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Final report

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prepared by	William Erskine
co-authors/ contributors/ collaborators	Al Imran Malik, Ken Flower, Matiur Rahman
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Contents

1 Acknowledgments

We wish to thank the scientists of Bangladesh Agricultural Research Institute (BARI), Bangladesh Rice Research Institute (BRRI), officers of Department of Agriculture Extension (DAE) and NGO (PROVA), International Rice Research Institute (IRRI) and International Center for Agricultural Research in the Dry Areas (ICARDA) and the administration of these institutes who actively participated in implementing the project in Bangladesh. Many farmers made valuable contributions by participating in the activities in on-farm trials, demonstrations, and surveys we conducted during the project period. Their knowledge and practical skills are admired by all who are privileged to work with them.

2 Executive summary

Legume production in Bangladesh has fallen significantly short of consumer demand becoming a major concern to national food security. Increasing the cropping intensity by replacing fallow with a legume between rice-rice cropping systems in western Bangladesh offered the prospect of increased legume production and improved farm household livelihoods. The project aimed to provide the research to reinvigorate pulse production in western Bangladesh through lentil and pea during *rabi* season (i.e. November to February) and mungbean during *kharif* 1 season (i.e. March to June).

To this end from 2011 and 2015 the project conducted on-farm participatory trials and demonstrations and on-station experiments to develop and promote appropriate agronomic packages in nine districts in western Bangladesh. During 2016, project outputs were followed up through communication and dissemination activities to increase impact. Project partners of the commissioned organization UWA included BARI, DAE, PROVA, ICARDA and IRRI. The project achieved major outcomes in all three legumes in the intensification of rice-based cropping systems through extra production worth AUS$ 68.1 million (1 AUS$=59.23 BDT).

Among the legumes, lentil is the most favoured in Bangladesh. The nine project districts grow ~70% of the country's lentils. From 2011-2015 the lentil cultivated area in project districts increased from 91,993 ha in 2010-11 to 129,631 ha in 2014-15 and production rose from 119,639 t to 173,886 t. This extra lentil production involved an additional ~112,000 households and provided an additional ~15,000 t of high quality dietary protein. The lentil area and production, outside the project districts, increased by only 16% and 13%, respectively, over the same period; therefore, much of the increase in production within project districts is attributable to the project. These changes come from the adoption of cultivars, relay sowing and Stemphylium blight management following project research and dissemination activities. For example, in 436 lentil demonstrations conducted over five seasons the overall yield advantage of the best management practice over adjacent non-demonstration plots was 28%.

For mung bean, the project developed integrated pest management and agronomic practices which resulted in farmers in western Bangladesh reliably produce mung bean. Project-recommended technologies have been disseminated through in 439 demonstrations in nine districts over five seasons. The key components of the agronomic package were cultivars, sowing time and method and integrated pest management. As a result, in project districts the mung bean area increased from 30,233 ha in 2010-11 to 42,732 ha in 2014-15 and production from 39,471 t to 53,998 t within the same period. Production declined in districts adjacent to the project focus mungbean area, so the above changes are attributed to this project.

Regarding peas, green vegetable pea was shown as beneficial from agronomic, economic and energy perspectives in replacing the fallow between aman and boro rice crops. At the start of the project, cultivar BARI Motorshuti-3 was identified as being able to reach the green pod stage in time to be market-ready, prior to boro rice transplanting. Inclusion of green vegetable pea increased farm productivity by 1.4-fold between successive rice crops. This higher system productivity gave more than 4-fold increase in net return to farmers. Adoption of green vegetable pea is at an early stage and requires follow-up.

The impact pathway involved training extension officers and farmers in the new pulse technologies. A total of 3,564 mung bean and 4,015 lentil farmers participated in day-long training sessions, and a total of ~26,500 farmers participated in field days, of which ~20 % were women. Case studies of success included evidence of unprompted expansion of lentil relay sowing following a demonstration in Atgoria to ~150 ha with the involvement of ~600 farmers, and the spontaneous conversion of half of a green pea experimental trial

into a business venture by a farmer who sold 100 kg dry pea seeds following season to non-participating neighbours.

The project provides a good example of high quality, collaborative (Australian/national program) research conducted on an important issue with multiple benefits including improved benefits to farm households, soil health, and dietary protein availability, cropping system intensification and diversification, and scientific publications and capacity building.

3 Background

In Bangladesh, despite progress, hot spots of hunger remained within the rapidly growing population at project onset in 2011. Traditionally pulses have complemented rice which dominates the national diet. But national pulse production within rice-based cropping was declining dramatically because of competition from more remunerative irrigated crops. Pulses have been marginalized to the shrinking rainfed areas of low productivity - partly also because of their susceptibility to biotic stresses. Pulse imports to fuel rising demand have overtaken national production. The reduction in plant protein production is a major concern of Government.

Crop diversification through intensification represents a strategy of growth in the agriculture sector that will concurrently improve household livelihoods and diets. Pulses contribute to diversification through their addition of fixed nitrogen and contributions to soil health and to overall system productivity. To reinvigorate national pulse production, this project planned to fit novel short-duration pulses (lentil, mungbean and field pea) into new cropping niches within rice-based systems in western Bangladesh to improve food and nutritional security.

Lentil has traditionally been considered as a subsistence crop to produce enough for household needs. Recently, however, lentil has proved to be more profitable than any of the irrigated cereals, whether grown with integrated crop management (ICM) or farmers' usual practice (Zareen and Johansen 2010). The relatively high profitability of lentil compared to the cereals is primarily attributable to the low level of inputs and high grain price per unit weight of grain. However, the extra cost of the recommended inputs (with ICM) for lentil increase their profitability over farmer practice due to the higher yield generated by the extra inputs). Hence we broadened focus beyond the rainfed land to a new specific short-duration niche for unirrigated pulses within the more extensive irrigated lands in the short winter fallow window - as a quick, low-cost rotation option.

