d under CT (63 person days ha^{-1}) and lowest were under PB (55 person days ha^{-1}). More labor requirement under CT was due to transplanting, more tillage operations, and irrigations as aus rice depends more on irrigation, etc.

The year and year* treatment effects were found non-significant but farmers effect was highly significant in all parameters.

Table 7.3.10 *Aus* rice crop performance (tha^{-1}) and its economics

Tillage options	Yield, Adjt. pooled mean			HI	BDT ha^{-1}			Labour use (person days ha^{-1})
	Straw	Grain	Biomass		Cost of production	Gross return	Net income	
CT(51)¥	4.19	3.49	7.63	0.47	45002a	65141	20045	63a
FB(14	4.42	3.65	8.14	0.47	36017b	68545	33219	58ab
MT(21)	4.52	3.48	7.99	0.46	37822ab	65639	27844	59ab
PB(51)	4.81	3.58	8.35	0.46	38283ab	67898	29746	55b
ST(51)	4.24	3.23	7.42	0.45	37772ab	60922	23299	61ab
ZT(16)	4.69	3.44	7.97	0.45	37310ab	65181	27848	59ab
ANOVA					Probability			
Year	0.117	0.249	0.116	0.116	0.230	0.117	0.125	0.115
Farmer	0.025	0.008	0.342	0.007	0.004	0.025	0.071	0.024
Treatment	0.139	0.262	0.076	0.553	0.033	0.092	0.063	0.052
Yr*Trt	0.263	0.206	0.490	0.157	0.011	0.283	0.085	0.187

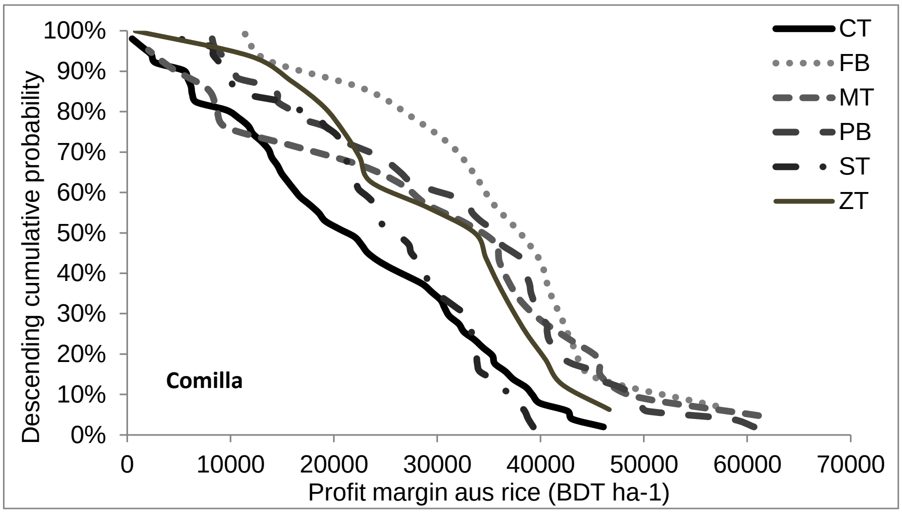
¥() represents the number of farmer replicates

Box plot in fig. 7.3.5 shows the variability in *aus* rice grain yield among the farmers. Farmers were consistently well distributed under MT, PB and ZT than others. In CT, grain yields were more towards 75th percentile and similarly also in FB but was opposite in ST.

In ST, the median for grain yield was more towards the Q1, indicating thatmore farmer producers were grouped towards lower than median and more variability was towards Q3.

Figure 7.3.6 results showed the descending cumulative distribution functions for farmers' profit margin. The FB showed highest assurance for high profit margin at higher as well as lower level of probability as compared to other tillage options. FB provided the BDT 11000 ha^{-1}, with100 % assurance to the farmers if they established rice with this technology and least assurance was provided by CT at all level of probability. The ST and ZT provide the intermediate assurance at 100% probability than CT and FB.

7.3.1.1.4 Effect of CA-based crop management on system perspective in R-M-MB system of northwest-Bangladesh:



7.3.6 Descending cumulative probability for profit margin from tillage options in Aus rice, Comilla

In the preceding three sections we discussed about the performance of alternative tillage options for individual crops but farmers' goal will be the performance of the whole system rather than of individual crops. During the project period from 2009-2013 many participating farmers maintained the same tillage for rice, maize and mungbean and established these crops in that tillage method on a system basis at least for 3 out of 5 years which we considered for analysis. Of course, many farmers maintained the same tillage for all crops in the R-M-MB system for 5 years too. A total of 79 farmers maintained their plots with same tillage on a system basis. The pooled data were analysed for year, farmer, treatment and year* treatment effects (Table 7.3.11). The year effect and year*treatment effect showed no differences between five years but farmer had strong significant effect.

As for individual crops for rice, different tillage options had no significant differences in biomass production, grain yield and HI. The rice biomass ranged from 9.88-10.32 tha^{-1}, grain yield from 4.62-4.85 t ha^{-1} and HI from 0.46-0.47. However, tillage options had significant effects on biomass and grain yield of maize and of the R-M-MB system.. Maize biomass production was highest for PB (17.27 t ha^{-1}). The biomass under PB was significantly higher than CT (15.05 t ha^{-1}) but was not significantly different from rest of the tillage options. Similar pattern was observed under system-level biomass production. In PB, 15.66% higher grain yield was obtained than in CT. The FB, MT and ST were unable to prove superior to CT and these were also similar to PB. The same pattern was observed for system-level grain yield between the different tillage options. There were non-significant differences for rice and maize HI between the different tillage options.

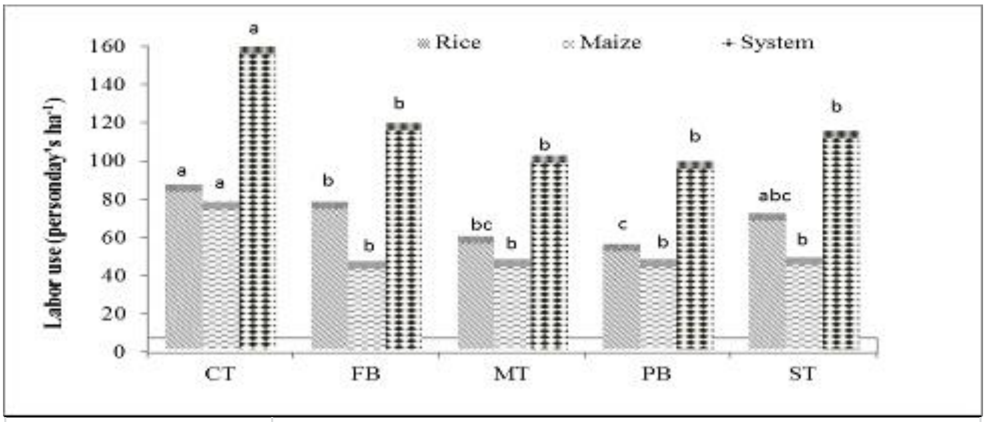
Table 7.3.11 Effect of alternative tillage options on crop yields in R-M-MB system

Tillage options	Biomass yield (t ha^{-1})			Grain yield (t ha^{-1})			HI	
	Rice	Maize	System	Rice	Maize	System	Rice	Maize

CT (69)	10.06	15.05b	25.12b	4.67	7.79b	12.47b	0.46	0.53
FB (39)	10.32	16.22ab	26.72ab	4.85	8.45ab	13.36ab	0.47	0.53
MT (35)	9.79	16.34ab	26.22ab	4.63	8.57ab	13.22ab	0.47	0.53
PB (56)	10.07	17.27a	27.37a	4.75	9.01a	13.76a	0.47	0.53
ST (79)	9.88	16.02ab	25.90ab	4.62	8.47ab	13.11ab	0.47	0.54
Variance				Probability				
Year	0.097	0.123	0.093	0.090	0.118	0.086	0.089	0.270
Farmer	0.002	0.001	0.001	0.004	0.002	0.001	0.009	0.002
Treatment	0.571	0.041	0.038	0.571	0.013	0.013	0.417	0.816
Trt*Yr	0.171	0.251	0.191	0.484	0.356	0.209	0.112	0.391

The partial economic analysis was computed on system basis (Table 7.3.12). Results were separated by year, farmer, treatment, and year*treatment. The year effect was non-significant along with year*treatment effect except for the system-level cost of production and system BC ratio. The farmer had strong effect on all economic parameters. Significant treatment effects were found in maize and system-level economic parameters but economic parameters in rice had non-significant effects. Cost of production for maize was higher in CT than FB and ST but was similar to MT and PB. No significant differences were found between different tillage options for system-level cost of production. In maize, CT provided lower gross return than PB but other tillage options (MT, ST and FB) provided similar returns for both maize and system. Farmers cultivating maize received higher net income (1350 USD ha^{-1}) under PB than CT and ST but ST also resulted in higher return than CT. The FB and MT resulted in similar net income to ST and PB. On system perspective, all CA-based tillage options provided better net income than CT. The PB provided 31% higher income than CT but similar to rest of the tillage options. In terms of BC ratio for rice, maize and system, the CT had smallest ratio than other rest of the tillage options.

For labour use for four years, the year had non-significant effect for rice, maize and system (Figure 7.3.7). Farmer and treatment effects showed clear differences between the tillage options for rice, maize and system. Interestingly, year*treatment interaction also showed the significant differences in labor use. It could be due to that the farmers were using more machines for planting and weed control by herbicides with time. In rice, labor use was higher under CT than FB, MT and PB but similar to ST. The lowest labor used was in PB than CT, FB and MT but non-significant



Variance	Probability (0.05)		
	Rice	Maize	System
Year	0.134	0.124	0.123
Farmer	0.009	0.001	0.002
Treatment	0.004	<.001	<.001
Trt*Yr	0.017	0.033	0.019

Figure 7.3.7 Labor use pattern in different tillage options (4-yr adjusted pooled mean) under R-M system

with ST. In maize, CT had maximum labor use than rest of the tillage options which had similar pattern for labor use. On system basis, similar pattern was observed as for maize, i.e, CT had maximum labour use than rest of the tillage options.

7.3.1.1.5 Effect of CA-based crop management on system perspective in R-M-R system of northwest-Bangladesh:

In Comilla, the *aman* rice- *rabi* maize-*aus* rice cropping system is dominated. We conducted 37 on-farm trials during 2009-13. Crop biomass yield, grain yield and HI were analysed for year, farmer, treatment, and year* treatment effects. Unfortunately, year, treatment and year*treatment effects were found non-significant in all three crops as well on system except the treatment effect showed differences for BC ratio (Table 7.3.13). Farmer had significant effects on biomass of maize, *aus* rice and system, grain yield of *aman* rice, *aus* rice and system, and HI of *aman* rice and maize.

Table 7.3.13. Effect of tillage options on crop performance (4 yrs mean) in *aman* rice—maize- *aus* rice cropping system during 2009-13 in Comilla, Bangladesh

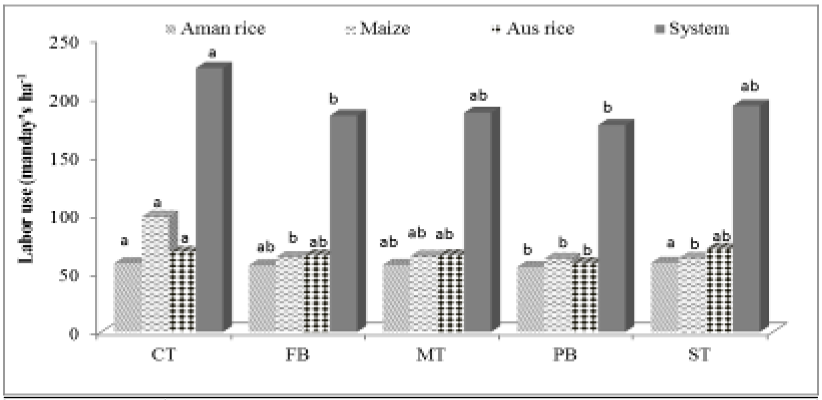
Tillage options	Biomass yield (t ha^{-1})				Grain yield (t ha^{-1})				HI			
	A. rice	Maize	*Aus* rice	System	A. rice	Maize	*Aus* rice	System	A. rice	Maize	*Aus* rice	
CT (37)	8.85	17.95	8.20	34.99	3.98	7.86	3.60	15.44	0.45	0.44	0.45	a
FB (15)	8.75	18.66	9.11	36.51	4.02	8.10	3.91	16.16	0.46	0.45	0.45	a
MT (13)	8.43	17.60	9.00	35.08	3.81	8.00	3.63	15.38	0.46	0.47	0.41	ab
PB (31)	8.84	17.87	8.97	35.72	3.96	7.94	3.58	15.51	0.45	0.45	0.42	ab
ST (40)	8.65	17.82	8.69	35.22	3.84	8.21	3.29	15.38	0.44	0.47	0.39	b
Variance					Probability							
Year	0.183	0.209	0.170	0.166	0.201	0.163	0.395	0.180	0.247	0.163	0.166	
Farmer	0.433	0.005	0.005	0.014	0.044	0.135	0.016	0.120	0.021	0.018	0.080	
Trt	0.838	0.658	0.473	0.492	0.702	0.541	0.223	0.432	0.578	0.273	0.013	
Yr*Trt	0.444	0.452	0.423	0.240	0.417	0.439	0.119	0.192	0.370	0.115	0.264	

Table 7.3.14. Partial economics (cost of production and gross return)for different tillage options (4 yrs mean) in aman rice-maize-aus rice cropping system during 2009-12 in Comilla.

Tillage options	Cost of production (USD ha^{-1})						Gross return (USD ha^{-1})			
	A.rice	Maize	*Aus*. rice		System		A.rice	Maize	*Aus*. rice	System
CT (37)	644	997	595	a	2240	a	1190	1884	907	3992
FB (15)	574	882	489	b	1944	b	1165	1953	991	4108
MT (13)	659	885	490	b	2041	b	1161	1879	966	4024
PB (31)	631	881	487	b	2004	b	1212	1919	929	4079
ST (40)	624	876	495	b	2000	b	1192	1978	881	4065
Variance					Probability					
Year	0.216	0.344	0.230		0.230		0.166	0.160	0.172	0.170
Farmer	0.003	0.007	0.029		0.003		0.018	0.023	0.188	0.008
Treatment	0.499	0.058	0.025		0.034		0.949	0.680	0.477	0.931
Yr*Trt	0.231	0.036	0.053		0.045		0.348	0.384	0.198	0.132

Except for aus rice and system cost of production and gross return were found non-significant for different tillage options (Table 7.3.14). Year had non-significant effect in both cost of production and gross return and similar response was observed with year*treatment effect except for cost of production for maize, aus rice and system. Costs of production for aus rice and system were higher for CT that other tillage options. Farmer had significant effect except for gross return for aus rice. There was higher net return under FB than CT but for remaining other tillage options it was similar (Table 7.3.15). In maize higher net return was recorded under ST than CT but other tillage options were non-significant. For Aus rice, the minimum net income was for CT than FB, MT and PB, but it was similar to ST. The CT provided lower net income (1760 USD ha^{-1}) than FB, PB and ST but it was similar to MT for system. BC ratios were lowest for CT than other tillage options for aman rice, maize and system except for MT for maize and system. There were no differences in BC ratio for aus rice.

Labour use for aman rice was lower in PB and ST than CT (Figure 7.3.8) but MT and FB it was intermediate. Maize labor use was highest under CT than rest of the tillage options except MT. CT had more number of labor use in aus rice than PB but rest of tillage options had similar labour use. For overall system, CT had more number of labor use than FB and PB but MT and ST were unable to reduce the labor use. The year, year*treatment effect was non-significant. Farmer had only significant effect in aman rice.



Variance	Probability			
	Aman rice	Maize	Aus rice	System
Year	0.167	0.228	0.163	0.234
Farmer	0.033	0.159	0.079	0.122
Treatment	0.003	0.022	0.006	0.013
Yr* Trt	0.439	0.054	0.120	0.055

Figure 7.3.8 Labour use pattern in rice-maize-rice system in Comilla

Table 7.3.12 Partial economics for different tillage options (4-yr adjusted pooled mean) in rice--maize cropping system during 2009-13 northwest Bangladesh

Tillage options	Cost of production (USD ha^{-1})			Gross return (USD ha^{-1})			Net income (USD ha^{-1})			B:C ratio		
	Rice	Maize	System	Rice	Maize	System	Rice	Maize	System	Rice	Maize	System
CT (69)	645	1027 a	1684	1269	1974 b	3260 b	582	945 c	1517 b	2.00	1.90 b	1.91 b
FB (39)	608	922 b	1550	1311	2120 ab	3472 ab	658	1203 ab	1865 a	2.23	2.33 a	2.21 a
MT (35)	607	949 ab	1567	1260	2156 ab	3427 ab	614	1204 ab	1820 a	2.18	2.28 a	2.18 a
PB (56)	580	954 ab	1547	1273	2304 a	3592 a	647	1350 a	1990 a	2.26	2.43 a	2.31 a
ST (79)	589	945 b	1550	1240	2141 ab	3407 ab	608	1201 b	1808 a	2.14	2.27 a	2.18 a
Variance						Probability						
Year	0.090	0.123	0.087	0.085	0.141	0.091	0.138	0.192	0.149	0.119	0.170	0.151
Farmer	0.001	0.001	0.001	0.001	0.003	0.001	0.002	0.003	0.003	0.001	0.002	0.005
Treatment	0.387	0.037	0.124	0.516	0.013	0.014	0.692	<0.001	0.001	0.412	0.001	0.002
Trt*Yr	0.057	0.117	0.032	0.125	0.447	0.253	0.066	0.232	0.243	0.222	0.477	0.045

Table 7.3.15 Partial economics (net income and B:C ratio) under different tillage options (4 yrs mean) under aman rice—maize-aus rice system during 2009-12 in Comilla.