Field pea is an under-researched pulse in Bangladesh, for which super-early types have great potential in new niches in the system. Options exist in the same system as lentil to re-introduce relay-sowing (relay sowing for pea was traditionally practised in some areas M. Rahman - pers. comm.) and/or super-early field pea material for dry seed production and/or green pod (vegetable) and as fodder for dairy cattle. Many new snack foods are pea-based and it has become a major import into the country. Australia produced 317,000 t/yr of field pea from 2005-2008 (FAO 2010) and the national field pea breeding program is undertaken by Pulse Breeding Australia (PBA) based in Victoria. A major benefit of the project to Australia will be in foliar disease management: anticipatory host-plant resistance information on powdery mildew and rust, with the former important in NSW and Bangladesh and the latter considered a high biosecurity risk to Australia. No international centre researches field pea.

Most pulses are grown in western Bangladesh. Recent advances in mungbean have been in southern Bangladesh. With scope available for an expansion of mungbean also to new niches in western Districts, we decided to focus geographically on this western region on the pulses - lentil, mungbean and field pea; all of which have major short season potential.

4 Objectives

The project aimed to improve farm productivity through crop diversification and intensification and thereby household food and nutritional security in western Bangladesh (Districts - Chuadanga, Faridpur, Jessore, Jhenaidah, Kushtia, Magura, Natore, Pabna, Rajbari and Rajshahi) through the identification, evaluation and promotion of unirrigated, short-duration pulse systems within rice-based cropping systems.

There were four initial **objectives** with **activities** (with a fifth added during project extension) as follows:

Objective 1: To identify, test, and promote short-duration lentil in rice-based systems

Activity 1.1 On-station evaluation for super-early lentil lines

Activity 1.2 Participatory on-farm evaluation of lentil relay cropping

Activity 1.3 Scaling-up of short-duration lentil cropping

Activity 1.4 Multiplication of seed of improved lines

Activity 1.5 On-station research of key constraints to lentil production

Objective 2: To test and promote short-duration mungbean in the *kharif* 1 season within a cropping system of lentil/mustard/wheat–mungbean–T*.* *aman* rice

Activity 2.1 Conduct on-farm adaptive trials of short-duration mung bean in *kharif* 1

Activity 2.2 Scaling-up of the mung cropping system

Activity 2.3 On-station research of key constraints to mungbean production

Objective 3: To identify, test, and promote short-duration pea

Activity 3.1 On-station evaluation of local and introduced pea germplasm

Activity 3.2 Participatory development of short-duration pea cropping for early dry seed production and/or green vegetable + cattle fodder production

Activity 3.3 Scaling-up of short-duration pea cropping

Objective 4: To ensure project focus, management and capacity building of national researchers and growers

Activity 4.1 Conduct workshops

Activity 4.2 Conduct surveys

Activity 4.3 Conduct capacity building

Objective 5: Activities to ensure impact during project extension to Sept-end 2016

Activity 5.1 Communication and dissemination activities

Activity 5.2 Getting the private sector in seed production

Activity 5.3 Getting the private sector in machinery service provision and pulses milling

Activity 5.4 Other activities

5 Methodology

The University of Western Australia (UWA) was the commissioned organization. Within UWA's framework, the country coordinator was based in the Bangladesh Office of the International Rice Research Institute (IRRI), which also administered national funding. With the assistance of the Bangladesh Agriculture Research Institute (BARI) Director General and Director Research, and the Director General and Director Field Services of the Department of Agriculture Extension, the project was implemented through the BARI Pulses Research Centre (PRC) & On-Farm Research Division (OFRD) and DAE Field service wing and a non-governmental organization PROVA. A scientist of the Bangladesh Rice Research Institute (BRRI) also contributed to the cropping sequence research. Progress in the field was monitored through regular bi-annual field visits by the UWA team (project leader and post-doctoral fellow [PDF]). Regular skype sessions were conducted by the project leader with the in-country coordinator. Country coordinator and PDF were in regular contact with PRC & OFRD scientists and DAE personnel via e-mail and skype/telephone. Day-to-day activities were primarily monitored in-country.

The project started with an inception workshop (7-9 Feb. 2011 at BARI) for stakeholders, in which national pulse status was summarised, niche opportunities for short-season pulses were identified, and a detailed project work plan for Year 1 planned. In each of the following years, scientists, extensionists and stakeholders gathered for a two-day workshop (usually in Sept.) to discuss the previous year's activities and to develop the work plan for the next year.

Field activities were of four main types: On-station experiments; on-farm trials conducted by researchers, and then up-scaling demonstrations by farmers. Experiments were repeated for 2-3 years. In most cases, if not stated, recommended fertilizer doses of 20:40:20:10 kg/ha (NPKS) were applied during final land preparation and a seed rate of 35 kg/ha for lentil for sole cropping and 25 kg/ha for mungbean was used. Seed rate for pea was variable depending on seed size. The fungicide iprodione (Rovral® 50WP) was applied 2- 3 times starting from the flowering stage to control Stemphylium blight of lentil. The insecticide imidachlorpid (Imitaf® 20 SL) was applied three times from flowering to pod-filling stage on mungbean against thrips (*Megalurothrips distalis*) and pod borer (*Maruca testulalis*). In the case of line sowing, mostly 30-cm spacing was used. Experiments were conducted by PRC, OFRD and BRRI scientists, on-farm trials were conducted by farmers under the supervision of research scientists and up-scaling demonstrations were conducted by farmers under the supervision of DAE and NGO personnel. Lentil, pea and mungbean on-station experiments were conducted at PRC-Ishurdi and RARS-Jessore with a restricted number at Gazipur. Whole cropping sequence experiments were conducted at the BRRI-Rajshahi station.