Tillage options	Net income (USD ha^{-1})				B:C ratio			
	A.rice	Maize	Aus. rice	System	A.rice	Maize	Aus. rice	System
CT (37)	553 b	892 b	312 b	1760 b	1.52 b	1.93 b	1.95	1.80 b
FB (15)	562 a	1069 ab	502 a	2130 a	2.06 a	2.21 a	2.05	2.10 a
MT (13)	525 ab	990 ab	463 a	1981 ab	1.98 a	2.12 ab	1.84	1.99 ab
PB (31)	587 ab	1041 ab	440 a	2073 a	1.92 a	2.19 a	2.08	2.06 a
ST (40)	572 ab	1097 a	387 ab	2062 a	1.79 a	2.27 a	2.01	2.05 a
Variance				Probability				
Year	0.166	0.160	0.173	0.162	0.192	0.160	0.184	0.167
Farmer	0.419	0.040	0.035	0.088	0.024	0.051	0.101	0.012
Treatment	0.892	0.054	0.001	0.001	0.001	0.001	0.669	0.016
Yr*Trt	0.331	0.479	0.479	0.422	0.452	0.352	0.185	0.432

7.3.1.2 Performance of rabi maize hybrids under different tillage methods in three districts of Bangladesh:

A multi-location experiment was conducted during 20012-13 to evaluate the maize hybrids under different tillage methods in farmers' fields. Results indicated that all growth and yield parameters behaved differently in all sites (Table 7.3.16). Tillage*hybrid interaction was found non-significant and site*hybrid interaction was also non-significant except 1000-grain weight. Plant height and cob length were more in CT than ST but for all other parameters (i.e., grains per cob, 1000-grain weight, and cob grith) there were similar patterns for the two tillage options. BARI maize hybrid (BHM9) was found tallest and was followed by Sunshine. The Pacific and Pinnacle were shortest but very close to 900M Gold while 981 was intermediate in plant height. The 1000-grain weight was maximum for Pinnacle, Sunshine and Pacific 984 followed by 900M Gold. The minimum 1000-grain weight was for BHM 9 and it was significantly lower than for 981. The lengthier cobs were achieved in 900M Gold followed by Pacific 984. The shorter cob length was achieved by Pinnacle and Sunshine but these were similar to 981 and BHM 9.

Table 7.3.16 Performance of maize hybrids under different tillage options at different locations during 2012-13 in Bangladesh.

Hybrids	Plant height (cm)		Grains cob^{-1}	1000 grain weight (g)		Cob girth (cm)	Cob length (cm)	
981	250.55	bc	464.28	279.50	bc	17.14	15.49	bc
900M Gold	245.49	cd	459.86	296.99	ab	17.63	15.52	a
BHM 9	258.96	a	477.60	265.97	c	17.26	15.26	bc
Pacific 984	242.71	d	433.16	300.04	a	17.54	15.24	ab
Pinnacle	243.46	d	424.10	306.48	a	16.81	15.27	c
Sunshine	253.70	ab	438.65	304.20	a	16.90	15.39	c
Tillage								
CT	251.18	A	438.99	294.66		17.08	15.32	A
ST	247.11	B	460.22	289.74		17.35	15.40	B
ANOVA				Probability				
Site	0.001		0.002	0.001		0.003	0.001	
Rep	0.001		0.001	0.001		0.001	0.001	
Tillage	0.027		0.111	0.358		0.272	0.021	
Hybrid	0.001		0.152	0.001		0.588	0.005	
Site*hybrid	0.126		0.421	0.009		0.102	0.455	
Tillage*hybrid	0.756		0.454	0.122		0.676	0.135	

Table 7.3.17 shows the yield and partial economics for different hybrids and tillage options. The site (*Upazilla*) and replication (farmer) were highly significant yield and economics parameters. The site*hybrids interaction showed different grain yield pattern, gross return and net income (p=0.06). The interaction results indicated that the maize hybrids perform differently in different sites, which is important for farmers to select best hybrid for their site. Tillage*hybrid interaction was not significantlt different for all yield and economic parameters. Tillage did not show any significant effects on yield parameters but showed significant differences for cost of production and net income. Cost of production was higher for CT than ST but it was reverse for net income.

BHM 9 produced higher stover yield followed by Sunshine. Pacific 984 produced the lower stover yield than Sunshine and BHM9. Grain yield was produced more by 900M Gold (9.55 t ha^{-1}) followed by Sunshine and 981 although they were not significantly different from each other but were different from BHM 9, Pacific 984 and Pinnacle. Maximum biomass production was by Sunshine (19.41 t ha^{-1}) and lowest by Pacific 984 and Pinnacle and other remaining hybrids produced intermediate biomass.

Similar to grain yield, gross return and net income were also higher with 900M Gold than BHM 9, Pacific 984 and Pinnacle but intermediate with 981 and Sunshine. These higher returns were due to higher grain yield.

Table 7.3.17 Crop yield and partial economics for maize hybrids under different tillage options at different locations during 2012-13 in Bangladesh

Hybrids	Yield (t ha^{-1})			HI	BDT ha^{-1}		
	Stover	Grain	Biomass		Production cost	Gross return	Net income
981	9.61bc	9.29ab	18.90abc	0.49a	106569	185905ab	79336ab
900M Gold	9.78abc	9.55a	19.32ab	0.4a	106827	191363a	84536a
BHM 9	10.32a	8.93c	19.25ab	0.46b	106167	179717c	73550c
Pacific 984	9.31c	8.94c	18.25c	0.49a	106158	179505c	73348c
Pinnacle	9.56bc	9.09bc	18.66c	0.49a	106371	182238bc	75867bc
Sunshine	10.09ab	9.32ab	19.41a	0.48ab	106591	187123ab	80532ab
Tillage							
CT	9.93	9.23	19.16	0.48	110740A	185256	74516B
ST	9.63	9.14	18.77	0.49	102155B	183362	81207A
ANOVA				Probability			
Site	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Rep	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Tillage	0.107	0.281	0.064	0.372	0.001	0.257	0.001
Hybrid	0.019	0.002	0.009	0.014	0.981	0.002	0.007
Site*hybrid	0.127	0.021	0.075	0.195	0.999	0.031	0.068
Tillage*hybrid	0.862	0.619	0.737	0.883	0.999	0.654	0.718

7.3.1.3 Performance of rice hybrids in boro/rabi season across Bangladesh (2010-11):

The rice hybrids performed differently across different locations. Across genotypes, mean yield was highest in Rangpur (10.1 t ha^{-1}) and lowest in Satkhira (1.2 t ha^{-1}) and across locations, mean yield of BRRI hybrid dhan 3 was highest (9.3 t ha^{-1}) followed by BIO452 (8.8 t ha^{-1}) and BRRI hybrid dhan 2 (8.6 t ha^{-1}).BIO404 and Hira also performed very well (8.0 t ha^{-1}). BIO452 performed best on all locations except in Rajshahi and Satkhira. Specifically, performance of BioSeeds hybrids was best in Rangpur and the BioSeed hybrid (BIO452) also performed best in Barisal. (Table 7.3.18).

Table:7.3.18: Mean grain yield of rice hybrids during 2010-11 *rabi (boro)* season in different locations of Bangladesh

Variety	Grain yield (t ha^{-1})					
	Gazipur	Rajshahi	Rangpur*	Barisal	Satkhira**	Mean

BIO404	7.3	6.8	10.0	7.7	0.6	8.0
BIO452	7.7	6.1	11.0	10.3	1.8	8.8
Alloran	7.8	7.6	-	-	-	7.7
Shathi	7.8	6.5	-	-	-	7.2
BRRI dhan 28	6.9	6.5	-	6.7	1.3	6.7
BRRI Hybrid 2	-	-	9.4	7.7	-	8.6
BRRI Hybrid 3	-	-	9.9	8.7	-	9.3
Hira 2	-	-	-	8.0	-	8.0
BRRI dhan 47	-	-	-	7.5	1.1	7.5
BINA dhan 8	-	-	-	-	1.1	-
Mean	7.5	6.7	10.1	8.1	1.2	

** Averages calculated excluding the yield of Satkhira.

Yields of all hybrids were lowest in Rajshahi. Hybrids gave higher grain yield than BRRI dhan 28 in all the locations, except BIO452 in Rajshahi (Table 7.3.18). In Gazipur, BIO452, Alloron and Shathi gave similar yield (7.7-7.8 t ha^{-1}) while BIO404 (7.3 t ha^{-1}) differed by 0.4 t ha^{-1} from BRRI dhan28 (6.9 t ha^{-1}). Alloron (7.6 t ha^{-1}) gave the highest yield in Rajshahi while BIO404 (6.8 t ha^{-1}) and Shathi (6.5 t ha^{-1}) gave similar yield to BRRI dhan 28 (6.5 t ha^{-1}). In Barisal, comparatively higher grain yield was obtained from all the varieties. Yield of BIO452 (10.3 t ha^{-1}) was the highest followed by BRRI hybrid 3 (8.7 t ha^{-1}) and Hira 2 (8.0 t ha^{-1}). In Satkhira, BIO452 gave highest yield (1.8 t ha^{-1}) while BRRI dhan 47 and BINA dhan 8 had the similar yields (1.1 t ha^{-1}). The lowest yield (0.64 t ha^{-1}) was recorded for BIO 404 in Satkhira. Yields of all varieties in Satkhira were very low presumably due to two reasons. There was severe stem borer attack at the heading stage from the neighboring harvested fields as it was planted late. Also there was high salinity (more than 4-5 ds m^{-1} in pond water) at the panicle initiation stage (45 DAT) which resulted in reduced yield.

7.3.1.4 Site specific nutrient management:

7.3.1.4.1 Aman rice

Nutrient Manager for Rice trial was conducted from 2009 to 2011 in 59, 43 and 83 farmers' fields, respectively in seven *upazillas* of three districts. For example, in 2011, in addition to the six project *upazillas*, the trials were also conducted in Rangpur Sadar *upazilla*. The rice varieties used were different across *upazillas.* In Comilla, BR 22, BRRI dhan 46 and BRRI dhan 49 were used. In Rajshahi, BR 3, BRRI dhan 28, ACI-1 (hybrid), and Guti Swarna were used while in Rangour, BR 11, BRRI dhan 49, and BRRI dhan 52 were used. There were no significant differences in grain yield between the three treatments in Dautkandi (Comilla), Mithapukur (Rangpur), and for ACI-1 in Durgapure (Rajshahi) while there was a significant effect in other *upazillas* and for the 2 rice varieties in Durgapure. For ACI-1 in Durgapure, yields in FFP were greater than BRRI and NM-based recommendations while in Borura, Paba, Rangpur Sadar and Gangachara, yields with NM and BRRI recommendations were similar and greater than that for FFP (Table 7.3.19).

Table 7.3.19: Effect of different fertilizer management practices on grain yield (t ha^{-1}) of different rice varieties in NM Rice evaluation trial in seven *upazillas* in three districts, Aman 2011

Treatment	Barura	Daudkandi		Paba	Durgapur			Rangpur Sadar		Gangachara	Mithapukur
	BRRI dhan 49 (n=10)	BR22 (n=27)	BRRI dhan 46 (n=4)	Guti swarna (n=10)	BRRI dhan 28 (n=2)	AC-1 (n=4)	BR3(n=4)	BR11 (n=6)	BRRI dhan 52 (n=4)	BRRI dhan 49 (n=6)	BRRI dhan 49 (n=6)
FP	4.10	2.74	2.86	4.71	4.44	5.08	4.48	5.38	5.06	3.41	5.38
BRRI	4.35	2.89	2.97	4.98	3.82	4.40	4.39	5.43	5.34	4.23	5.68
NM	4.45	2.88	3.04	5.18	3.57	4.12	4.02	5.68	5.49	4.46	5.68
$LSD_{0.05}$	0.18	NS	NS	0.41	NS	0.58	NS	0.25	0.31	0.60	NS
CV (%)	4.3	12.1	3.7	8.8	7.7	7.4	13.3	3.6	3.3	11.6	6.3

Table 7.3.20: NM validation trials for *Aman* ricein farmers' field during 2013

Treatment	Grain yield (tha^{-1})	Gross return (BDT ha^{-1})	Net return over (BDT ha^{-1})	Total fertilizer cost (BDT ha^{-1})
FFP (60)	4.20	73760	61939	11821
NM (60)	4.12	72394	66255	6140

In 2013 the NM validation trials were conducted in 300 farmers' fields but only 60 farmers were closely monitored for crop cut yield with maintaining fertilizer information. Table 7.3.20 reveals that there were no differences in rice grain yield but farmers can save more than 5000 BDT by using less fertilizers, especially N. Ffarmers can earn more than that they earn from their own practice of fertilizer management.

7.3.1.4.2 Boro rice

The mean yields and yield components of boro rice for different NM evaluation treatment from several farmers' fields in the three districts in 2010-11 are presented in Table 7.3.21. Across the six locations in Comilla and Rajshahi, grain yields were significantly different between the treatments in most locations but yield components were significantly different only in locations in Rajshahi. Except for Chaura in Comilla, yields with SRDI recommendation were consistently greater than other treatments.

Table: 7.3.21: Effect of different nutrient management practices on yield and yield components of *boro* rice (2010-11)

Treatment	Tillers (m^{-2})	Panicles (m^{-2})	Grains ($panicle^{-1}$)	1000 grain wt (g)	Straw yield (t ha^{-1})	Grain yield (t ha^{-1})
Bramanpara, Comilla						
BRRI	373	361	108	28.6	4.4	6.3
FFP	374	357	108	28.5	4.6	6.2
NM	353	341	97	28.3	4.8	5.5
LSD (0.05)	NS	NS	NS	NS	NS	0.24
CV (%)	15.8	17.9	17.3	0.7	7.2	7.2
Chaura, Comilla						
NM	329	312	114	24.5	6.4	8.5
STB	344	329	114	25.2	6.5	8.6

BRRI	332	317	121	24.8	5.5	7.9
FFP	341	320	108	24.7	6.1	8
LSD (0.05)	NS	NS	NS	NS	NS	NS
CV (%)	10.1	13.2	6.5	5.9	12.8	7.4
			Barura, Comilla			
NM	293	278	113	22	-	5.90
FFP	287	272	116	22	-	5.84
BRRI	283	265	117	23	-	6.24
SRDI	298	284	120	23	-	6.51
LSD (0.05)	NS	NS	NS4	NS		0.47
CV(%)	7.8	7.2	7.1	4.3		8.9
			Paba, Charghat, Rajshahi			
FP	354	335	146	19.6	3.9	5.8
BRRI	383	360	143	19.7	4.0	6.0
SRDI	372	352	152	19.8	3.8	5.9
NM	389	364	138	21.1	3.9	5.2
LSD (0.05)	33	26	13	1.2	0.19	0.26
CV (%)	9.0	7.6	9.3	6.2	5.0	4.6
			Durgapure, Rajshahi			
NM	287	271	149	25	-	4.91
BRRI	295	280	153	24	-	5.43
SRDI	309	294	164	25	-	5.70
FFP	316	301	172	25	-	6.15
CV (%)	5.8	5.9	4.7	3.8		9.8
LSD (0.05)	16.1	15.4	6.8	NS		0.50

NM recommendation performed similar to other treatments in Chaura and similar to BRRI recommendation in Borura but performed poor than other treatments in most other locations. An economic analysis will be performed to conclude the profitability of the nutrient management treatments.

7.3.1.4.3 Rabi maize

Omission plots and Nutrient Manager for Rabi Maize evaluation trials 2011-13: As expected, the response of *rabi* maize to N, P, K, S and Zn has been variable across sites. However, in Comilla, it was not clear from those trials whether there was S and Zn deficiency or whether the more than expected yield response to K was real or artefact. The trial results indicated the need for evaluating the prototype version of NM for *Rabi* Maize in Rajshahi and Rangpur and continuing one more season of omission plot trials in Comilla.

Thus, in 2011-12, Nutrient Manager for *Rabi* Maize evaluation trials were conducted in 39 farmers' fields in four *upazillas* in Rangpur and Rajshahi and omission plot trials in 36 farmers' fields in three *upazillas* in Comilla and Rajshahi. There was heavy storm and rainfall at crop maturity in Comilla, damaging the crops completely in six farmers' fields. Hence yield couldn't be recorded from those fields. In 2012-13 in total 63 farmers' field for omissions with Crop Manager validation compared to Nutrient Expert, BARC recommendation and Farmers' practice were evaluated.