Implementation followed the four objectives, each with specific activities to achieve outputs and/milestones (see Section 4). The methodology for each activity is now described briefly:

Objective 1: *Identify, test, and promote short-duration lentil*

To fit short duration lentil into a new cropping niche required different combinations of agronomic components such as: 1. super-short duration lines with minimum yield potential of 1 t/ha and disease resistance; 2. relay cropping, especially broadcasting prior to the harvest of monsoonal transplanted (T. *aman*) rice.

Activity 1.1 On-station lentil evaluation for super-early varieties

Six lines (LRIL21-109, LRIL22-15, LRIL 22-70, LRIL22-95, LRIL22-146 and LRIL22-215) selected from the sole cropping experiment in 2010 (conducted by national programme) and released control cultivars (BARI Masur-3 and BARI Masur-5) were evaluated under relay cropping in the winter seasons of 2011 and 2012. The experiments were in a randomised complete block design with three replications with a plot size of 4 x 5 m. The protocol for relay sowing was developed by Ali (2011), where seed was broadcast by hand into a uniform standing crop of monsoonal rice before harvest, when water was only visible as small puddles in the rice field. The lentil seed was primed in tap water overnight (~10 h) and relay sown the next day on 2 November 2011 and 11 November 2012 at a rate of 50 kg/ha. Rice was manually harvested two weeks after lentil broadcasting to leave ~25 cm of rice straw, when lentils were at the 2-3 leaf stage. Fertilizer and fungicide was applied as above, with the exception of urea being broadcasted 2 days after rice harvest.

<u>Screening of cultivars/advanced lines/genotypes in late planting</u>: A total of 18 cultivars/advanced lines/genotypes (BARI Masur-3,-4,-5,-6 and -7, BINA Masur-5 and -6, LRIL-21-109, LRIL-22-70, LRIL-22-205, LRIL-22-133, LRIL-22-68, LR-9-25, BLX-05008-15, BLX-04005-9, BLX-01013-1, BLX-06004-2, BLX-06004-12) were compared in late sowing condition with optimum sowing in two successive years.

Activity 1.2 Participatory on-farm evaluation of lentil relay cropping

<u>Relay lentil</u>: On-farm evaluation and demonstrations of relay sowing into standing aman rice were conducted with farmers' participation in Pabna, Natore, Kushtia, and Faridpur districts. In these evaluations and demonstrations, cultivars BARI Masur-6 and -7 were used. Relay sowing was done as above (Activity 1.1). The yields of the demonstration plot and neighbouring farmer's traditionally-cultivated lentil were recorded for comparison.

<u>Adaptive trial</u>: Five lentil varieties, BARI Masur-4, 5, 6, and 7 and BINA Masur-2, were evaluated in farmers' fields. Seeds of each variety were line-sown in 0.027 ha plots in three replications at each location of districts, Jessore, Jhenaidah, Magura, and Rajshahi. Following the results, high-yielding varieties were selected for lentil up-scaling activities.

Activity 1.3 Scaling-up of short-duration lentil cropping

Early-maturing lentil lines (including the super-early lines sown under relay conditions) despite their early flowering were not ready for harvest at mid-February. As farmers start transplanting *boro* rice ~ February 1st, clearly the new super-early lentils did not fit into the window between a T. *aman* rice crop and the spring T. *boro* rice. Research focus was re-directed to fit lentil into the rice-based system toward the opportunity between T. *aman* followed by the T. *aus* rice system (transplanted in March) (Annual Report 2012).

<u>On-farm demonstrations</u>: In the nine project districts following optimum management package on-farm demonstrations were conducted. Focus was to ensure use of BARI cultivar, and fungicidal application to control *Stemphylium* blight. From 2012 to 2014, each demonstration comprised a ~1 ha plot of four to five farmers. In 2015, each demonstration used a ~2-ha plot. A total of 436 on-farm demonstrations of optimum management practice (BARI cultivar, fungicidal application to control *Stemphylium* blight and line sowing) were conducted across five *rabi* seasons. Individual season analyses are given in the respective Annual Reports. We performed an across-season analysis by an unbalanced ANOVAs of individual factor effects taking advantage of the fact as it was not possible to apply every factor at the same level in every demonstration. In this way we could tease out the magnitude of individual factor effects in the package across seasons.

For demonstrations of relay-sown lentil primed seeds of BARI Masur-6/BARI Masur-7 at 50–55 kg seed/ha were sown as a relay crop into standing aman rice fields a fortnight before harvest under saturated moisture conditions during late October-early November. Fertilizer at 20-20-10 kg/ha of PKS was applied as basal during sowing and N at 14 kg/ha was top dressed at 20–25 days after sowing. Weeding was done once and Rovral (50WP) was applied at 0.2% twice starting from flowering stage to protect the crop against Stemphylium blight. Data on yield and yield parameters were recorded from the relay plot and also from the neighbouring traditionally-cultivated farmer's plot for comparison.

Furthermore, the project started a re-focus on a burning un-anticipated issue – Stemphylium blight management (See below in Activity 1.5), which was not planned in the original project specification.

Activity 1.4 Multiplication of seed of improved lines

Focusing on the injection of quality seed into the project and to farmers: Seed of varieties - BARI Masur 5, 6 and 7 were multiplied at PRC, Ishurdi throughout the project duration following optimum management package (see above 1.2 Methodology).

Activity 1.5 On-station research of key constraints to lentil production

In the *rabi* season of project Yr1, lentil experienced a devastating outbreak of *Stemphylium* blight caused by *Stemphylium botryosum*. Consequently the project started a re-focus on this burning un-anticipated issue – Stemphylium blight management (See below in Activity 1.5) - unplanned in the original project specification. Lentil experiments in Yr2 shifted to combat the disease. Research on *Stemphylium* blight of lentil was started in the laboratory of BARI Pathology Division. Root rot disease caused by *Fusarium oxysporum* and *Sclerotium rolfsii* was also prevalent in wet areas in the field and to combat the disease a management package was developed.

Stemphylium blight: Experiments were undertaken for *Stemphylium* blight disease management 1. To identify genetic resistance to *Stemphylium* blight, 2. To understand the source and survival mechanism of inoculum, and 3. To develop a disease management system with appropriate fungicides and an application schedule.

1. *Identify genetic resistance to Stemphylium blight*: A total of 30 lentil lines were evaluated in four separate experiments over three seasons at Ishurdi, Jessore and Gazipur. BARI Masur-1 was the susceptible check throughout. Initially at Ishurdi 9 lines (LRIL 22-36, LRIL 22-158, LRIL 22-112, LRIL 22-198, LRIL 22-165, LRIL 22-175, LRIL 21-36, LRIL 21-5888, LRIL 21-129) and at Jessore 11 lines (BD-3807, BD-3810, BD-3931, BD-3943, BD-3948, BD-3974, BD-4053, BD-4134, BD-5983, BD-5989, BD-5996) were evaluated.

   Eight lines selected from initial experiments (LRIL 21-5888, LRIL 22-36, LRIL 22-198, LRIL 21-36, BD-3807, BD-4053, BD-3943, BD-4134) were screened in two locations (Ishurdi & Gazipur) in two consecutive years. Furthermore, another 10 advanced lines (BLX 06004-2, BLX 04004-3, BLX 01013-1, BLX 04005-9, BLX 07004-7, BLX 06004-12, ILL 5134, LR 9-25, BLX 05002-3, BLX 07003-6) were also screened at the same locations.

   Plot size was 2 rows 3 m-long at Ishurdi and Gazipur; and 2 rows 2 m-long at Jessore. Debris of *Stemphylium*-infected lentil plants from the previous year was spread between rows at the start of flowering in the initial experiment and in the experiment with the advanced lines at Gazipur. Other experiments were artificially inoculated with spores of *Stemphylium botryosum*. The concentration of the inoculum was 18,000 conidia/ml. Humid conditions were created using a poly-hood for 48 hours after inoculation. Experiments were monitored regularly to observe *Stemphylium* blight disease. A *Stemphylium* scoring scale (0–5) with 0 = no infection, 1 = a few scattered leaf infections but no twig blighted, 2 = 5–10% leaflet infection and/or a few scattered (1%) twigs blighted, 3 = 11–20% leaflet infection and/or 1–5% twigs blighted, 4 = 21–50% leaflet infection and/or 6–10% twigs blighted, and 5 = 51% leaflet infection and/or = 10% twigs blighted was used as in Bakr and Ahmed (1992).

2. *Source and survival mechanism of inoculum*: Lentil seeds were collected from Gazipur, Jessore and Ishurdi. One hundred seeds were placed on blotter paper and incubated at 25 °C temperature. After 7 days seed samples were observed by stereo and compound microscopy and *Stemphylium* infected seeds and plant parts identified on the basis of mycelial and conidial characteristics. *Stemphylium* conidia were isolated from seeds and were transferred to Petri plates containing V8 agar media. The plates were then kept in an incubator at 25 °C for 4 days in the dark and then the plates were placed under NUV light for 12 hours light and dark cycle for sporulation. After sporulation conidia were collected and confirmed.

After sporulation the conidia were collected from Petri dishes by floating the plate with sterilized distilled water and then gently dislodging the conidia with a brush. Tween 20 solution was added @ 1 drop/l ml of sterilized distilled water. The concentration of conidial suspension was fixed at 5 X 104 conidia/ml. Viability of conidia was confirmed by a germination test.
Seeds of BARI Masur-1 were sown in plastic pots and after 28 days lentil plants were inoculated with the *Stemphylium* spore suspension and the whole plant covered with a polythene bag and inoculated pots maintained at 25 °C. After 48 hours of inoculation disease symptoms were investigated. Infected leaves were collected and cultured again on V8 agar media to confirm the pathogen.

To study pathogen survival an experiment was conducted at PRC-Ishurdi and RARS-Jessore. *Stemphylium*-infected lentil crop debris was placed on the soil surface and kept at 10- and 15-cm depth of soil during April. For the soil surface, the debris was placed on the soil in a wooden structure and covered with a nylon net to protect it from the elements. For 10- and 15-cm soil depth, approximately 1 kg of crop debris was placed in a cotton bag. In each case, five replications were maintained. Samples from each treatment were taken at 15-day intervals. Then, 1 g of crop debris was soaked in sterilized water for 30 minutes. Vortex stirrers were used for dislodging fungal spores/mycelia. Then, the presence of *Stemphylium* was identified by stereo and compound microscopy. Germinability of the spores was also tested by suspension in a watch glass and maintenance at 24 ^{o}C for 30, 60, and 90 minutes. Data were recorded two times every month after initiation of the experiment. Observations were recorded on the presence or abundance of spores, viability of spores, and pseudothecia/ascospore production.

3. *Development of a disease management system with appropriate fungicides and an application schedule*: Experiments were conducted for two consecutive years at Ishurdi, Jessore and Gazipur with four fungicides Iprodione (0.2%) (Rovral 50 WP), (Fenamidone + Mancozeb) (0.1%) (Secure 600 WG) Companion (mancozeb) (0.2%), Mancozeb (0.2%) (Indofil M-45), and a control (spray without fungicide). Three spray schedules (7-day, 10-day, and 15-day intervals from flowering stage) were in the main plots and fungicides in sub-plots at Gazipur and at Jessore; at Ishurdi the spray schedule was 7-day intervals. The experiment had three replications and a plot size of 3 × 4 m. Seeds of susceptible variety BARI Masur-1 were used in the experiment and *Stemphylium* blight scored on the 0–5 scale.