Nutrient Manager for *rabi* maize evaluation trials in Rangpur showed yield and all yield-attributing characters significant at 5% level of significance. Grain yield was highest for SRDI recommendation for other nutrients with NM-based recommendation for N followed by SRDI recommendations for all nutrients (Table 7.3.22). The greatest yield for SRDI NM-N was due to high cob weight and high HI. In both *upazillas* in Rajshhai, grain and stover yield were significantly different between treatments (Table 7.3.23). Grain yield in Durgapure was greater for SRDINM-N than rest of the treatments due to greater straw yield and greater cob weight. In Paba, grain yield was greatest for SRDI and SRDI NM-N and lowest for NM due to higher HI and greater number of cobs per plant in the former two treatments (Table 7.3.22). In both districts, NMKr produced slightly greater yield than NM-based fertilizers only.

Table 7.3.22: Evaluation trials for Nutrient Manager in *rabi* maize during 2011-12 at Rangpur (N=20)

Nutrient Management	Cob plant^{-1}	Stover (t ha^{-1})	Grain yield (t ha^{-1})	Cob wt (t ha^{-1})	Cob:grain ratio	HI
NM	1.00a	10.48a	8.42e	0.90d	0.11b	0.46b
NM Kr	1.00ab	9.75a	8.69d	0.98c	0.11a	0.47ab
NM -S	1.00ab	10.16a	8.95c	1.03b	0.12a	0.47ab
SRDI	1.00b	10.20a	9.26b	1.05ab	0.11a	0.48ab
SRDI NM-N	1.00ab	9.98a	9.46a	1.08a	0.11a	0.49a

Table 7.3.23: Evaluation trials for Nutrient Manager in *rabi* maize crop during 2011-12 at Rajshahi

Nutrient Management	Cob plant^{-1}	Stover (t ha^{-1})	Grain yield (t ha^{-1})	Cob wt (t ha^{-1})	Cob:grain ratio	HI
Durgapure (N=9)						
NM	1.01a	10.99b	8.50a	2.04a	0.23a	0.44a

NM Kr	1.00a	11.18b	8.78a	1.96a	0.22a	0.44a
NM -S	1.01a	11.17ab	8.74a	2.00a	0.24a	0.44a
SRDI	1.01a	11.78ab	8.70a	2.16a	0.24a	0.43a
SRDI NM-N	1.01a	12.18a	9.35b	2.20a	0.24a	0.44a
Paba (N=10)						
NM	1.00b	10.04b	6.74d	1.28b	0.19a	0.40a
NM Kr	1.01ab	11.56a	7.64bc	1.36a	0.18a	0.40a
NM -S	1.01a	12.11a	7.53c	1.37a	0.18a	0.39a
SRDI	1.02a	11.90a	8.11a	1.31ab	0.16b	0.41a
SRDI NM-N	1.02a	11.68a	7.85ab	1.29ab	0.17b	0.40a

Omission plot trials in Comilla showed that except for number of cobs plant^{-1}, grain yield and all other yield-attributing characters were significantly different between treatments (Table 7.3.24). As expected, there was significant grain yield response to N and K but no response to Zn and S. Yield response to K in both *upazillas* was lower than in the previous two years.

Table 7.3.24: Nutrient Manager evaluation trials (nutrient sufficiency) in *rabi* maize during 2011-12 in Comilla.

Nutrient management	Cob plant^{-1}	Stover (t ha^{-1})	Grain yield (t ha^{-1})	Cob wt (t ha^{-1})	Cob:grain ratio	HI
Barura (N=9)						
NPK+Zn+S	1.02a	9.12a	6.69a	1.40a	0.21b	0.43a
-N	1.01a	6.24b	4.04c	0.98c	0.25ab	0.39a
-P	1.02a	8.54a	5.62b	1.40a	0.25ab	0.40a
-K	1.03a	5.98b	4.04c	1.11b	0.29a	0.40a
NPK	1.02a	9.12a	6.30a	1.41a	0.23b	0.41a
Dautkandi (N=17)						
NPK+Zn+S	1.00a	10.45a	6.62a	1.56a	0.25a	0.39a
-N	1.00a	9.91b	4.31c	1.13b	0.28a	0.29c
-P	1.00a	10.34a	6.31a	1.53a	0.25a	0.38a
-K	0.98a	9.56b	4.90b	1.23b	0.27a	0.34b
NPK	1.00a	10.85a	6.62a	1.53a	0.24a	0.39a

Site-specific nutrient management in *rabi* maize (2010-11): In 20010-11, the omission plot trial tested –N, –P, –K, NPK, NK and low dose of P (low P), NP and low dose of K (low K), and N plus low doses of P and K (low PK) treatments in 17 farmers' fields in Comilla, 17 in Rajshahi, and 8 in Rangpur. The N, P, and K dose was 255, 74, and 200 kg ha^{-1}, respectively. The NPK treatment gave a mean yield of 9.02, 8.84, and 8.06 t ha^{-1} in Comilla, Rajshahi, and Rangpur, respectively (Table 7.3.25).

Nutrient omission responses in rabi maize

Table:7.3.25. Effect of omission of nutrient(s) from a complete NPK treatment in *rabi* maize in three districts (2010- 2011)

Treatment	Comilla (n=17)				Rajshahi (n=17)				Rangpur (n = 8)			
	Grain yield (t ha^{-1})	Stover yield (t ha^{-1})	HI	Cobs (m^{-2})	Grain yield (t ha^{-1})	Stover yield (t ha^{-1})	HI	Cobs (m^{-2})	Grain yield (t ha^{-1})	Stover yield (t ha^{-1})	HI	Cob (m^{-2})
–N	4.37	3.61	0.54	7	5.34	4.64	0.54	6	3.64	3.93	0.48	6
–P	7.69	4.88	0.61	7	7.31	6.02	0.55	6	5.62	5.50	0.51	6
–K	3.41	2.81	0.55	6	6.65	5.66	0.54	6	6.02	5.58	0.52	6
NPK	9.02	6.03	0.60	7	8.84	7.83	0.53	7	8.06	7.31	0.52	7
NK and Low P	8.67	6.13	0.59	7	7.98	7.02	0.53	6	6.04	5.55	0.52	6
NP and Low K	8.98	5.70	0.61	7	7.71	7.18	0.52	6	5.77	5.60	0.51	6
N Low PK	8.80	5.89	0.60	7	7.73	6.96	0.53	6	5.67	5.14	0.53	6
$LSD_{0.05}$	0.70	0.52	0.04	0.4	0.53	0.71	0.02	0.2	0.85	0.70	0.03	0.3
CV (%)	14.1	15.3	10.20	9.1	9.4	6.6	4.5	6.6	14.4	12.5	5.2	4.1

Omission of N, P, and K compared with NPK treatment significantly reduced grain yield at all three locations. The –N plot in Comilla, Rajshahi, and Rangpur yielded 4.37, 5.34, and

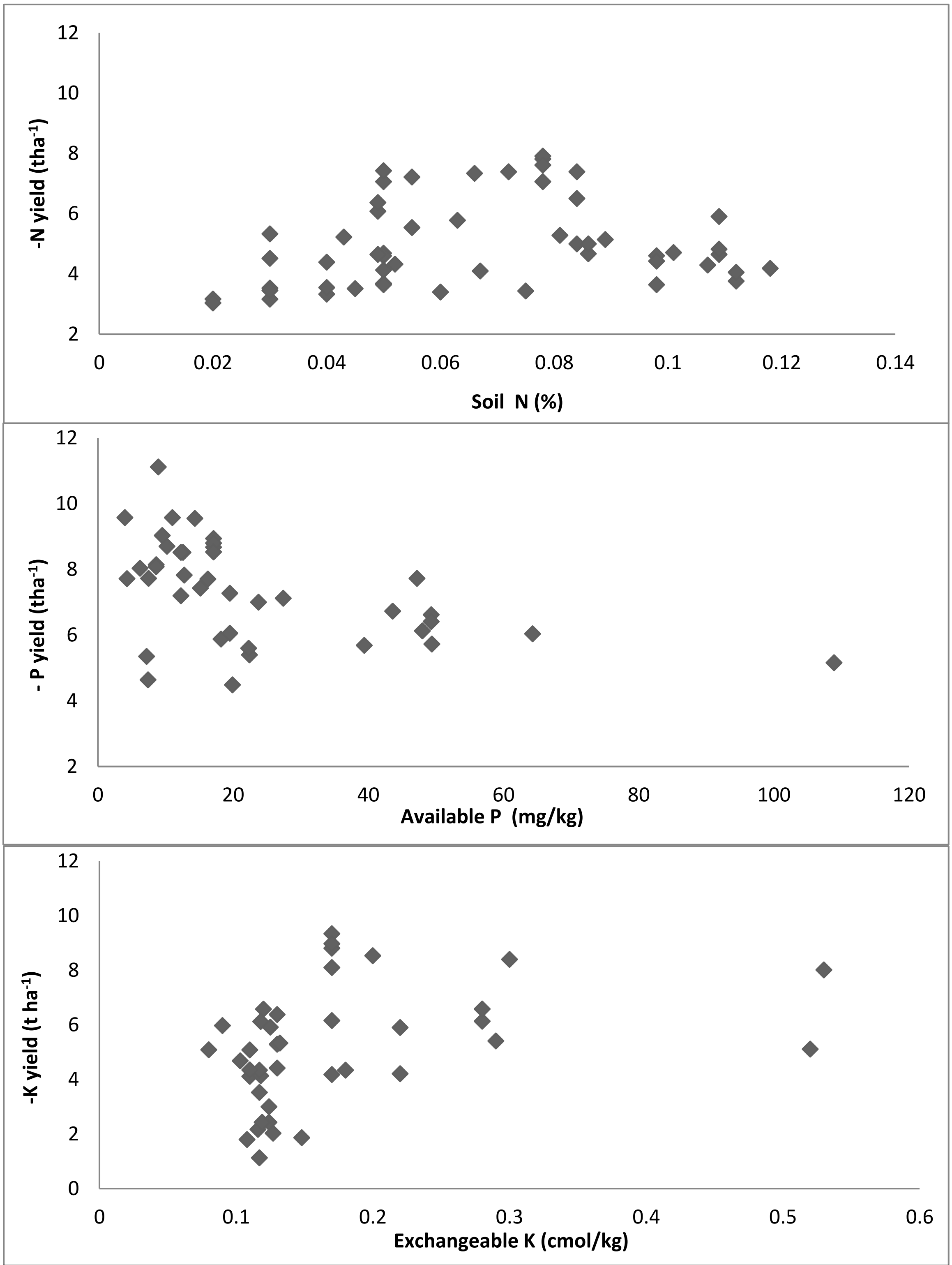


Fig. 7.3.9. Relationdships between soil N, soil available P and exchangeable K and mazie yield in –N, -P and –K, respectively

3.43 tha^{-1}, respectively. But, some farmers' fields showed much lower yield in –N plots compared with the mean yield at all the locations. Yields in –P plots were 7.69, 7.31, and 5.50 tha^{-1} in Comilla, Rajshahi, and Rangpur, respectively. Omission of K decreased maize yield significantly more than –P did in Comilla, but not in Rajshahi and Rangpur (Fig. 7.3.9).

Figure 7.3.9 shows that the yield in –N plots was not well correlated with the soil total N content. Soil N content across the locations varied from 0.02% to 0.12% and the yield in –

N plots varied from 1.8 to 7.8 t ha^{-1}, but the relationship between soil N and yield with native N was very poor. Similarly, soil available P and maize yield in –P plots showed a poor relationship. Soil exchangeable K varied from less than 0.08 to 0.53 cmol kg^{-1} and maize yield varied from 1.1 to 9.3 t ha^{-1}, but the Figure demonstrated that soil test K poorly explained the yield of maize in –K treatments.

The response of maize to applied N, P, and K was quite variable within a district (Table 7.3.26). About 4-5 t ha^{-1} yield response to N was observed in 3 out of 28 farmers' fields in Comilla, 4 out of 16 farmers' fields in Rajshahi, and 2 out of 8 farmers' fields in Rangpur. About a 4–5 t ha^{-1} yield response with K was observed in eight farmers' fields in Comilla and two both in Rajshahi and Rangpur. In case of P omission plot < 1 and 1-2 t ha^{-1} yield gain was observed in most of farmers' fields in all districts.

Table:7.3.26. Yield gain (t ha^{-1}) due to N, P and K application in *rabi* maize in farmers' fields (2010– 2011)

Yield gain (t ha^{-1})	Comilla (n=28)			Rajshahi (n=16)			Rangpur (n=8)		
	N	P	K	N	P	K	N	P	K
	--------------------------------Number of farmers' field----------------------								
<1.0	0	18	0	0	6	3	0	1	1
1.1 – 2.0	6	5	0	3	7	5	0	1	3
2.1 – 3.0	7	5	3	4	2	2	1	2	2
3.1 – 4.0	7	0	3	3	1	2	2	3	0
4.1 - 5.0	3	0	8	4	0	2	2	1	2
5.1-6.0	2	0	4	2	0	1	2	0	0
6.1-7.0	1	0	8	0	0	0	1	0	0
>7	1	0	1	0	0	0	0	0	0

The agronomic-use efficiency of N, P, and K in *rabi* maize 2010-11 for the three districts is presented in Table 7.3.27. AEN, AEP, and AEK varied widely across districts as well as across farmers' fields within a district. The maximum AEN in Comilla, Rajshahi, and Rangpur was observed as 31.0, 23.3, and 25.9 kg grain kg^{-1} N, which represents a reasonable value for soils containing about 1% organic carbon. However, the mean and median of AEN at all three districts represent an underestimation. The median AEP in Comilla (25.1) was higher than in Rajshahi (19.9) and lower than in Rangpur (35.3), but AEK was higher in Comilla than at the other two districts.

Table:7.3.27. Agronomic use efficiency (kg grain kg^{-1} nutrient) of *rabi* maize in the three districts (2010-2011)

Attribute	Minimum	Maximum	Mean	Median
	Comilla (n = 17)			
AEN, kg grain/kg N	6.7	31.0	18.2	18.2
AEP, kg grain/kg P	-32.7	36.8	17.8	25.1
AEK, kg grain/kg K	19.6	38.3	28.2	26.5
	Rajshahi (n = 17)			
AEN, kg grain/kg N	4.4	23.3	13.7	13.2
AEP, kg grain/kg P	3.1	52.7	20.4	19.9
AEK, kg grain/kg K	0.3	26.8	11.0	9.3
	Rangpur (n = 8)			
AEN, kg grain/kg N	11.3	25.9	17.4	17.2

AEP, kg grain/kg P	-7	59.3	32.7	35.3
AEK, kg grain/kg K	-8	21.1	10.2	10.9

Nutrient (N, P, and K) uptake by maize shows large variation among districts (Table 7.3.28). N, P and K uptake by maize in the three districts was not similar. In Comilla, N uptake varied from 18-33 kg ha^{-1} in the four treatments. In Rangpur, it varied from 16 to 37 kg ha^{-1}. In Rajshahi, the –N treatment showed the lowest N uptake of 24 kg ha^{-1} while the NPK treatment showed the highest (47 kg ha^{-1}). N uptake in Rajshahi was higher than in both Rangpur and Comilla.

Phosphorus uptake in –P treatment was not significantly different from that in NPK treatment in all experiment sites (Table 7.3.28). In contrast, K uptake in NPK plot was significantly greater than in –K plot in all districts. K uptake varied from 234 kg ha^{-1} in –K plot in Comilla to 869 kg ha^{-1} in NPK-treated plots in Rajshahi.

Table:7.3.28. Nitrogen, P, and K uptake (kg ha^{-1}) by *rabi* maize at three districts of Bangladesh, 2009

Treatment	Nutrient uptake (kg ha^{-1})								
	Comilla			Rajshahi			Rangpur		
	N	P	K	N	P	K	N	P	K
−N	18	34	365	24	56	579	16	43	444
−P	30	52	554	36	73	729	28	61	638
−K	14	26	234	33	71	672	35	69	699
NPK	33	53	638	47	101	869	37	81	843
$LSD_{0.05}$	6	15	90	13	34	144	6	29	128
CV (%)	23	36	19	30	37	16	16	37	16

Table 7.3.29 shows the apparent recovery of applied N, P, and K by *rabi* maize. Very low apparent N recovery in the experimental sites represents either very high doses of applied N or too high soil native N-supplying capacity. Rajshahi demonstrated apparent P and K recovery of 37% and 99%, respectively, indicating the soils were deficient in both elements. Among the three districts apparent K recovery in Comilla was very high, and in Rajshahi was higher than in Rangpur. Very high apparent recovery of K in Comilla indicated that the soils in Comilla were very deficient, and soils in Raishahi were more deficient than in Rangpur.

Table: 7.3.29. Apparent recovery (%) of applied N, P, and K by *rabi* maize (2010-11)

District	Apparent recovery (%)		
	N	P	K
Comilla	6	1	203
Rajshahi	12	37	99
Rangpur	8	11	72

7.3.1.4.4 Kharif maize

NM Maize evaluation in *Kharif*-1 season (2011): There is now a prototype version of Nutrient Manger for *Kharif*-1 Maize and needs to be evaluated. Thus, in the Nutrient Manager for Kharif-1 Maize evaluation trials in 2011, four treatments were being evaluated in 27 farmers' fields in Comilla, 26 in Rajshahi, and 7 in Rangpur. The treatments were: (i) farmer's fertilizer practice (ii) BARI recommendation (iii) NM-based recommendation with current yield (NMC), and (iv) NM-based recommendation with higher yield (NMH). There were no significant differences in grain yield among the four treatments for fields in Comilla and Rajshahi while for fields in Rangpur, yield wad significantly lower in farmer's fertilizer practice than the other three treatments (Table 7.3.30).

Table 7.3.30: Grain yield for different nutrient management treatments in *kharif*-1 maize in Nutrient Manger for Maize evaluation trials, 2011.

Treatment	Grain yield (t ha^{-1})		
	Comilla (n=27)	Rajshahi (n=26)	Rangpur (n=7)
Farmer's fertilizer practice	7.22	6.45	4.67
BARI recommendation	7.29	6.48	5.95
NMC	7.21	6.04	5.94
NMH	7.37	6.37	6.07
LSD_{005}	NS	NS	0.62
CV (%)	8.30	13.70	9.80

Overall, 107 on-farms validation trials were conducted in farmers' fields during 2011-13 in 6 *upazillas* of three districts (Table 7.3.31). There were no differences observed in maize grain yield. The significant difference was observed in fertilizer cost and use. The maximum fertilizer cost was involved when farmers followed the BARI recommendation than others. The NM practices followed lower dose of fertilizer than BARI and farmers practice and saved more fertilizer cost.

Table 7.3.31: NM validation trials for *Kharif-1* maize during 2011-13

Nutrient recommendations	Grain yield (t ha^{-1})	BDT ha^{-1}			
		Fertilizer cost		Gross return	Net return
BARI (107)	7.11	15006	a	111898	96893
FP (107)	6.78	6350	bc	107170	100820
NM (107)	7.06	10522	b	112898	102377
NMC (107)	6.87	3749	c	108145	104396
NMH (107)	7.13	4857	c	112138	107281
ANNOVA	Probability				
Yr	0.221	0.200		0.218	0.206
Rep	<0.001	0.109		<0.001	<0.001
Trt	0.285	0.017		0.453	0.369
Yr*trt	0.165	0.146		0.164	<0.001

7.3.2 On-station basic research study:

7.3.2.1 The effect of rice and maize establishment methods on weed populations and successions and annual productivity in R-M systems:

An experiment was initiated in 2009 at BRRI, Rangpur to investigate the effect of different crop establishment/tillage options with three weed management options for R-M system. There are three crop establishment methods (conventional puddling and transplanting-TPR, dry tillage followed by direct seeded rice-CTDSR and zero-tillage direct seeded rice-ZTDSR) and superimposed two tillage options in the subsequent maize crop (zero-tillage-ZTM and conventional tillage-CTM) and three weed management options in rice (chemical control with herbicides, CW), manual hand weeding (HW), and weedy. . Results were analysed for rice crop establishment methods, maize tillage options and weed management options in rice and their interactions (Table 7.3.2.1). It is clear from the first three years that rice crop establishment methods had no had no residual effect on grain yield of succeeding maize but in year 4 grain yield was higher when grown after CTDSR and ZTDSR than TPR.

For maize data analysis we differentiated treatments in combination of rice crop establishment followed by maize tillage options, so there were six treatment combinations. In Yr-1, CTDSR-CTM gave higher maize grain yield than the other tillage options except TPR-CTM and ZTDSR-CTM. All zero-till maize (ZTM) plots gave lower yield when it was grown after different rice crop establishment methods but CTDSR-ZTM was similar to CTM grown after TPR and ZTDSR. In Yr-2 and 3, maize grain yield was more in CTDSR-CTM and TPR-CTM than CTDSR-ZTM but rest were at par. InYr-4, ZTM plots resulted in higher yields when it was grown in any combination than TPR-CTM but was similar to CTDSR-CTM and ZTDSR-CTM.

Rice weed management options did not affect the succeeding maize yield; indicating no residual effects on maize yield from the previous rice weed management treatments. There were no interaction effects observed on maize yield.

The rice crop establishment methods had significant effects on rice grain yield in all 4 years. At the beginning of the experiment in yr-1, TPR gave more yield than CTDSR but similar to ZTDSR. In yr-2, ZTDSR provided more yield than CTDSR but similar to TPR. In yr-3 and 4 both ZTDSR and TPR proved better than CTDSR. CTDSR gave lower yield in all 4 years than two other remainders.

Maize tillage options had significant effects on rice yield. Rice yield in yr-1 was higher in TPR-ZTM than rest of the tillage combinations. ZTDSR-ZTM and TPR-CTM produced higher yield than CTDSR-ZTM but similar to ZTDSR-CTM and CTDSR-CTM. CTDSR-ZTM produced lower yields in all 4 years. In Yr-2, ZTDSR-ZTM gave higher yield with TPR-ZTM and CTDSR-CTM than CTDSR-ZTM and TPR-CTM but similar to ZTDSR-ZTM. In yr-3, again ZTDSR-ZTM gave higher yield than both CTM and ZTM after CTDSR. In Yr-4 TPR after both CTM and ZTM gave more yield than after CTDSR in both CTM-ZTM and at par with ZTDSR combination. The ZTDSR-ZTM gave more yield in first 3 years and similar in 4^{th} year than CTDSR.

Weed management options showed clear significant differences on rice yield. Both chemical weed control (CW) and manual hand weeding (HW) had better control on weed management than no weed control and yield was significantly lower in no weed control plots than both the other treatments. In Yr-1 to Yr-3 there were no differences in grain yield of rice in CW and HW treatments but in Yr-4, CW proved to be more superior to HW.

Table 7.3.2.1: Effect of crop establishment/tillage and weed management options in R-M system at BRRI, Rangpur during 2009-13

Treatment	Maize grain yield (tha^{-1})								Rice grain yield ($t\ ha^{-1}$)							
	2009-10		2010-11		2011-12		2012-13		2010		2011		2012		2013	
Crop establishment options in rice (CEOR)																
CTDSR	7.92		8.62		8.62		8.93	a	4.42	b	3.94	b	3.99	b	4.18	b
TPR	7.74		8.68		8.65		8.43	b	4.81	a	4.08	ab	4.27	a	4.74	a
ZTDSR	7.81		8.66		8.62		8.78	a	4.63	ab	4.36	a	4.38	a	4.53	a
Tillage options in Maize (TOM)																
CTDSR-CTM	8.12	a	8.83	a	8.84	ab	8.86	a	4.52	bc	4.28	a	3.93	b	4.28	bc
CTDSR-ZTM	7.73	bc	8.41	b	8.40	b	8.99	a	4.32	c	3.61	c	4.04	b	4.09	c
TPR-CTM	7.93	ab	8.86	a	8.86	a	8.14	b	4.66	b	3.84	bc	4.30	ab	4.82	a
TPR-ZTM	7.54	c	8.51	ab	8.44	ab	8.72	a	4.97	a	4.32	a	4.24	ab	4.67	a
ZTDSR-CTM	7.97	ab	8.76	ab	8.76	ab	8.62	ab	4.61	bc	4.17	ab	4.30	ab	4.61	ab
ZTDSR-ZTM	7.65	c	8.56	ab	8.49	ab	8.94	a	4.66	b	4.56	a	4.46	a	4.46	ab
Weed management option in rice (WMOR)																
CW	7.79		8.63		8.60		8.84		5.21	a	4.96	a	4.83	a	5.29	a
HW	7.78		8.68		8.69		8.67		5.20	a	4.60	a	4.59	a	4.91	b
TC	7.90		8.65		8.60		8.63		3.45	b	2.82	b	3.23	b	3.26	c
ANOVA	Probability															
Rep	0.918		0.001		0.003		0.538		0.001		0.417		0.764		0.006	
CEOR	0.259		0.912		0.972		0.017		0.012		0.093		0.021		0.001	
TOM	0.002		0.017		0.010		0.021		0.571		0.656		0.544		0.135	
WMOR	0.454		0.974		0.869		0.417		<0.001		<0.001		<0.001		<0.001	
CEOR*TOM	0.926		0.771		0.856		0.245		0.148		0.005		0.705		0.985	
ECOR*WMOR	0.954		0.871		0.825		0.347		<0.001		0.001		0.011		<0.001	
TOM*WMOR	0.670		0.889		0.782		0.421		0.067		0.533		0.666		0.151	
CEOR*TOM*WMOR	0.443		0.215		0.218		0.232		0.469		0.248		0.725		0.076	

7.3.2.2 Optimization of maize hybrids population

Maize is a new crop in Bangladesh, and there is no enough information on plant geometry and optimum plant population for maximizing the maize yield. Hence, a 3-yr experiment was conducted at BRRI, Rangpur station with five plant population levels (Table 7.3.2.2). The experiment was initiated during 2009-10 but after one season it was modified and continued in 2010-2012.

Table 7.3.2.2: Plant geometry (cm) and population (ha^{-1})

Treatment	2009-10		2010-2012	
	Spacing	Plant population	Spacing	Plant population
T1	75x25	53000	70x20	65000
T2	75x22	60000	65x22	70000
T3	70x22	65000	60x22	75000
T4	65x25	70000	55x22	82000
T5	60x22	75000	50x22	90000

Rabi **maize 2009-10:** There were significant differences among the various plant population densities in 2009-10 *rabi* season (Fig. 7.3.2.1). The growth and yield components responses, however, were contrary to the grain yield. Significant treatment differences were recorded for grains cob^{-1} at various plant spacings. The maximum number of grains cob^{-1} (373) was recorded with 75 cm×25 cm spacing while the minimum number of grains cob^{-1} (345) was recorded with 70 cm×22 cm. The highest plant height (155.8 cm) was recorded with 75×25 cm spacing followed by 75×22 cm (152.8 cm). The lowest plant height (143.7 cm) was recorded with 65×22 cm (Table 7.3.2.3). The highest 100 grain weight (40.05 gm) was with 75 cm×25 cm plant spacing and the minimum grain weight (37.74 g) was with 65 cm×22 cm plant spacing. The maximum stover yield (10.26 t ha-1) was with 60 cm × 22 cm plant spacing due to higher plant population. On the other hand, the minimum stover yield was with 75 cm× 25 cm plant spacing. The maximum grain yield of 8.71 t ha^{-1} was obtained with 60 cm×22 cm (T5) plant spacing followed by T4. On the contrary, the minimum grain yield (7.40 t ha^{-1}) was with 75 cm×25 cm (T1) but it was non-significant with T2 and T3 (Figure 7.3.2.1). The responses of cobs $plant^{-1}$, grains cob^{-1} and 100 grain weight were contrary to that of grain yield. In the first year, individual plant performance was better where more space was provided but the maximum yield was obtained with higher plant densities due to more plants in a unit area..

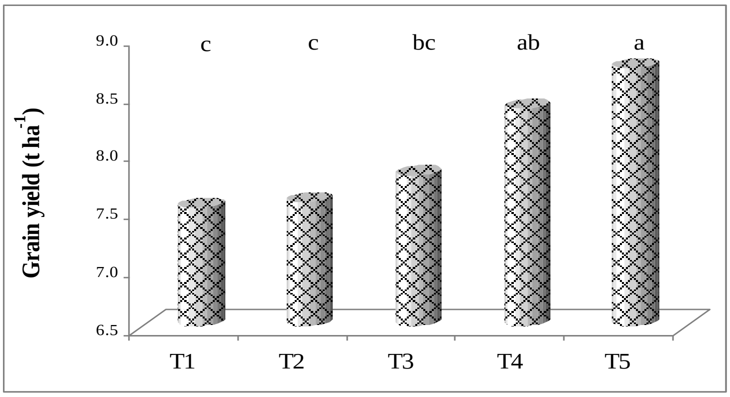


Figure 7.3.2.1 Maize yield as affected by plant population density in *rabi* maize 2009-10.

Table7.3.2.3 Agronomical parameters as affected by plant population density in *rabi* maize 2009-10

Plant population	Plant height	Cobs $plant^{-1}$	Grains cob^{-1}	100 grain wt (gm)	Stover yield (t ha^{-1})	Harvest index

	(cm)					
T1	194 a	1.03 a	373[a]	40.05 a	9.23 b	0.46 a
T2	189 a	0.96 a	362 ab	39.49 ab	9.46 b	0.44 a
T3	183 a	1.03 a	345 c	38.63 bc	9.46 b	0.45 a
T4	198 a	1.00 a	349 c	37.74 c	10.26 a	0.45 a
T5	199 a	1.00 a	352 bc	37.81 c	10.20 a	0.46 a
ANOVA				Probability		
Rep	0.904	0.508	0.004	0.013	0.138	0.780
Plant population	0.616	0.824	<0.001	<0.001	<0.001	0.553

***Rabi* maize 2011-12:** Plant height was significantly affected by plant density (Fig. 7.3.2.2; Table 7.3.2.4). The tallest plants (199 cm) were recorded in T1 while short statured plants were recorded in T4 (187 cm) and T5 (186 cm) due to crowding effect and higher intra-specific competition for resources. This explains that as the number of plants increases in a given area the competition among the plants for nutrients uptake and sunlight interception also increases.

The number of cobs per plant was significantly affected by plant density. It is significantly lower (0.88) in T5 than the other treatments. The treatments with 65,000 plants ha^{-1} produced the highest number of grains per cob (422) followed by T2 (418) with 70,000 plants ha^{-1}. The lowest number of grains per cob (369) was recorded with 90,000 plants ha^{-1}. The data revealed that grain weight was significantly affected by different plant population densities. The population of 65,000 plants ha^{-1} produced the highest grain weight of 42.77 gm. The lowest 100-grain weight was found in T5 treatment.

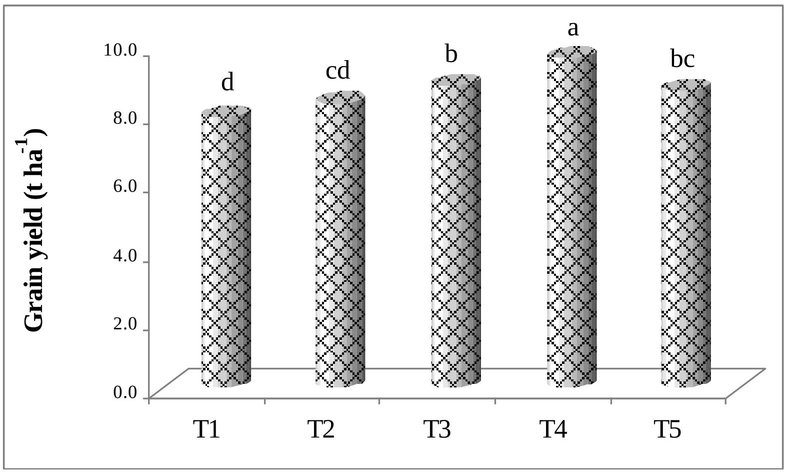


Figure 7.3.2.2 Maize grain yield under different geometry and plant population during 2010-12

The stover yield increased significantly with increasing plant densities. Treatment with population of 1, 00,000 plants ha^{-1} produced the maximum stover yield of 11.85 t ha^{-1}, while lowest stover yield of 8.83 t ha^{-1} was recorded with plant population of 65,000 plants ha^{-1}. The highest stover was found with T5 due to presence of maximum plant population per hectare.

Maize HI showed significant variation among plant densities. Maximum value (0.47) of HI was recorded for T1 and the lowest value was recorded for T5 .

Table7.3.2.4 Physiological and agronomic parameters as affected by plant population in maize 2011-12.

Plant population	Plant height (cm)	Cobs plant^{-1}	Grains cob^{-1}	100 grain wt (gm)	Stover yield (t ha^{-1})	Harvest index
T1	199 a	0.99 a	422 a	42.77 a	8.83 e	0.47 a
T2	191 b	1.00 a	418 a	40.90 b	9.65 d	0.46 a

T3	188 bc	0.96 a	407 a	40.45 b	10.32 c	0.46 a
T4	187 c	0.97 a	406 a	38.31 c	11.40 b	0.46 a
T5	186 c	0.88 b	369 a	35.92 d	11.85 a	0.42 b
ANOVA				Probability		
Year	0.603	0.002	0.289	0.056	0.990	0.460
Rep	0.001	0.006	0.153	0.002	0.022	0.016
Plant population	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
yr x plant Pop	0.831	0.001	0.541	0.006	0.999	0.386

Grain yield was significantly affected by plant population density (Fig 7.3.2.2). The maximum grain yield (9.68 t ha^{-1}) was recorded for T4 with population of 82,000 plants ha^{-1} and the minimum grain yield (7.96 t ha^{-1}) was with T1. Yield increased from T1 to T4 but from T5 it decreased with maximum plant density.