<u>Effect of date of sowing</u>: Three field experiments, two at Ishurdi and one at Jessore, were conducted in two consecutive years for APSIM crop model development. Popular variety BARI Masur-6 was sown at three sowing dates, early, optimum, and late sowing. Plot size was 3 × 6 m. Emergence, growth and development were carefully monitored. During harvest, data on yield-contributing characters were recorded from 10 randomly selected plants from each plot and grain yield was recorded from 2.0 m^2 plots.

Objective 2: *To test and promote short-duration mungbean in* kharif 1 *season within a cropping system of lentil/mustard/wheat - mungbean - T.* aman *rice*

In the highly intensive cropping schedule in western Bangladesh the key season to expand mungbean production is *kharif 1* sown in March. During the project, recommended optimum cultivation technology (i.e. line sowing, need base irrigation, timely weeding and timely spraying of insecticide) for the cultivation of mungbean was disseminated among farmers through specific activities described below.

Activity 2.1 Conduct on-farm adaptive trials of short-duration mung bean in kharif 1

Adaptive trials for five released varieties (BARI Mung-5, BARI Mung-6, BU Mung-4, BINA Mung-5 and BINA Mung-8) were conducted Natore, Pabna, Jessore, Magura/Rajshahi and Faridpur districts in two consecutive years at the start of the project. Seeds of each variety were sown in lines into plots of 5 × 5 m. A pre-sowing irrigation was given to facilitate germination. Weeding by hand was done as required. The experiments were sown during the third week of March. Yield and yield-contributing characters were recorded during harvest and analysed statistically. From these trials, BARI Mung-6 was selected for the up-scaling program of demonstrations.

<u>On-farm trial of sowing method</u>: Various sowing methods - line sowing by hand and mechanised options – were evaluated against traditional hand broadcasting. Popular variety, BARI Mung-6, was used in all trials. A comparison of traditional sowing method (broadcast) and line sowing was conducted at Pabna, Natore, Kushtia, Jessore, Faridpur, and Rajshahi districts in four replicates. Line-sowing was done mostly with small hand plough; and traditional bullock plough (where available). Seeds were broadcast by hand at 25 kg seed/ha. In line sowing seeds were also sown by hand at ~30 cm spacing. The plant population was counted per m^2 area at harvest, seed yield was recorded from each plot. An economic analysis was conducted for gross return and gross margins.
Small-scale mechanization options were compared depending on machine availability on station and on-farm. In on-station experiment, five sowing techniques, cultivator + line sowing manually within furrow and laddering, cultivator + line sowing manually within furrow and laddering followed by mulching with wheat straw, surface seeding + Rotivator ploughing, surface seeding + one laddering and PTOS seeding after wheat were evaluated compared to farmers' practice (i.e. two ploughings with power tiller). Furthermore, in on-farm experiments in 2 districts, Pabna and Jessore, bed planter and power tiller operated seeder (PTOS) were compared with farmers' practice broadcast by hand at 30 kg seed/ha.

Activity 2.2 Scaling-up of the mungbean cropping system

Over the entire project a total of 439 on-farm demonstrations of mungbean were conducted in project districts to familiarize optimum cultivation practices (i.e. BARI cultivar, line sowing, need-base irrigation, timely weeding and timely application of insecticides) and to expand the use of new varieties among farmers. A similar methodology was used for implementation as in lentil (above) and the across-season analysis by an unbalanced ANOVAs of individual factor effects was also as in lentil.

Focusing on the injection of quality seed into the project and to the farmers: Seed of varieties - BARI Mung 6 was multiplied at PRC- Ishurdi, RARS- Jessore, and PRSS-Gazipur throughout the project duration following optimum management package (described in Methodology).

Activity 2.3 On-station research of key constraints to mungbean production

<u>Pest management</u>: Commercially available insecticides were evaluated to develop a cost effective management package to control key insects pests [i.e. whitefly (*Bemisia tabaci*), thrips (*Callothrips indicus*) and stem fly (*Ophiomyia phaseoli*)] at Ishurdi. Eight insecticides treatments were as follows: T1 = Cypermethrin (Ripcord 10 EC) at 1 ml/l of water, T2 = Chlorpyrifos + Cypermethrin (Nitro 505 EC) at 1 ml/l of water, T3 = Lambda cyhalothrin (Reeva 2.5 EC) at 1 ml/l of water, T4 = Dimethoate (Tafgor 40 EC) at 2 ml/l of water, T5 = Thiamethoxam + Chlorantraniliprole (Voliam flexi 300 SC) at 0.5 ml/l of water, T6 = Emamectin benzoate (Wonder 5 G) at 1 g/l, T7 = Fipronil (Regent 50 SC) at 0.5 ml/l of water, T8 = Imidachloprid (Imitaf 20 SL) at 0.5 ml/l of water. Untreated control (water spray) was also included.

Three applications were made, first at 20 days after sowing (DAS) when plants were in active vegetative growth stage (i.e., two trifoliate leaf stage) against leaf feeding and sucking insect pests. Second application was done at 100% flowering stage (35 DAS) and the third at 100% podding stage (42 DAS) for flower thrips and pod borers because both the pests appeared at that time.

<u>Weed control</u>: Different herbicides were evaluated to study the efficacy of the chemicals on weed control in mungbean cultivation. Initially eight herbicides [i.e. Phenoxaprop-T-ethyl (Whip super) at 741 ml/ha, Oxadiargyl (Topstar) at 296.2 g/ha, Ethoxy sulphuron

(Sunrise) 98.8 g/ha, 2,4-D (2,4-D Amine) at 2,223 ml/ha, Pyrazo sulphuron ethyl (Herbikil) at 123.5 g/ha, Protilachlor (Commit) at 988 ml/ha, Butachlor (Vechete at 24.7 kg/ha), and Carfentazone ethyl (Hammar) at 104 ml/ha] were evaluated. Selected two herbicides, Phenoxaprop-T-ethyl (Whip super) at 741 ml/ha and Oxadiargyl (Topstar) at 296.2 g/ha, were further evaluated at two locations in more detail with following treatments, pre-sowing and post sowing application of Oxadiargyl (40%) (Topstar 40 WP) at 0.03 g/m2 and Phenoxaprop-T-ethyl (9%) (Whip super 250 ml) at 0.08 ml/m2. To compare farmers' and optimum practice with the herbicides hand weeding two times, weed-free plot, and no weeding (control) were also included. The unit plot size was 3 × 4 m. Weeds were collected from a 1 m^2 area from two places in each plot at 20 DAE (days after emergence) and then oven-dried and weighed.