7.3.2.3 Evaluation of pre- and post-emergence herbicides for weed control in aman direct-seeded rice

An experiment was conducted at multi-location at BRRI-Rajshahi and Rangpur station during 2010 but it was again conducted at BRRI-Rajshahi during 2012. The Rajshahi data were analysed for two years. Combined analysis showed year had a strong effect on weed management options but in year* weed control options it differed for unfilled grain, sterility and grain yield.

The total number of tillers m^{-2} was significantly affected by different weed control options. The tillers were produced in order of Weedfree=Sunrise+1HW≥ Hammar (post)≥ Topstar+1HW≥ Sunrise(post) ≥ Hammnar+1HW≥ Panida+Hammar≥ Panida+1HW≥ Panida+ Sunrise≥ Topstar+Sunrise> Panida(Pre)> Topstar> Weedy. The weedy plots produced minimum number of tillers (217 m^{-2}) than weed free and herbicide+1HW options. The higher number of panicles (284 m^{-2}) was recorded in Sunrise+1HW followed by Weed free then Weedy. The lowest panicles (190 m^{-2}) were observed in the weedy plot (Table 7.3.2.5).

There was no difference between the weed control options for panicle length. Maximum number of filled grains panicle^{-1} was with Panida (Pre) followed by the Weed free plot than weedy plot, Panida+1HW, Hammar+1HW. Other tillage options showed intermediate response in term of filled grains. More unfilled grains were observed in Sunrise+1HW followed by both pre emergence herbicides. The lower number of unfilled grains was in Weedy, Weed free, both tank mixture of post emergence herbicide combinations and Sunrise (post). Other tillage options showed intermediate response for unfilled grains. The highest sterility % was observed in Topstar (Pre) followed by Sunrise+1HW while the lower sterility % was with Topstar+1HW.

Clear differences were observed in grain yield between different weed control options. Weed free plot resulted in higher yield (4.94 t ha^{-1}) followed by herbicide use +1HW options except Panida+1HW but it was significantly lower than Weed free plot only. It clearly indicated that application of pre-emergence herbicide (Panida and Topstar) alone was unable to control the weeds, gaving yield penalty. The application of pre-emergence followed by post emergence herbicide was at par with herbicide+1HW options but significantly lower than weed- free plot. Weedy plots gave lowest yield compared to other weed control management options. Either herbicide alone or manual weeding alone is not a good option for weed control in DSR. Overall, the combination of herbicide application with 1HW provides good weed control for DSR.

Table7.3.2.5: Effect of weed control options on *aman* direct seeded rice crop performance

Weed control options	Number m^{-2}		Panicle length (cm)	Grains $panicle^{-1}$		Sterility (%)	Yield (t ha^{-1})
	Tiller	Panicle		Filled	Unfilled		
Panida(pre)	231bcd	218bcd	23.67	138a	33.94ab	19.07ab	3.09e
Topstar(pre)	229cd	211cd	23.32	121abc	33.37ab	21.31a	3.31de
Hammar(post)	282ab	239abc	22.90	127abc	28.63abc	18.40abc	3.57cde
Sunrise(post)	274abc	252abc	41.70	126abc	22.77c	15.29bc	3.75cde
Panida+1HW	264abcd	252abc	22.67	113c	25.43bc	18.40abc	3.84bcde
Panida+Hammar	268abc	250abc	23.02	120abc	27.37abc	18.39abc	4.16bc
Panida+sunrise	262abcd	233bcd	21.90	128abc	23.88c	15.52bc	4.02bcd
Topstar+1HW	276abc	220bcd	22.94	138a	22.12c	13.77c	4.18abc
Topstar+Hammar	253abcd	238abc	22.64	117abc	27.50abc	19.14ab	3.82bcde
Topstar+Sunrise	254abcd	238abc	22.75	122abc	21.18c	14.64bc	3.86bcde
Hammar+1HW	273abc	253abc	38.54	113c	22.50c	17.42abc	4.57ab
Sunrise+1HW	285a	284a	23.08	121abc	34.60a	21.65a	4.27abc
Weedfree	299a	261ab	24.37	133ab	22.867c	14.92bc	4.94a
Weedy	217d	190d	22.68	110c	22.40c	16.93abc	2.28f
ANOVA				Probability			
Year	0.001	0.001	0.184	0.003	0.001	0.049	0.001
Rep	0.948	0.964	0.114	0.315	0.498	0.490	0.719
Weed control	0.094	0.034	0.501	0.066	0.015	0.034	0.001
Yr*WCO	0.196	0.204	0.529	0.145	0.025	0.027	0.051

7.3.2.4 Effect of different tillage/crop establishment methods and residue management options in R-M-MB system at BRRI Rajshahi

This experiment investigated the effect of different tillage/crop establishment options with different levels of residue in R-M-MB system. All crop yield data were converted into rice equivalent yield to see the treatment effects on total system. The yield effects were analysed for year, tillage, residue, year*tillage, year*residue, residue*tillage (Table 7.3.2.6). The year, replication and residue effects were significant for all rice equivalent yields. Year*residue and tillage*residue effects were found non-significant for all crop yield parameters. The year*tillage had significant effect only on rice yield but others had no such effect.

Minimum tillage (MT) produced lower rice yield than other tillage options except zero tillage (ZT). Other than MT, all other tillage options produced similar yields. Rice equivalent maize yield on fresh bed (FB) produced higher yield (12.06 t ha^{-1}) than other tillage options except PB. ZT produced significantly higher yield than CT but similar to PB and ST. ST and MT produced similar yield but higher than CT. Of all the tillage options, the lowest yield was attained with CT. System rice equivalent yield showed maximum yield from both bed planting system (FB and PB) than rest of the tillage options. ST and ZT gave higher system yield than CT but similar to MT. CT was least performer in terms of system yield.

Retention of crop residue resulted in more rice equivalent yield in all three crops (Table 7.3.2.6). In rice the full residue retention of previous mungbean and maize rresulted in higher yields than half of the residue retention and residue removal. Half residue retention was significantly better over residue removal. The order of rice grain yield was full residue retention> half residue retention> removal of residue. In terms of maize and mungbean grain yield, full and half residue retention produced more yield than residue removal. For total system, rice equivalent yield at each level of increment of residue gave significant yield gain. The maximum system yield was with full residue retention followed by half residue retention and minimum was with residue removal.

Table 7.3.2.6 Effect of tillage/crop establishment and residue management options on rice equivalent yield in R-M-MB system during 2011-13, BRRI, Rajshahi

Treatment	Rice equivalent yield (t ha^{-1})							
Tillage	Rice		Maize		Mungbean		System	
CT	4.62	a	10.28	d	4.60		19.49	c
FB	4.62	a	12.06	a	4.73		21.41	a
MT	4.25	b	11.19	c	4.69		20.13	bc
PB	4.65	a	11.78	ab	4.73		21.16	a
ST	4.53	a	11.24	c	4.64		20.42	b
ZT	4.44	ab	11.33	bc	4.55		20.32	b
Residue								
Full	4.78	a	11.68	a	4.84	a	21.30	a
Half	4.49	b	11.36	a	4.54	a	20.40	b
Remove	4.29	c	10.90	b	4.58	b	19.77	c
ANOVA	Probability							
Year	0.001		<0.001		0.990		0.158	
Rep	0.016		0.004		0.197		0.034	
Tillage	0.019		<0.001		0.357		<0.001	
Residue	<0.001		0.005		<0.001		<0.001	
Yr*till	0.003		0.261		0.997		0.149	
Yr*residue	0.099		0.583		0.999		0.398	
till*residue	0.805		0.549		0.087		0.718	

7.3.2.5 Study on tillage and maize hybrid options under R-M-MB system at RWRC, BARI-Rajshahi:

This experiment was set up during 2009 to evaluate tillage options and maize hybrids on R-M system. The growth and yield parameters were collected and also economic analysis was carried out during 4 years. Data were analysed for year, tillage, hybrid, year*tillage, year*hybrid, tillage*hybrid effects. Mean pooled data showed that year had significant effects, and year*hybrid and tillage*hybrid also had some effects for most of the parameters (Table 7.3.2.7 amd 7.3.2.8).

Among the maize hybrids, BHM 7 was tallest, NK40 was shortest and Pacific was intermediate. All other hybrids were different to each other. The same pattern was followed for cob girth as for plant height. More numbers of cobs plant^{-1} were produced by Pacific than NK 450, and BHM 7 was at par with Pacific. BHM7 produced more numbers of grains cob^{-1} than others. NK40 had bolder grain than the other two hybrids. Lengthier cob was in BHM 7 than the other two hybrids.

Fresh beds resulted in taller plants than the other tillage options. CT had more plant height than ST and ZT but similar to MT and PB. ZT had smallest plants of all the tillage options. Cobs plant^{-1}, 1000-grain weight and cob length showed differences among the tillage options. MT produced highest numbers of grains cob^{-1} and FB the lowest. MT was at par with PB, CT and ST, and FB was at par with ZT. Bigger size cobs were produced with CT and MT than ST and ZT but these were non-significant with FB and PB.

The grain yield was highest with NK40 followed by BHM 7 than Pacific. Similar response was followed for biomass production (Table 7.3.2.8). NK 40 had higher HI than the other two hybrids. The cost of production for all three maize hybrids was significant with each other in order of BHM7>NK40>Pacific and same order followed for net income. The higher gross return was for BHM 7 and NK40 than Pacific.

ZT produced the lowest grain yield (9.03 t ha^{-1}) than other tillage options except PB. PB and ST also had similar yield. CT, FB, ST and MT produced significantly similar yields. Biomass also followed similar response to grain yield except that ST produced intermediate biomass. The highest cost of production was recorded for CT among all the tillage options. FB also needed more input resources than other tillage options but lower than CT. The lowest cost of production was recorded for ZT<PB<ST and these were significantly different from MT.

Similar gross return was received from CT, FB, and MT but these were significantly higher than ZT and PB and intermediate with ST. Net income was more for FB and MT than PB and ZT but was similar to CT and ST. The lowest net income was from ZT but was similar to PB.

Table 7.3.2.7 Tillage and maize hybrids effects on growth and yield parameters under R-M-MB system during 2009-13 at RWRC, BARI-Rajshahi

Hybrid	Pl ht (cm)	Cob plant^{-1}	Grains	1000 GW (g)	Cob (cm)	
					Girth	Length
BHM7	212a	1.00a	437a	365b	16.68a	15.01b
NK40	185b	0.99b	401b	376a	16.28b	16.32a
Pacific	200c	1.01a	414b	347c	15.73c	16.25a
Tillage						
CT	201b	1.00	425ab	368	16.49a	15.85
FB	205a	0.99	392c	368	16.30ab	15.91
MT	199bc	1.00	436a	365	16.49a	15.80
PB	200b	1.00	418ab	355	16.15ab	15.76
ST	196c	1.00	422ab	360	15.99b	16.10
ZT	193d	1.00	409bc	362	15.97b	15.74
ANOVA			Probability			
Year	0.001	0.632	0.001	0.001	0.001	0.001
Rep	0.104	0.183	0.086	0.543	0.619	0.255
Tillage	0.001	0.838	0.002	0.348	0.041	0.968
Hybrid	0.001	0.002	0.001	0.001	0.001	0.001
Yr*Trt	0.001	0.971	0.055	0.414	0.103	0.302
Yr*Hyb	0.001	0.037	0.001	0.001	0.001	0.115
Trt*Hyb	0.001	0.549	0.001	0.024	0.182	0.614

Table 7.3.2.8 Tillage and maize hybrids effects on yield and economics under R-M-MB system at RWRC, BARI-Rajshahi during 2009-13

Hybrid	Yield (t ha^{-1})		HI	BDT (ha^{-1})		
	Grain	Biomass		Cost of production	Gross return	Net return
BHM7	9.87a	19.38a	0.52b	71245a	187800a	116555a
NK40	10.25a	19.29a	0.53a	70563bc	194753a	124190b
Pacific	9.24b	18.13b	0.51b	69705c	175284b	105579c
			Tillage			
CT	10.15a	19.46a	0.53	73525a	193892a	120367ab
FB	10.17a	19.76a	0.52	71875b	193127a	121252a
MT	10.06a	19.45a	0.52	69834c	192112a	122278a

PB	9.50bc	18.17b	0.52	69327de	180281bc	110954bc
ST	9.79ab	18.81ab	0.52	69538cd	185140ab	115602ab
ZT	9.03c	17.94b	0.51	68927e	171120c	102193c
ANOVA			Probability			
Year	0.001	0.001	0.001	0.001	0.001	0.001
Rep	0.103	0.025	0.642	0.084	0.063	0.062
Tillage	0.001	0.002	0.635	0.001	0.001	0.002
Hybrid	0.001	0.001	0.003	0.001	0.001	0.001
Yr*Trt	0.001	0.003	0.006	0.001	0.001	0.005
Yr*Hyb	0.001	0.001	0.076	0.001	0.001	0.001
Trt*Hyb	0.004	0.223	0.024	0.001	0.007	0.002

Similar tillage options were evaluated for *aman* rice in R-M system. *Aman* rice data were analysed for year, tillage and year*tillage effects. The year effect had significant differences; year*tillage also had significant effects except tiller and 1000-grain weight (Table 7.3.2.9). All the parameters showed differences between tillage options except total number of tillers. The taller rice plants were recorded in conventional tillage-transplanted rice (CTTPR) than fresh bed direct seeded rice (FBDSR), minimum tillage direct seeded rice (MTDSR) and strip tillage direct seeded rice (STDSR) but non-significant with permanent bed direct seeded rice (PBDSR) and zero-tillage direct seeded rice(ZTDSR). Smaller rice plants were measured in FBDSR than rest of the tillage options. The STDSR had smaller plant height than PBDSR and CT. The maximum number of panicles was recorded under MTDSR followed by ZTDSR. The less number of panicles m^{-2} was recorded under CTTPR and PBDSR but these were at par with STDSR and FBDSR. The numbers of filled grains $panicle^{-1}$ showed significant differences among different tillage options and were in order MTDSR>STDSR>PBDSR>ZTDSR>CTTPR>FBDSR. Unfilled grains were more in MTDSR than rest of the tillage options. Total numbers of grains followed the same pattern as filled grains except ZTDSR and CTTPR, which were similar to each other. 1000-grain weight was more in PBDSR than STDSR and other tillage options were at par.

Table 7.3.2.9 Effect of different tillage/crop establishment on rice growth, yield and yield parameters during 2009-13 at RWRC, BARI, Rajshahi

Tillage	Pl ht (cm)	Number (m^{-2})		Grains $panicle^{-1}$			1000 GW (g)
		Tiller	Panicle	Filled	Unfilled	Total grain	
MTDSR	96bcd	259	240a	180a	30.00b	210a	17.23ab
PBDSR	98ab	231	197c	153c	23.07b	176c	17.87a
STDSR	95cd	240	217bc	162b	28.53b	190b	16.89b
ZTDSR	98abc	664	229ab	143d	25.13b	168d	17.37ab
CTTPR	99a	223	206c	137e	31.07b	168d	17.40ab
FBDSR	92d	241	218bc	128f	28.87b	157e	17.31ab
ANOVA				Probability			
Year	0.001	0.251	0.001	0.001	0.001	0.001	0.038
Rep	0.708	0.387	0.325	0.034	0.230	0.039	0.220
Tillage	0.004	0.426	0.006	0.001	0.001	0.001	0.190
Yr*Till	0.012	0.405	0.001	0.001	0.001	0.001	0.921

Yield parameters were analyzed for year, tillage and year*tillage effects. All ANOVA effects including year, treatment and year*tillage had significant effects but replication was not significant (Table 7.3.2.10). The highest straw yield was in MTDSR followed by CTTTPR among all the tillage options. MTDSR produced higher yield among the tillage options except CTTPR. CTTPR produced more rice yield than PBDSR, STDSR and ZDDSR but at par with FBDSR. The lowest rice yield was in ZTDSR but at par with PBDSR among all the tillage options. Similar biomass was produced by MTDSR and CTTPR and was significantly higher than rest of the tillage options. STDSR and FBDSR produced similar biomass but higher than ZTDSR. ZTDSR produced lower biomass than other tillage options but at par with PBDSR. HI was lowest in ZTDSR among all the tillage options. Except ZTDSR all other tillage options had similar HI.

Table 7.3.2.10 Rice yield under different tillage options/crop establishment during 2009-13

Tillage	Yield (t ha^{-1})			HI
	Straw	Grain	Biomass	
MTDSR	4.59a	3.69a	8.28a	0.45a
PBDSR	4.14b	3.13cd	7.28bc	0.44a
STDSR	4.20b	3.19c	7.39b	0.44a
ZTDSR	4.11b	2.87d	6.98c	0.42b
CTTPR	4.71a	3.5ab	8.28a	0.44a
FBDSR	4.16b	3.34bc	7.50b	0.45a
ANOVA			Probability	
Year	0.001	0.001	0.001	0.001
Rep	0.248	0.148	0.492	0.016
Tillage	0.001	0.001	0.001	0.006
Yr*Till	0.001	0.002	0.001	0.037

7.3.2.6 Study on tillage options in R-M-MB system in Comilla

The experiment at BARI, Comilla, began in 2009 with mungbean as the first crop under the R-M-MB system. Across the tillage options, the rice straw yield ranged from 5.56-6.15 t ha^{-1} and rice grain yield ranged 5.22-5.49 t ha^{-1}. Only biomass showed the significant differences with more biomass production in CT than FBDSR but at par with MTDSR (Table 7.3.2.11)

Table 7.3.2.11 Effect of different tillage option on *aman* rice in R-M-MB system during 2010-2013 at BARI, Comilla

Tillage options	Yield (t ha^{-1})			HI
	Straw	Grain	Biomass	
BDSR	5.56	5.22	10.48b	0.50
CTTPR	5.92	5.40	11.82a	0.46
MTDSR	6.15	5.49	11.45ab	0.48
ANOVA			Probability	
Year	0.050	0.001	0.001	0.362
Rep	0.138	0.416	0.289	0.032
Treatment	0.545	0.454	0.057	0.179
Yr*Trt	0.086	0.181	0.251	0.298

Stover and biomass yields of maize did not show any significant differences between the tillage options (Table 7.3.2.12). Grain yield was higher in BP and MP than CT. HI was also more more in MT than CT but at par with BP. Year showed significant effect but year* tillage was non-significant.

Table 7.3.2.12 Effect of different tillage options on *rabi* maize in R-M-MB system during 2010-13 at BARI station, Comilla

Tillage options	Yield (t ha^{-1})			HI
	Stover	Grain	Biomass	
BP	7.61	8.17a	17.08	0.48ab
CT	7.53	7.64b	16.42	0.46b

MT	6.89	8.03ab	16.15	0.50a
ANOVA		Probability		
Year	0.002	0.001	0.017	0.001
Rep	0.876	0.706	0.969	0.759
Treatment	0.205	0.117	0.350	0.022
Yr*Trt	0.679	0.180	0.738	0.154

Mungbean yields depict that year and year*treatment had significant effects for all parameters except the year*treatment for HI (Table 7.3.2.13). There was no difference in stover yield between tillage methods. The grain yield was significantly higher in BP than CT and MT. Biomass production was significantly lower in CT than the other two tillage methods. Similar pattern was followed for HI.

Table 7.3.2.13 Effect of different tillage option on mungbean in R-M-MB system during 2010-2013 at BARI, Comilla

Tillage options	Yield (t ha^{-1})			HI
	Stover	Grain	Biomass	
BP	0.93	1.12a	2.04a	0.54a
CT	0.88	0.82b	1.70b	0.48b
MT	0.93	1.11b	2.04a	0.54a
ANOVA		Probability		
Year	0.00	0.00	0.00	0.01
Rep	0.00	0.01	0.00	0.00
Treatment	0.78	0.00	0.00	0.03
Yr*Trt	0.061	0.001	0.002	0.554

Table 7.3.2.14 shows the rice equivalent yield for all three crops and for system. As stated above, rice grain yield had no differences among the tillage options. Maize rice equivalent yield also followed the same response as rice yield. Mungbean rice equivalent yield showed significant difference between tillage options with higher yield for BP than CT but at par with MT. There was no difference on rice equivalent system yield and ranged from 18.25-19.27 t ha^{-1}.

Table 7.3.2.14 Effect of different tillage options on rice equivalent yield of R-M-MB system during 2010-2013 at BARI, Comilla

Tillage options	Rice equivalent yield (t ha^{-1})			
	Rice	Maize	Mungbean	System
BP	5.22	9.94	4.11a	19.27
CT	5.40	9.84	3.01b	18.25
MT	5.49	9.00	4.08a	18.57
ANOVA		Probability		
Year	0.001	0.002	0.001	0.001
Rep	0.883	0.878	0.012	0.766
Treatment	0.694	0.218	0.001	0.318
Yr*Trt	0.179	0.677	0.004	0.288

7.3.2.7 Study on improved tillage options in R-P-M system:

Rice-potao-maize system based on-station experiment was conducted at BARI, Comilla from 2010- 2013. *Aman* rice data were analysed for year, tillage, year*tillage effects. Year showed the significant differences but tillage, replication and year*tillage did not show any differences (Table 7.3.2.15). All parameters were found similar for different tillage options. Grain yield of rice ranged from 5.12 to 5.24 t ha^{-1} across the tillage options.

Table 7.3.2.15 Effect of different tillage options on *aman* rice performance in R-P-M system during 2010-2013 at BARI, Comilla

Tillage options	Pl ht (cm)	Tillers (m^{-2})		Panicle length (cm)	Grains panicle^{-1}			1000 Gr wt. (g)	Yield (t ha^{-1})			HI
		Total	Unproductive		Filled	Unfilled	Total		Straw	Grain	Biomass	
BDSR	108	351	36	24.91	165	32	196	19.25	5.11	5.21	10.32	0.50
CTTPR	109	341	33	25.07	159	27	186	19.43	5.24	5.24	10.48	0.50
MTDSR	109	379	41	25.33	150	37	187	19.13	5.35	5.12	10.47	0.49
ANOVA	Probability											
Year	0.01	0.01	0.01	0.02	0.01	0.01	0.07	0.01	0.01	0.01	0.01	0.01
Rep	0.10	0.34	0.17	0.43	0.41	0.62	0.63	0.14	0.52	0.50	0.98	0.26
Treatment	0.34	0.15	0.38	0.53	0.06	0.06	0.25	0.87	0.47	0.84	0.84	0.65
Yr*Trt	0.90	0.74	0.08	0.97	0.27	0.04	0.21	0.14	0.19	0.08	0.18	0.06

For *kharif*-1 maize, year had significant differences but replication and tillage had non-significant effects except stover and biomass (Table 7.3.2.16). CT produced more stover yield than BP but similarly with MT, and similar pattern was observed for biomass production too.

Table 7.3.2.16: Effect of different tillage options on *Kharif*-1 maize in R-P-M system during 2010-13 at BARI station, Comilla

Tillage options	Pl. ht. (cm)	cobs plant -1	Grains cob-1	250 - GW (g)	Cob grith (cm)	Cob length (cm)	Yield (t ha^{-1})			HI
							Stover	Grain	Biomass	
BP	182	0.95	406	101	15.14	17.91	6.48b	7.01	15.45b	0.45
CT	175	0.95	402	102	15.30	18.26	7.51a	7.42	16.88a	0.43
MT	180	0.95	407	100	15.25	18.16	7.51a	7.46	16.94a	0.44
ANOVA	Probability									
Year	0.01	0.01	0.02	0.00	0.01	0.09	0.23	0.01	0.01	0.01
Rep	0.88	0.20	0.41	0.56	0.97	0.35	0.48	0.13	0.29	0.35
Treatment	0.36	0.66	0.96	0.53	0.82	0.79	0.02	0.25	0.02	0.26
Yr*Trt	0.25	0.01	0.73	0.44	0.94	0.53	0.79	0.13	0.44	0.32

Figure 7.3.2.3 represents the potato tuber yield. MT produced higher potato yield than CT but similar to BP. The rice equivalent yield for *kharif*-1 maize and potato and system is presented in Table 7.3.2.17 For potato rice equivalent yield, MT produced higher yield than CT but at par with BP. There were no significant differences in maize rice equivalent yield between the tillage options. For system rice equivalent yield, the maximum yield was with MT than BP and CT. R-P-M

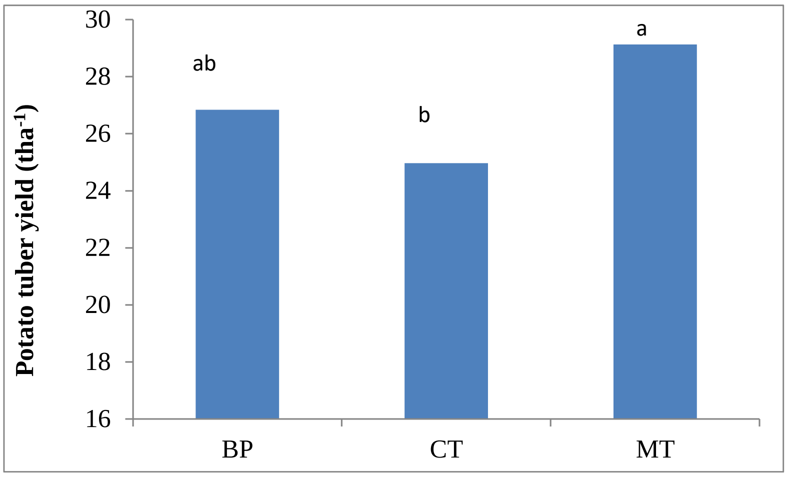


Figure 7.3.2.3 Potato tuber yield under different tillage options during 2010-13

Table 7.3.2.17 Rice equivalent yield for R-P-M system

Tillage	Rice equivalent yield (t ha^{-1})			
	Rice	Potato	Maize	System
BP	5.54	14.49ab	7.01	27.04b
CT	5.56	13.48b	7.42	26.46b
MT	5.48	15.73a	7.46	28.67a
ANOVA	Probability			
Year	0.001	0.006	0.001	0.001
Rep	0.748	0.012	0.623	0.014
Treatment	0.955	0.016	0.311	0.012
Yr*Trt	0.092	0.093	0.194	0.021

7.3.2.8 Evaluation of conservation tillage and weed management options on production potential and weed incidences for dry seeded rice:

The tillage, weed management and tillage x weed management interactions showed significant effect on yield components across the years (Table 7.3.2 18 and 19).

Number of panicles: The number of panicles m^{-2} was registered maximum in ST and minimum in FB in both years where ther were identical in FB and PB. Irrespective of tillage options, W_1 recorded significantly highest and W_5 the lowest number of panicles m^{-2} in both years. In 2010, W_2, W_3, and W_4 responded similarly. The interaction effect showed highest number of panicle m^{-2} for ST with W_1, which was statistically similar to all other weed free and post-emergence + 1 HW plots in both the years. Weedy (control) plots had the comparatively lower numbers of panicle m^{-2} over the years.

Table 7.3.2.18: Yield components of *aman* rice as affected by tillage and weed management options, 2010

	ZT	ST	MT	PB	FB	CT	Mean
			Panicles m^{-2} (no.)				
W_1	252	260	249	241	239	252	249
W_2	236	232	226	205	206	248	226

W_3	236	243	235	209	216	228	228
W_4	218	226	214	223	216	227	221
W_5	194	195	208	187	180	196	193
Mean	227	231	226	213	211	230	
LSD (0.05)	T = 10.9	W = 12.4	T x W = 30.3				
			Panicle length (cm)				
W_1	24.3	23.6	23.4	25.0	24.5	24.0	24.1
W_2	23.6	24.0	23.3	23.7	25.1	24.0	24.0
W_3	23.8	23.4	23.6	24.1	25.3	23.9	24.1
W_4	23.5	22.6	23.5	24.2	23.4	23.6	23.5
W_5	21.8	21.9	22.9	24.1	24.3	21.4	22.7
Mean	23.4	23.1	23.3	24.2	24.5	**23.4**	
LSD(0.05)	T = 0.93	W = 0.70	T x W = 1.73				
			Grains panicle^{-1} (No.)				
W_1	124	127	117	137	140	131	129
W_2	124	125	119	141	146	135	131
W_3	115	117	113	148	148	135	129
W_4	125	123	120	139	142	128	130
W_5	116	114	120	116	123	119	118
Mean	121	121	118	136	140	129	
LSD (0.05)	T = 11.7	W = 7.0	T x W = 14.2				

Panicle length: An inverse relation was observed between the number of panicles m^{-2} and the panicle length (Table 7.3.2.18 and 19). The longer panicles were obtained in FB followed by PB whereas the shorter panicles were obtained in ZT and MT, respectively in both years. The panicle length was similar in W_1, W_2, and W_3 and was significantly superior to control (W_5). The tillage and weed management showed positive interaction, with the longer panicles in FB with W_3 and shorter in CT with W_5 in both the years. The results also revealed that the weedy plots had shorter panicles compared with other plots across the years.

Table 7.3.2.19: Yield components of *Aman* rice as affected by tillage and weed management options, 2011

	ZT	ST	MT	PB	FB	CT	Mean
			Panicles m^{-2} (No.)				
W_1	246	271	264	237	226	257	250
W_2	260	254	244	244	204	258	244
W_3	254	267	246	230	244	223	244
W_4	241	238	222	237	244	251	239
W_5	194	214	204	193	174	220	200
Mean	239	249	236	228	218	242	
LSD (0.0%)	T = 18.0	W = 16.7	T x W = 28.1				
			Panicle length (cm)				
W_1	24.3	23.6	23.4	24.6	24.2	23.9	24.0
W_2	23.7	24.2	23.6	23.2	25.1	24.0	23.9
W_3	23.8	23.4	23.3	23.8	25.3	23.8	23.9
W_4	23.5	22.6	23.5	24.2	23.4	23.5	23.4
W_5	21.4	22.3	22.1	24.0	23.8	21.5	22.5
Mean	23.3	23.2	23.2	24.0	24.3	23.3	
LSD (0.05)	T = 1.11	W = 0.73	T x W = 1.50				
			Grains panicle^{-1} (No.)				
W_1	143	152	120	147	159	156	146
W_2	131	140	137	141	161	141	142
W_3	113	127	120	152	157	143	135

W_4	124	130	110	154	149	135	134
W_5	121	123	130	132	136	121	128
Mean	127	134	124	145	153	139	
LSD (0.05)	T = 23.3	W = 10.7	T x W = 31.0				

Grains panicle^{-1}: As for panicle length, higher numbers of filled grains panicle^{-1} were recorded in FB followed by PB in both the years (Table 7.3.2.18 and 19). MT resulted in lower numbers of filled grains panicle^{-1} over the years. Irrespective of tillage options, maximum numbers of filled grains panicle^{-1} were found in W_2 and W_1, respectively in both years. The lowest numbers of panicles m^{-2} were obtained in W_5 which were statistically different from rest of the treatments. The numbers of filled grains panicle^{-1} remained unchanged in weed free and herbicide applied plots. The results also indicated that the raised bed plots (either fresh or permanent bed) resulted in comparatively higher numbers of filled grains panicle^{-1} in both the years.

Grain and straw yield: The grain yield of rice was little affected by the tillage options in both years (Table 7.3.2.20). CT and MT respectively, recorded the highest and the lowest grain yield in both years, but CT, FB and PB and ZT were significantly similar in first year and CT, ZT, FB and PB were similar in the succeeding year. Grain yield of rice was highest in W_1 and was closely followed by W_2 while the significantly lower grain yield was recorded in W_5. Among herbicide applied treatments, grain yield was significantly higher in W_2 than W_3, indicating that a post-emergence herbicide supplemented with one hand weeding is necessary to obtain high yield. The interactions indicated that all the weed free and post-emergence + 1 hand weeding plots showed similar effects on grain yield of rice. The tillage options did not have any significant effect on straw yield of rice in the first year but it had slight effect in the succeeding year (Table 7.3.2.20). Weed management options, however, produced significant influence on straw yield of rice in both years. Straw yield responded similarly to grain yield. The interactions results revealed that the highest straw yield was achieved in ST with W_1 and ST with W_3, respectively during 2010 and 2011. The interactions also indicated that the all weedy plots had comparable straw yield and had significantly less compared with other treatments across the years.

Table 7.3.2.20: Grain and straw yield of *Aman* rice as affected by tillage and weed management options, 2010 and 2011

	ZT	ST	MT	PB	FB	CT	Mean
				2010			
				Grain yield (t ha^{-1})			
W_1	4.56	4.54	4.04	4.89	4.89	4.99	4.65
W_2	4.47	4.50	4.34	4.76	4.75	4.71	4.59
W_3	4.21	3.88	3.81	4.61	4.54	4.46	4.25
W_4	3.81	3.71	3.12	4.16	4.17	4.12	3.85
W_5	2.72	2.85	3.33	2.69	2.70	3.13	2.90
Mean	3.95	3.89	3.73	4.22	4.21	4.28	
LSD (0.05)	T = 0.37	W = 0.59	T x W = 0.73				
				Straw yield (t ha^{-1})			
W_1	6.28	6.86	6.23	6.21	6.46	6.01	6.34
W_2	6.47	5.78	5.80	6.30	5.81	6.34	6.08
W_3	4.80	5.04	5.06	5.74	6.56	6.11	5.55
W_4	5.69	5.10	5.14	6.00	5.66	5.48	5.51
W_5	4.30	4.41	5.46	4.46	4.65	5.14	4.74
Mean	5.51	5.44	5.54	5.74	5.83	5.82	
LSD (0.05)	T = 0.31	W = 0.56	T x W = 1.33				
				2011			
				Grain yield (t ha^{-1})			
W_1	4.99	4.87	3.85	5.11	5.01	5.12	4.82
W_2	4.50	4.64	4.54	4.87	5.01	5.00	4.76

W_3	3.79	4.11	4.04	4.49	4.44	4.35	4.20
W_4	3.40	3.55	3.76	4.37	4.07	4.27	3.90
W_5	2.95	3.08	2.36	2.82	2.36	3.13	2.78
Mean	3.93	4.05	3.71	4.33	4.18	4.37	
LSD (0.05)	T = 0.39	W = 0.60	T x W = 0.81				
			Straw yield (t ha^{-1})				
W_1	6.84	6.74	5.86	6.25	6.13	6.63	6.41
W_2	6.10	6.08	6.22	6.48	6.13	5.99	6.17
W_3	6.00	6.92	5.50	6.60	6.89	6.55	6.41
W_4	5.64	5.68	6.08	6.75	5.66	5.80	5.94
W_5	5.34	4.80	4.45	5.27	5.07	5.48	5.07
Mean	5.99	6.04	5.62	6.27	5.98	6.09	
LSD (0.05)	T = 0.34	W = 0.47	T x W = 1.22				

7.4 Objective 4: To build capacity and disseminate key management options for R-M systems through public-private sector partnerships.