Objective 3: *To identify, test and promote short-duration pea in rice-based systems in Western Bangladesh*

In the *rabi* season we aimed to fit a pea crop in the fallow window between the harvest of transplanted *aman* (T. *aman*) rice and the transplanting of *boro* rice in early February. To meet the challenge to make pea production profitable in this cropping niche, an extensive experimental plan and on-farm demonstrations were designed - described below.

Activity 3.1 On-station evaluation of local and introduced pea germplasm

Local pea germplasm from Bangladesh collection (220 accessions), introduced germplasm from Pulse Breeding Australia (PBA) and the Australian Temperate Field Crops Collection (ATFCC), Victoria (218 acc.) were evaluated for use in the T. *aman* and *boro* rice cropping system at Ishurdi. Bangladesh germplasm collection was planted in one-/ two-row plots of 2 m length with plant spacing of 40 cm × ~5 cm; and for Australian collection, unit plot size was 2 rows × 2 m with 40-cm row spacing.

<u>Relay sowing</u>: Evaluation of 91 pea genotypes/lines (Bangladesh collection) was undertaken under relay-sowing into T. *aman* rice at Ishurdi. Furthermore, to fit the T. *aman* - pea – *boro* sequence, varietal evaluation for green pods (i.e. 7 varieties, BARI Motorshuti-1 and -3, IPSA Motorshuti-1, and -3, Jhikorgachha local and Natore local) was undertaken at three research stations (Ishurdi, Jamalpur and Gazipur) by relay sowing pea into T. *aman* rice. Protocol for relay sowing has been described in Activity 1.2.

Ten genotypes (i.e. BARI Motorshuti-1, BARI Motorshuti-3, Natore local-1, Natore local-2 , IPSA-3, Jhikorgacha local, Bagha local, BD-4190, BD-4142 and BD-418) selected from germplasm evaluation for relay cropping into T. *aman* rice were compared in relay and sole cropping in two consecutive years. The experiments had three sowing treatments for pea into T. aman rice - 1. Relay sowing on November 1 – the optimum date for relay cropping; 2. Sole sowing on November 1; and 3. Sole sowing on November 11 - the optimum date to sow for sole cropping. Treatments 1 and 3 are realistic agronomically. But Treatment 2 - which necessitated premature harvest/destruction of the rice crop - was included to de-construct the difference between Treatments 1 and 3 into the individual effects of sowing date and sowing method.

<u>Yield experiment</u>: Fourteen genotypes (i.e. long duration: Natore local-2, BD 4223, BD 7211, BD 9053, BD 9047, BD 4228, BD 4209 and BD 9052; short duration: 34223, Pea 88, Early 94, Early 97, 244105 and BARI Motorshuti-3) were evaluated for two consecutive years at Ishurdi and Jessore. Plot size was 6 rows × 4 m with line-to-line spacing of 35 cm. Data were recorded on quantitative traits from five randomly selected plants and powdery mildew disease score was recorded from the whole plot using the modified (0–4) scale.

<u>Cropping system intensification</u>: Cropping sequence experiment with T. *aman*, pea as green vegetable and boro rice was conducted over three years at Experimental Farm, Bangladesh Rice Research Institute, Regional Station, Rajshahi. Two varieties of T. *aman* rice, BRRI dhan33 (short duration) and BRRI dhan49 (long duration), 6 pea varieties (i.e. BARI Motoshuti-1 and -3, IPSA Motoshuti-1,-2 and -3 and Natore Local), and lentil BARI

Masur-6, Boro rice BRRI dhan28 was cultivated on the same experimental plot in a sequence. There were two other treatments included leaving a fallow between T. *aman* and *boro* rice as control. A randomised complete block design was used with three replications and plots were 9 x 4 m. Rice cultivars BRRI dhan49 and BRRI dhan33 were hand transplanted on the same date (Table 3.1) at 5-leaf stage (30 d old) at line to line 25 cm and 15 cm hill to hill spacing. Pea cultivars were hand-sown on two different dates (Table 3.1) at 70 kg ha^{-1} at 40 x 10 cm spacing after rice harvest at two different dates as short and long duration aman rice matured at different date. Rice was weighed with husk on and Pea green pods were weighted fresh.

Pea diseases and insects: In pea-growing areas (i.e. Jessore, Jhenaidah, Norail, Pabna, and Natore districts and research stations, Ishurdi and Jessore) were surveyed for disease on pea. Disease was assessed on three sampling areas (100 plants/sample) selected at random from each field. In every unit area, the total number of diseased plants and healthy plants was counted. The incidence and severity of diseases were recorded at seedling and podding stages.

For the insect survey, the crop was visited at peak flowering and podding stages. The varieties Natore local-1, Natore local-2, and IPSA Motoshuti-3 were examined. Insect pest data were collected from three dispersed plots in each location. The thrips population in flowers was assessed from 50 opened flowers randomly collected from three plots of each location. The collected flowers were immediately opened carefully on the white paper board and the adult and pre-adult thrips present in the flowers were counted.