7.4.1 Build approval and consensus across stakeholders through a technical working group for adapting, testing, and disseminating key BMPs for R-M systems.

The R-M project formed the Technical Working Groups (TEGs) in the three districts at the beginning of the project but these groups were not found quite active due to frequent changes in management positions. The project organized annual meetings and a mid-term review meeting with core partners and different stakeholders from public and private sector for reviewing the project progress. In addition to that, project management also organized meetings with, and visits to farmers' fields for, high level policy makers, research managers, private sector and NOGs persons. R-M project strongly believes that the R-M and R-P-M systems are expanding rapidly in the project districts with catalytic role of the project. Several on-farm research activities conducted under the project helped us convince the policy makers, researchers and extension organizations for promoting mechanization and low input cost requiring CA-based technologies. The project generated information on SSNM through web-based decision support tools such as Nutrient Manager for rice and maize. Rice Crop Manager has been endorsed by BRRI and has been taken up by the DAE for scaling-out in farmers' fields. CA-based crop management programme on the national level has been initiated by BARI for further research and outreach in farmers' fields.

Dr. Wais Kabir, ED, BARC interacting with farmers and project team members at Rajshahi

7.4.2 Conduct orientation training and demonstrations for researchers and extension workers from within the project:

The project organized several short- and long-term trainings for national researchers and project staff at national, regional and international levels. The main foci of the trainings were: CA-based crop management practices, SSNM through decision support tools, data management and statistical software handling, use of sprayers and spraying techniques for herbicide applications, hands-on training on 2-wheel tractor operated machineries, etc. One international travelling seminar to Nepal was organized for 9 R-M project personnel to provide exposure to Nepal agriculture. Two project scientists were sent for an international level advanced CA-course in India organized by CIMMYT and Punjab Agriculture University (PAU), Ludhiana. Regional courses on-capacity building on CA-based crop management in Bangladesh were also held for national researchers from BARI, BRRI, RDRS, BARD, IDE and CIMMYT researchers. In total, 31 trainings were conducted during the project period with 789 researchers, extension officers, private sector persons, advanced farmers, trained (Table 7.4.1). The innovative project farmers and service providers and scientists were sent for participation in regional consultancy on improving wheat productivity in Asia, organized by APAARI-CIMMYT and FAO in Thailand and in the regional dialogue on CA in New Delhi. Project scientists were always encouraged for presenting the project outcomes at national and international workshops, conferences and meetings. One project staff has been awarded for higher studies in Australia through John Wright fellowship.

Table 7.4.1. Details of training, meetings and communication activiites.

Serial no.	Date	Name of the activities	Organizer	Location	No. of Participants
1	21-23 April 2009	Hands on training on CA	CIMMYT, IRRI and BARI	RWRC, Rajshahi	18
2	14-15 June 2009	Training on 2-wheel tractor operated farm machineries for sowing and establishment of rice, wheat and maize	CIMMYT, IRRI and BARI	Farm Machinery and Post Harvest Division, BARI, Gazipur	16
3	04- 08 October 2009	Travelling workshop	CIMMYT and IRRI	Rangpur, Rajshahi and Comilla	14
4	25-26 October 2009	First annual review 2008-09	CIMMYT and IRRI	BRRI conference room, Gazipur	50
5	1-3 January 2010	Training on basic statistics and data analysis using CROPSTAT software	IRRI and CIMMYT	BRRI training room, Gazipur	14
6	03-08 April 2010	Travelling workshop	CIMMYT and IRRI	Rangpur, Rajshahi and Comilla	15
7	28-29 April 2010	Hands on CA machineries and CA based crop management	CIMMYT, IRRI and BARI	BARI, Comilla	60
8	4-5 May 2010	Training on machineries operations and maintenance and dry seeded rice (DSR)	CIMMYT, IRRI and BARI	WRC, Dinajpur	35

9	3-4 October 2010	Second annual review and planning meetings	IRRI and CIMMYT	BRAC center, Dhaka	100
10	3-5 January 2011	Training course on statistical analysis of field experiment data using CROPSTAT	IRRI and CIMMYT	BRRI, Gazipur	15
11	20-24 March 2011	Travelling seminar Bangladesh-Nepal: exchange of rice-maize expertise	IRRI and CIMMYT	R-M and CSISA project site in Nepal and Bangladesh	12
12	3-6 April 2011	FGD and field level survey workshop on adoption of R-M systems	IRRI and CIMMYT	Gangachara, Rangpur	22
13	7-10 April 2011	FGD and field level survey workshop on adoption of R-M systems	IRRI and CIMMYT	Mithapukur, Rangpur	18
14	20-24 March 2011	Traveling seminar 2011	IRRI and CIMMYT	Rangpur, Rajshahi and Comilla	20
15	17 April 2011	Workshop on data collection and management	IRRI and CIMMYT	WRC, Rajshahi	15
16	11-13 June 2011	Workshop on data collection and management and analysis	IRRI and CIMMYT	IRRI-CIMMYT Office, Dhaka	15
17	16-18 October 2011	CA based machinery training	IRRI and CIMMYT	RWRC, Rajshahi	25
18	26-27 February 2012	Data management & protocols of “ Nutrient Omission Plot” trials conducted jointly by R-M and CISSA project”	CIMMYT	IRRI-CIMMYT Office, Dhaka	12
19	11-15 June 2012	Capacity building course on CA-based crop management in Bangladesh	WRC and CIMMYT	WRC, Rajshahi	24
20	26 May-12 June 2012	Advanced course on CA-based crop management in South Asia 2012	CIMMYT and PAU, India	PAU, India	2
21	27-30 September 2012	R-M project midterm review meeting	CIMMYT	Rajshahi	55
22	16 October 2012	Orientation Programme to Nutrient Manager (NM) for Rice	CIMMYT and IRRI	Dhaka	20
23	4-5 November 12	Training for Nutrient Expert (NE) and Preliminary Nutrient Decision Tools (PNDT) computer software for	CIMMYT	Dhaka	26

		fertilizer management of Hybrid Maize			
24	12 November 2012	Discussion of activities on BRRI Rangpur on R-M project	BRRI, Rangpur	Rangpur	8
25	19-20 December 2012	FGD and field level survey workshop on adoption of R-M systems	RDRS	Gangachara, Rangpur	30
26	23-24 December 2012	FGD and field level survey workshop on adoption of R-M systems	RDRS	Mithapukur, Rangpur	33
27	26-27 February 13	Training on Data Management and Protocols for Nutrient Omission Plot Trials for *Rabi* maize	CIMMYT	Dhaka	7
28	17 May 2013	Farmers motivational training	RDRS	Mithapukur, Rangpur	33
29	02 August 2013	Farmer motivational meeting	BRRI and BARI	Daudkandi, Comilla	26
30	09 September 2013	Farmer motivational meeting	BRRI and BARI	Daudkandi, Comilla	31
31	09 December 2013	Farmer motivational meeting	BRRI and BARI	Barura, Comilla	18
Total beneficiaries					789

7.4.3 Conduct training of trainers (TOT) for high- to mid-level extension workers from public and private sector, and NGOs:

Similarly, a number of trainings were organized for extension officers, input-dealers, manufactures and service providers at three project sites during the project duration. These trainings were organized by R-M project representatives from BARI, BRRI, BARD and RDRS locally but we also organized trainings at the national level (Table 7.4.1 and 7.4.2).

7.4.4 Conduct training for grass-roots-level extension workers and farmers, and on-farm demonstrations within and outside the focus districts through grass-roots-level GOs and NGOs:

Farmers, service providers, and local manufacturers were trained through local level trainings organized by the project staff locally before each crop season. Farmers from outside of the project villages also participated in many training programs and field days. Travelling seminars and farmer to farmer exchange visits were conducted for farmers and different stakeholders including manufacturers, input dealers and service providers as knowledge

exchange was the main focus of the project. At least 1 travelling seminar was organized in each season in which knowledge was exchanged between farmers in different districts and allowed cross learnings from each other. The field days were organized in each season in each site for the different stakeholders including extension officers, input dealers, service providers, and farmers from different villages and communities. In total, 59, travelling seminars and exchange visits, field days, and farmers' group discussions were organized by providing direct benefit to 3546 farmers, service providers, and input dealers, etc. (Table 7.4.2).

Table 7.4.2 Field days and farmer exchange visits

List of Activities	BARI		BRRI		BARD		RDRS		Total	
	No.	Participants	No.	Participants	No.	Participants	No.	Participants	No.	Participants
Farmers' field day	6	675	3	150	5	475	11	1435	25	**2735**
Exchange visits	9	199	2	140	7	170	16	302	34	**811**
Total	**15**	**874**	**5**	**290**	**12**	**645**	**27**	**1737**	**59**	**3546**

In addition to these activities, many on-farm field demonstrations were conducted for service providers and project field staff involving the local extension officers and input-dealers within and outside of the project domains (Table 7.4.3).

Table 7.4.3 Technology extension through demonstration plots conducted by farmers in *rabi* and *kharif*-1 maize

Partner/site	Bed planting		Strip/reduced/zero tillage		Total	
	No. farmers	Area (decimal)	No. farmers	Area (decimal)	No. farmers	Area (decimal)
BARD, Comilla	19	434	12	162	31	596
BRRI/BARI, Comilla	4	77	46	1246	50	1323
WRC, BARI, Rajshahi	129	4021	23	789	152	4810
BRRI, Rajshahi	6	365	12	160	18	525
RDRS, Rangpur	41	607	12	135	53	742
Total	199	5504	105	2492	304	7996

1 ha=250 decmals

Simultaneously field demonstrations for rice were also conducted by the innovative farmers and more than 100 farmers conducted such demonstrations on direct seeded rice and un-puddled transplanted rice.

Project field staffs prescribed Crop Manager based SSNM recommendations for *boro* rice, *aman* rice and *rabi* and kharif maize to more than 2000 farmers, and this information can be accessed through IRRI web.

7.4.5 Disseminate new scientific knowledge and promising technologies to different stakeholders and farmers through farmers' fairs and field days, local communication means, printed and electronic media and Cereals Knowledge Bank, and other web site publications, etc.:

The project heavily emphasized on the technology dissemination by using many tools including field days, field demonstrations, local communication through extension department, local service provides, input dealers and innovative farmers. Project success stories were well captured by print and electronic media at local and national level. In addition, CIMMYT and IRRI web sites and weekly bulletins covered the project success, and technological benefits, technical interventions at farmers' fields etc.

Farmers' field days:

Farmers learn more through their peers and farmer to farmer interaction by sharing their experiences with each other. More than 25 field days were organized during the project period in all 6 *Upazillas* though the core partners in which at least 100 farmers in each village attended those field days. In those field days, all local stakeholders including extension agencies, manufacturers, local service providers, input dealers, policy persons at local level, neighbouring farmers (male and female) attended. The field days were organized at the the adaptive research trials and demonstration plots sites in each season when crops were either at planting time or at flowering stage of the crops. More field days were emphasized in *rabi* crops than summer crops. In field days farmers shared their experiences with each other but they also provided their feelings, experiences, and feedback about the technology to the scientists, extension officers, manufacturers and input dealers for further improvement of the technology. The details of the field days are summarized in table 7.4.2.

Exchange field visits:

Most efficient way for technology dissemination is multi-stakeholders' exchange visits in farmers' fields from one geographical area to another because it is not necessary that a technology which is successful in its domain area will be successful in the domain areas of other technology and vice versa. During exchange visits, farmers, service providers and input dealers shareed their experiences and tried to realize the mistakes and problems for the success or failure of a technology. We faced such experience during the first 2 years, that more technology acceptance was in Rajshahi than Rangpur and Comilla, but later exchange visits were very helpful to convince Rangpur and Comilla farmers to use new technology even for the replacement of *boro* rice by *rabi* and *kharif-1* maize. Initially farmers were not ready to accept such idea and the idea such as mechanical planting of maize and rice. However, later on after seeing by their eyes and by sharing their experiences with those who were confident about the technologies they were convinced and adopted the new technologies. In total, more than 34 exchange visits were organized in the three districts. In each exchange visit, 20-25 participants visited and stayed for 3-4 days in the communities and interacted with each other.

Print media:

The project activities were covered and highlighted well by printing media through local and national newspapers in Bangla and English. The many success stories, technological benefits, including relatative benefits from rice-maize over rice-rice systems were well highlighted. Mechanization of 2-wheel tractor operated machineries especially strip-tillage, bed planting, zero tillage, were also highlighted.

Leaflets:

In the final year, we produced three leaflets on "Conservation agriculture based crop management practices and benefits", Strip tillage crop establishment techniques", and "Bed planting techniques and methods". All leaflets were produced in in Bangla so farmers could understand and read easily. Fifteen thousand copies of each leaflet were printed through the project and distributed to the farmers through project network, DAE, BARC, BARI, BRRI, BARD and RDRS. The contents of the leaflets were appreciated by different stakeholders including farmers.

Posters:

We also produced one poster on “Hybrid maize with leafy vegetables intercrops technologies” in Bangla using pictorial materials. Three thousand copies of the poster were produced and distributed to the farmers. We are glad to see the posters being used by farmers and input dealers at their shops and house walls.

Bulletins:

Rice-maize project produced “Sustainable crop intensification through conservation agricultural techniques” in Bangla by RDRS and distributed to extension officers, innovative farmers and input dealers and also has been displaying at RDRS publication display board. CIMMYT produced one small pocket bulletin on “Guidelines for hybrid maize production technology” and distributed to the farmers.

Book:

A very high quality design book for two wheel tractor machineries “Made in Bangladesh: Scale-Appropriate Machinery for Agricultural Resources Conservation” has been published. This is a combined outcome of R-M, CSISA-MI, CSISA-BD and ANEP projects. This book will be asset for manufacturers, engineers and scientists. Initially three hundred copies were printed but it can be accessed through CIMMYT web.

Electronic media:

R-M and CSISA-BD projects jointly produced 30,000 copies of very high quality DVDs “Save More Grow More” based on the CA-based technologies generated and tested under these two projects. These DVDs were shown across Bangladesh through a LCD projector and were distributed to the farmers. In addition, project successes and highlights were also covered by local TV channels and broadcasted in Krishi Darshan Program.

8 Impacts

The project has made great efforts by bridging together farmers, researchers, extension agencies, manufacturers, input dealers, policy makers and private sector at different levels through farmers' participatory on-farm research trials. Besides on-farm trials, projects also focused on basic strategic research at research stations with the help of core partners. The project efforts were well recognized by the faming communities, and public and private sector agencies including policy makers. Thus the primary impacts at this stage are in terms of science and development and impacts on the researchers, small holder farmers, and extension systems at local and national levels.

8.1 Scientific impacts – now and in 5 years

Rice-maize production system is relatively a new system in Bangladesh and is still emerging in many places in the country. Therefore only a little information is available for this production system. There is also a need to optimize the production practices for maize because this is a newly introduced crop in Bangladesh. Scientists need to generate the information on sowing time, plant population, agronomic management, SSNM, irrigation and weed management, etc. In addition to that, farmers need more information for further intensifying and optimizing the system to reap more from the system. Besides these, so far, little efforts have been made on developing and evaluating CA-based crop management practices on production-M system in Bangladesh as well as in the region.

In this project, big efforts were made for conducting on-farm participatory research trials in farmers' fields with direct and joint involvement of researchers and farmers. Approximately 200 on-farm trials on CA based crop production ttechnologies were conducted in R-M-MB, R-M-R and R-P-M systems. Detailed information were collected on soil, crops and partial economics in standard data formats. A large data base is ready for publications in the near future and these data sets will be useful for other researchers for different purposes, including simulation modelling.

Site specific nutrient management through decision support tool for rice and maize in R-M systems were well taken. Large number (>500) of on-farm research trials were conducted in *boro* and *aman* rice and in *rabi* and *kharif*-1 maize through nutrient omission and sufficiency plots for determining the nutrient supplying capacity of soils across Bangladesh. The soil and plant information were used for evaluating the Nutrient/Crop Manager for rice and maize in Bangladesh. The Rice Crop Manager has already been endorsed by BRRI and is now available for the scientific communities. The Maize Crop Manager is in advanced stage of development and is expected to be available very soon.

Great efforts were made to identify the abiotic stress tolerant maize genotypes for further advanced breeding especially for early and late water logged resistant hybrids and high yield composites. Information generated from this activity provided an opportunity for advanced breeding for developing waterlogging tolerant maize hybrids.