Activity 3.2 Participatory development of short-duration pea cropping for early dry seed production and/or green vegetable + cattle fodder production

We started experimentation with two options for pea: Cropping for early dry seed production and for green vegetable production. On-station experiments on cropping system intensification negated the possibility of dry pea harvest as it takes more than 100 days to reach to maturity which is 40 days more than the typical fallow period in the dominant cropping pattern of T. *aman* and *boro*. However, the green vegetable pea crop showed great potential on-station which was then tested on-farm.

Green pea vegetable as fallow replacement: T. *aman* and *boro* rice were cultivated by farmers without any intervention from the project in unit plot area of 0.13 ha. Pea (BARI Motoshuti-3) was sown in line with 20-cm spacing at 200 kg/ha following T. *aman* rice harvest. Seeds were primed overnight. Fertilizers, NPKS @ 14-20-20-10 kg/ha, were applied during final land preparation. Marketable green pods were harvested twice from plots and then pea haulms harvested as cattle fodder. Data on yield attributes were collected. The cultivation cost and yields of rice were also recorded from neighbouring farmers' fields where the land was remained fallow over dry season. The on-farm trials were conducted in Jessore, Jhenaidah and Kushtia districts.

Relay cropping: To replace fallow in T. *aman*-fallow-T. *aus*/jute cropping pattern a relay pea trial was conducted in three districts (Faridpur, Pabna and Jamalpur). Seeds of cultivar Natore local-2 was broadcasted by hand at 90 kg/ha following protocol for relay sowing (see Activity 1.1).

Activity 3.3 Scaling-up of short-duration pea cropping

Demonstrations were conducted to introduce green pea vegetable as a fallow replacement in T. *aman*-fallow-*boro* cropping pattern. A seed rate of 150 kg/ha was used. After the pea harvest, farmers transplanted *boro* rice as usual.

Focusing on the injection of quality seed into the project and to the farmers: Seed of varieties - BARI Motoshuti-3, Natore local and Jhikorgachha local was multiplied at Ishurdi, Jessore and Gazipur throughout the project duration following optimum management package (described in Introduction of Methodology).

Objective 4: *To ensure project focus, management and capacity building of national researchers and growers*

To effectively manage the project the following activities were conducted to bring stakeholders together – national and international project partners (BARI, BRRI, DAE and local NGO – PROVA, and the International centres ICARDA and IRRI-Bangladesh).

Activity 4.1 Conduct workshops

Project started with an inception workshop (February 7-9, 2011) at BARI, Gazipur that summarized pulse status identifying opportunities for short-season pulses and previous relevant research, and then developed a work plan. From then on, annual review and planning workshop was held to discuss annual outputs and develop a plan of action for following year. Half-way through the project lifespan a mid-term review was carried out by ACIAR and recommendations made to focus on some specific research areas. At the end, we ran a wrap-up workshop to discuss project achievements and the way forward. Project partners also met with other ACIAR project leaders (i.e. LWR/2010/080) to look for synergies to maximize impact.

For effective implementation and to monitor project activities 'implementation workshops' were organised each year where scientists from PRC and OFRD; and DAE personnel participated. Furthermore, each year two traveling workshops, ~5 days long, were conducted to monitor progress and opportunities for future research.

Activity 4.2 Conduct surveys

Surveys were conducted at the start (baseline) and end of the project (adoption) in the nine project districts. A total of 600 growers for baseline and 480 growers for adoption survey were randomly selected for interview. Varietal status, cultivation methods, input use, constraints of pulses, potential niches for expansion of pulses, and impact of project were identified.

Activity 4.3 Conduct capacity building

Capacity building activities were done in two ways: exposure of farmers and extensionists to optimum cropping technology (i.e. farmers' training) and educational study visits for scientists.

Farmers training and field days: At the start of cropping season of lentil and mungbean, farmers in the project areas were exposed to a day-long training. At the podsetting stage of growth field days were organised at selected demonstrations, so that farmers and neighbours could see for themselves the benefits of optimum management practices on the crop. The activity was led by BARI scientists. Field level DAE personnel were also attended the training sessions and field days.

Educational tour: Nepal is a major regional lentil producing country with a well-developed lentil relay-cropping production system. Two DAE personnel and two BARI scientists along with the IRRI-pulse project coordinator made a study visit to lentil production regions in Nepal each year. Furthermore, three managerial-level scientists (DG, BARI; IBO representative; and the project coordinator) visited UWA research activities on chickpea, pea, and canola; collaborative activities of Murdoch University with Bangladesh; and CSIRO's activities on lupins, etc.

Objective 5: *Activities to ensure impact during project extension to June-end 2016*

To increase the project's impact through communication and dissemination activities and to involve the private sector (seeds, machinery service providers, pulses milling tools, or others) the project was extended.

Activity 5.1 Communication and dissemination activities

Six sessions of farmer training on lentil and mungbean quality seed production were conducted in DAE offices at Natore, Chuadanga, Magura, Jhenaidah and PRC-Ishurdi, RARS-Jessore. In each training session there were 25 participants (22 farmers, 3 Sub-Assistant Agricultural Officers [SAAO]). The training was conducted in a participatory manner. Before starting the training participants' knowledge about quality seed was assessed through a survey questionnaire. End of each training session participants' knowledge was again assessed through discussion. A brochure on "Quality seed production and storage technology on lentil and mungbean" was distributed among the participants.

Activity 5.2 Getting the private sector in seed production

A questionnaire was developed and data collected from the four best-known seed companies in Bangladesh through personal interview. Relevant information was also collected from BADC.

Activity 5.3 Getting the private sector in machinery service provision and pulses milling

Survey questionnaire was designed for the manufacturer, service provider, farmer and the officers who are involved in promotion of the farm machines. Information was collected through direct interview of the respondents. Regarding pulses milling, information from three manufacturers and four mini mill owners through interviews.

Activity 5.4 Other activities

Following activities were also done:

Screening of pea genotypes for suitability in relay sowing on standing aman rice in Bangladesh.

Screening for salinity tolerance of lentil at germination.