The project partner scientists conducted on-station experiments on system optimization, weed management techniques and optimization of residues for CA based management, tfor the R-M systems. These on-station experiments provided further confidence to the scientific communities in Bangladesh.

All the above on-farm and on-station experiments provide information and data and the potential platforms and directions for Bangladeshi researchers for conducting the current and future research. These data and information can be used for simulation studies, future planning for national programmes, opportunities for new funding, and also for donor communities.

The project staff and the national partners published several papers either jointly or in collaboration with other scientists in Bangladesh and in the region and also presented the research findings in various national and international workshops, meetings and conferences (see below under "Publications" section for details). Some papers are under preparation for publication. This is the biggest scientific impact of the project.

8.2 Capacity impacts – now and in 5 years

The project made several efforts for capacity building of different stakeholders including famer communities, local service providers, extension agents, and researchers in local and national levels. The large numbers of on-farm participatory trials were conducted in farmers' fields. Through these trials farmers directly interacted with researchers for better understanding about the new technologies. The direct interaction between farmers and scientists through the participatory research trials built trust and relationship between farmers and researchers.Through this project, farmers believed that crops can be grown without tillage and that they developed hands-on skills on using the new planting machineries operated by 2-wheel tractor. These participatory farmers are now champions on the CA-based crop management practices within the communities and now they are advocating for use of such practices to the neighbour farmers. Likewise, several on-farm trials on SSNM through decision support tool were conducted in several farmers' fields with direct involvement of farmers. Through the omission and sufficiency plot trials, farmers closely observed the deficiency symptoms of the nutrients and yield losses due to deficiency of individual nutrients in rice and maize and now they realized the importance of each nutrient. After seeing the K deficiency and the results from these trials, farmers started apply K fertilizers especially in Comilla. The farmers also realized the importance of SSNM through validation trials that the SSNM fertilizer application is better than the blanket recommendations.

The project conducted many hands-on training programs on-CA machineries operations for service providers in the communities. The service providers are now active in the project sites as well as outside of the project domains and now more service providers are coming forward for providing mechanized services to the farmers. The local manufacturers were also directly involved in the project and they received the advanced training on designing and manufacturing within and outside Bangladesh. The local manufacturers are now capable of producing the 2-wheel tractor operated planters and other machineries commercially. Besides that, local input dealers enriched their knowledge about herbicides, sprayers and spray techniques for weed management. By closely observing the on-farm trials the local extension agents/officers also enriched their awareness about the new technologies. Through the project efforts, now the Crop Manager for Rice has already been endorsed by DAE for large scale out scaling through BRRI.

A number of young scientists/researchers were involved in this project that needed advanced training and mentoring for their confidence building in scientific communities. By using the expertise from the project and also outsourcing as required, experts from national and international centes conducted several scientific training courses especially on CA-based crop management practices including small machineries, weed management and spray techniques, SSNM through decision support tools, data management and statistical software tools for data analysis, designing and developing implementation protocols for on-farm and on-station research trials. These trainings helped develop capacity building of young scientists of the partner organizations.

A number of scientists from BRRI and BARI participated in advanced courses in at IRRI and CIMMYT headquarters. Through this project two scientists from BARI and RDRS participated in an international advanced course on conservation agriculture organized by

CIMMYT-PAU in Ludhiana during 2012. Both scientists are now assets for their organizations for further capacity building in the areas of CA-based crop management practices.

The project also provided the platform for the project scientists to present project findings in the national and international fora including world congress on CA, international agronomy congress etc. Through these events scientists got exposure at international levels which will help boost their confidence in science.

R-M project also provided a platform for higher studies (Ph.D.) to two project scientists who are now doing Ph.D. on SSNM and CA-based practices in R-M systems. These scientists will be the potential assets in their field for advancing the capability of their and their organization’s research.Two scientists involved in the project were awarded John Allwright Fellowship which will provide future leaderships in their expertise for the Bangladesh scientific community.

Finally, the project built the working relationship between different stakeholders at different levels bringing together researchers, farmers, service providers, input dealers, extension agencies and manufacturers which can be utilized further for other purposes. The relationship between ACIAR and national research and development institutes has developed further with recognized strengths, and these relations will be of much useful in many aspects.

8.3 Community impacts – now and in 5 years

The community impacts of the project were assessed through the final adoption and impact survey conducted in 2013. The survey indicated some visual community impacts in the project areas. Many of the capacity impacts mentioned in the preceding section have also led to the varying degrees of community impacts in the project sites.

8.3.1 Economic impacts

From a large number of on-farm participatory trials results clearly showed the economic benefits in terms of increased grain yield, reduced labor use, reduced cost of production, increased net income, and increased water savings from CA-based production systems over the conventional practices in both rice and maize. In rice the farmers produced either similar or slightly higher yields compared to the conventional practice but with reduced cost of production and reduced labor use. The overall net profit margins from CA pratices in rice are 4000-5000 BTD ha^{-1} higher than the conventional practice. The benefits, however, are much higher in maize than rice. New CA based crop management systems resulted in higher grain yield by 8 to 11%, reduced labor use10-20 person days, and cost of production savings by 7000-8000 BDT ha^{-1}. CA based crop production systems in maize can provide 13000-24000 BDT ha^{-1} profit margins over the conventional system. The total margins on system basis are 20000-30000 BDT ha^{-1} over the conventional practice.

Similarly, the results from the SSNM decision support tools indicated that farmers can be benefited by saving from the use of the overdose of fertilizers especially the nitrogenous fertilizers. Through the SSNM farmers can optimize their fertilizers for their fields and get higher grain yield with the saving of 4000-7000 BDT ha^{-1} of fertilizer costs. These fertilizer savings can make a big contribution to the national economy. Likewise, the mechanical planting for maize can save more than 10000 BDT over the manual planting.

8.3.2 Social impacts

from the final adoption study on the statistics of the trends of maize area and production showed that maize production is increasing with very fast rate in Bangladesh, especially in north-west districts where project activities were conducted. It will have big social impact on farmers. The mid-term and final adoption surveys indicated that farmers' adoption rates of both *kharif*-1 and *rabi* maize are high and *rabi* maize is replacing *boro* rice and other winter crops like wheat. The diversification of R-R systems to R-M systems removes the drudgery due to rice transplanting in ponded water, which causes several skin diseases to male and female farm labours.

The on-farm participatory trials with the farming communities helped build the trust between the researchers and farmers and other stakeholders. Two-wheel tractor based mechanization was tested and spread through service providers. These service providers are now available in the communities for further services. The mechanization had great impact on the farming communities because it can reduce time, save farm labor and avoid the risk of adverse climates and reduce drudgery to male and female farmers. The benefits from the new technologies will improve farmers' livelihoods and betterment now and into future.

8.3.3 Environmental impacts

. R-R systems in northwest Bangladesh are one of the major causes of depletion of the ground water table because these systems need much higher irrigation water compared to the R-M systems.That's why now R-M and R-W systems are being promoted by the Government of Bangladesh to avoid the exploitation of ground water. The project demonstrated significant benefits of R-M systems over R-R systems. By the adoption of R-M systems the pumping cost can reduce drastically due to less fuel burning. The reduced fuel consumption can drastically reduce the carbon emissions in the environment. Direct environmental benefits can be realised by reducing the area of boro rice which will help reduce methane emissions from paddy fields. SSNM trials clearly indicated that fertilizer consumptions, especially the N fertilizers, can be reduced which can reduce the nitrous oxide emission in the environment. SSNM can provide site specific fertilizer recommendations which can help sustain the soil health.

8.4 Communication and dissemination activities

From the beginning of the project, we focused on farmer participatory trials and demonstrations in the project communities. We focused on farmers' field days, exchange visits, traveling seminars within and outside of the project sites and districts. The project staff worked directly with farmers in their fields with the direct involvement of farmers, extension agents, service providers, local input dealers and policy makers to provide farmers' fields as platforms for technology testing, spread and adoption. Initially the project provided the machineries and new inputs like herbicides and quality seed to farmers participating in the on-farm trials. The project staff took the responsibilities for risk from new technologies and built confidence among the farmers.The project also slowly built the confidence with the local service providers for buying new machineries and connected with good manufactures with the assurance of post-sales of those machineries.

The communication with farmers and various stakeholders and disseminations of research results were carried out through various communication and dissemination means as described in section 7.4.5 above.

9 Conclusions and recommendations

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9.1 Conclusions

Based on the findings from different objectives, we can conclude the following under each objective:

Under objective 1, the baseline survey conducted in April 2009 showed that, except a few machines in Rajshahi, there was no mechanization in all the three districts for seeding/planting but it was marginally mechanized for post-harvest activities like harvesting and threshing . The survey also indicated that new emerging cropping systems like R-M, R-P-M and rice-potato-jute, etc., were new to the farmers but were getting popularized in all the three districts. The mid-term adoption survey results indicated that maize was getting popular with project interventions in both *rabi* and *kharif*-1 season and that CA-based crop management practices had started to adopt by farmers.

The final adoption and impact survey carried out in April-May 2013 indicated that the adoption of *rabi* maize was rising rapidly by 33%, 23% and 61% in 2013 compared to 5%, 2% and 23 % in 2008 in Rangpur, Rajshahi and Comilla, respectively. *Rabi* maize had mostly replaced *boro* rice but also wheat and other crops in all the three districts. The doption of *Kahrif 1* maize, however, was noted only in Rangpur. The CA-based crop management practices (zero-tillage, strip tillage, bed planting and minimum tillage etc.) became familiar with the farmers through on-farm participatory trials which were initiated during 2009. The participant farmers were the main adopters of the technologies due to conduct of on-farm trials in their plots and the extension activities but such technologies were still unknown to the farmers of the control villages. Zero or minimum tillage was adopted in more than 13% area of *Rabi* maize, with highest (23%) in Rajshahi and least (8.4%) in Comilla. The adoption of bed planting was higher in *Kharif-1* maize after potato than *rabi* maize and it was more in Rangpur than the other two districts. The adoption of CA-based crop management practices was higher in maize than rice. Farmers provided mixed opinion about the rice crop yields under CA-based crop management practices and it needs further research especially on weed management techniques, especially in DSR. Non-participatory farmers in the project villages were well aware of these technologies but it was not possible for larger adoption by them due to lack of CA-based machineries.

Under objective 2, through the CIMMYT's Maize Program, inbreds/hybrids were evaluated for the early and late excess moisture tolerance through cup screening, field evaluation and S1 to S2 advanced generations. From the cup screening experiment in control conditions results revealed that none of the existing hybrids in Bangladesh possess acceptable high moisture/water logging tolerance at early stages. From the four years of screenings, a few hybrid and inbred lines were identified with comparatively less susceptible to the high moisture stress, but none of them found worth advancing for on-farm trials and for further advanced breeding. On the basis of phenotypic characteristics, 10 inbreds were found less susceptible to excess water at seedling stage. Considering survival percentage six inbred lines viz. E15, E298, E47, E50, E55 and E57 and one susceptible line were selected for crossing in diallel fashion. From the multi-location field evaluation of hybrids/inbreds for late water logging tolerance results suggested that only a few hybrids (Uttaran-2, 900M Gold, and Pinnacle) were found moderately tolerant which can be recommended for *rabi* and *kharif -1* maize in Bangladesh.

Under objective 3, several on-farm and on-station trials were conducted under different cropping systems- R-M-MB, R-P-M and R-M-R with the principlels of CA and SSNM. . In

CA, approximate 200 on-farm participatory trials were executed under different tillage options including conventional tillage (CT), fresh beds (FB), and minimum tillage by PTOS (MT), permanent beds (PB), strip tillage (ST) and zero-tillage (ZT) for different crops in system perspective. The results of T. *Aman* rice under different tillage options showed similar grain yield and economic parameters but higher number of labor (person days ha^{-1}) in CT than other alternative tillage options. From the cumulative profit margins analysis it showed that CA-based tillage options were more profitable than CT. The *rabi* maize results showed that CA-based tillage options produced 9% higher grain yield with lesser input cost and more profit margin of BDT 19500 ha^{-1} over CT. The labor used was much lower under CA-based tillage options (50-52 person-days ha^{-1}) than conventional tillage (80 person day's ha^{-1}). Descending probability functions showed that CA –based tillage options for maize, especially PB and ST, performed consistently better than CT at all probability levels and provided more risk coverage to the farmers. As in T. *Ama*n rice, there were no significant differences in grain yield and partial economics between different tillage options in *Aus* rice. The results of R-M-MB system trials showed that PB planting produced 11% higher system grain yield, higher net return, and lesser labor use over CT followed by other CA-based tillage options. On the other hand in the R-M-R system, all the tillage-options produced similar system grain yield, even though, CA-based crop management practices resulted in more net returns over CT.

Several on-farm nutrient omission and sufficiency trials were conducted for evaluation of Crop Manager/Nutrient Manager to provide SSNM-based fertilizer recommendations for rice and maize through decision support tools. The results indicated that there were no positive correlations between available soil nutrients (N, P, K) and grain yield of maize and rice, indicating that there were factors other than the nutrients which affected the crop yields. The NM based fertilizer recommendation for T. aman provided similar yield to BRRI recommendation or farmer's fertilizer practice but with less fertilizer use and hence saved approx.. BDT 5000 ha^{-1} through fertilizers cost only. In *boro* rice NM recommendation also resulted in higher or similar yield but with saving of fertilizer use, especially N. In *kharif*-1 maize, more savings of fertilizers were achieved when it was grown after potato and by using the NM based fertilizer recommendations. Nutrient response was highest for N followed P and K in both *aman* and *boro* rice and both *rabi* and *kharif-1* maize but in Comilla the K response was higher than P. The Rice Crop Manager was endorsed by BRRI and now it is available at IRRI web page webapps.irri.org/**bd**/rcm/for rice for free access to the farmers, extension officers and researchers but the Maize Crop Manager is still under development stage. It is expected to be available in the coming years webapps.irri.org/**bd**/mcm/ for maize.

Results from 4 years of on-station experiments indicated that the CA-based crop management practices had carry-over effects on the succeeding maize in the R-M permanent bed system. Initially maize grain yield was lower in ZT rice followed by ZT maize but from the 3rd year onward maize grain yield was higher in ZT than CT. It was also found that rice yield was either higher or similar in CA-based tillage practices than CT. Crop residue retention in CA-based tillage options produced more grain yield than residue removal in rice, maize and mungbean in R-M-MB system. In the R-P-M system the improved management practices provided higher rice equivalent yield on a system basis than the traditional practice. It was also observed that integrated weed management in combination of pre- and post-emergence herbicides with one hand weeding in DSR was more effective than either herbicides or hand weeding alone. From three years of study on the optimization of plant population for maize, it ws found that 75,000 to 82,000 plants ha^{-1} at the spacing of 60 by 22 cm and 60 by 20 cm produced maximum grain yield of maize compared to other populations and spacing.

For capacity building, several short- and long term training courses were organized for researchers, extension officers, private partners, input dealers, and service providers during the project duration. Thirty-one training courses were conducted which benefited 789 participants representing different stakeholders. Likewise, a total of 3546 participants received direct benefit through 59 field days and exchange visits. Several copies of leaflets, posters, bulletins, books and other extension materials about the the CA-based technologies were developed and distributed to farmers and various stakeholders. The project has facilitated for fine-tuning and developing new prototype planters, which are now commercially available in Bangladesh. Various extension and dissemination activities were conducted for large scale adoption of the CA-based and nutrient management technologies both within and outside of the project domains.

9.2 Recommendations

Based on the findings of project activities carried out for 5 years, we provide the following major recommendations:

1. The project has generated many data and information and made considerable impacts on the scientific community and the farmers on the ground. However, many of those data have not been used in writing scientific papers for journals and other puplications. If writing of papers based on those data be carried out and published in high-impact scientific journals the project will have large scientific impact.

2. Though many on-station experiments have generated ueful information they need to be experimented further for making valid conclusions and making recommendations to farmers. For example, though the agronomic and economic benefits of CA-based tillage and crop establishment options have been fully observed for maize in both *rabi* and *kharif-1* season and farmers and other stakeholders were convinced about those technologies such benfits to *aman* rice were not fully apparent and conclusive and hence were not convincing to farmers. Experiments in both farmers' fields and research stations need to be continued to fully understand and conclude the response of *aman* rice to CA-based tillage and crop establishment options and to convey the message to farmers and other stakeholders.

3. Likewise, though farmers were convinced about the benefits of 2-wheel tractor mounted machineries (e.g., PTOS and Bed Planter) they are not easily available to farmers ein the villages. Though service providers for machines exist in some areas they are not enough. Hence even though farmers are interested to purchase or rent and use those machines they can not get them easily. This needs to be addressed by policy.

4. In terms of nutrient management, Crop Manager for rice has been released for farmers but for maze it is still udner development. Priority must be given for continuing development and release Crop Manager for maize to farmers. Also, with help of extension, Crop Manager for rice and maize needs to reach the large numbers of farmers in Bangaldesh.

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11 Appendixes

11.1 Appendix 1:

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