Data analysis to develop a pea and a lentil growth model based on APSIM and weather based disease (*Stemphylium* blight) forecasting model.

Preparation of manuscripts for submission to international journals.

6 Achievements against activities and outputs/milestones

Objective 1: To identify, test and promote short duration lentil in rice based systems

no.	activity	outputs/ milestones	completion date	comments
1.1	On-station evaluation for super-early lentil lines	Super-early lines flowered earlier than standard lines. However, there was no advantage in maturity time over existing cultivars and they had a low yield potential	March 2013	Super-early lines (6) and two BARI control varieties were relay-sown into T. aman rice at Ishurdi during 2011-12 and 2012-13. Super-early lines flowered ±15 d earlier than BARI controls, but did not mature earlier than the BARI varieties. With this result the project re-directed focus to fit lentil into the rice-based system away from the window between the T. *aman* and the spring T. boro rice crops toward the opportunity between T. *aman* followed by the T. *aus* rice system.
1.2	Participatory on-farm evaluation of lentil relay cropping	Farmer validated technology for lentil relay sowing	March 2015	An average yield increase (~51%) of relay sowing over sole-cropping (farmers' practice) was found and attributed to the early establishment of the relay-sown crop and also to disease management provided by the project recommendation. Overall, farmers were enthusiastic with the outcome of the relay sowing and many have adopted the practice within the cropping pattern of T. *aman*-lentil-*aus* rice
1.3	Scaling-up of short-duration lentil cropping	Large -scale demonstrations	March 2016	Following the result of activity 1.1 project re-directed focus (see activity 1.1). A total of 436 on-farm demonstrations of optimum management practice (BARI cultivar, fungicidal application to control *Stemphylium* blight and line sowing) were conducted. Overall the average yield of demonstration plots was 28 % higher than neighbouring farmers' (control) over 5 seasons.
1.4	Multiplication of seed of improved lines	On-station multiplication of seeds of lentils	March 2015	A total of 14.9 t of quality seed of lentil cultivars BARI Masur 5, 6, and 7 was produced. Seeds were used for up-scaling activities and distributed among farmers involved in project.
1.5	On-station research of key constraints to lentil production	Partial resistance to Stemphylium blight cultivar was identified and management package was developed	March 2014	Experiments on management of Stemphylium blight caused by *Stemphylium botryosum*, foot rot caused by *Sclerotium rolfsii*, were conducted. Best options from the results were communicated to the farmers in on farm demonstrations.

Objective 2: To test and promote short-duration mungbean in kharif 1 *season within a cropping system of lentil/mustard/wheat - mungbean - T. aman rice*

no.	activity	outputs/ milestones	completion date	comments
2.1	Conduct on-farm adaptive trials of short-duration mungbean in kharif 1	Farmer validated short duration mungbean technology	June 2013	Five new mungbean varieties (BARI Mung 5 & 6, BINA Mung 5 & 8, and BU Mung 4) were compared during 2011 & 2012 in 5 Districts. BARI Mung 6 was the highest yielding (mean 1.75 t/ha) cultivar in both years. BARI Mung 6 was used in all demonstration activities
2.2	Scaling-up of mung cropping system	Large number farmers adopted the mungbean in their cropping system	June 2014	A total of 439 on-farm demonstrations of mungbean were conducted to familiarize optimum cultivation practices (line sowing, need base irrigation, timely weeding and timely application of insecticides) and expand the use of new varieties among farmers. Overall the average yield of demonstration plots was 19 % higher over neighbouring farmers' plots (control).
2.3	On-station research of key constraints to mungbean production	Identified high yielding cultivar, disease management package	June 2014	Experiments on management package against insect pest complex, weed management with herbicides, screening for resistance to Cercospora leaf spot (CLS) and yellow mosaic virus (YMV) and different sowing methods were carried out. Best options from the results were communicated to the farmers in on-farm demonstrations.

PC = partner country, A = Australia

Objective 3: To identify, test and promote short-duration pea in rice-based systems in Western Bangladesh.

no.	activity	outputs/ milestones	completion date	comments
3.1	On-station evaluation of local and introduced pea germplasm	Identified early peas with seed yield potential and/or vegetable quality & disease resistance	March 2013	A total of 438 pea accessions (BARI collection 220 & introduced collection 218) were evaluated. Twenty-two accessions from the national collection and 8 from Australian collection were selected for further evaluation. Cultivar BARI Motorshuti 1 – already released for vegetable production - was identified with great broad-acre cropping potential.
3.2	Participatory development of short-duration pea cropping for early dry seed production and/or green vegetable + cattle fodder production	Farmer validated technology for short-duration pea cropping	March 2015	Adaptive trials of relay-sowing of pea into T. *aman* were conducted to incorporate between T. *aman* and T. *aus*. On-farm trials of green pea harvest were conducted to introduce the cropping pattern: T. *aman*-sole pea-*boro* (irrigated rice). The inclusion of an extra crop, pea as green pod vegetable, increased farm productivity by 1.4-fold over the dominant cropping sequence (rice - fallow - rice) and farm net income by four-fold.
3.3	Scaling-up of short-duration pea cropping	Wide adoption by farmers	March 2015	A total of 3 demonstrations of BARI Motoshuti-3 were conducted in farmers' fields.

Objective 4: To ensure project focus, management and capacity building of national researchers and growers.

no.	activity	outputs/ milestones	completion date	comments
4.1	Conduct workshops	Start-up stakeholder workshop to summarise pulse status, identify opportunities for short-season pulses and to develop Year 1 work-plan	February 2011	An inception workshop was held with national and international stakeholders and a detailed work plan developed for subsequent Year1 activities.
		Annual review and planning workshop	August/Sept, each year	Discussed annual results and developed work plan for following year with stakeholders
		Mid-Term Review	August 2013	Recommendations were made to focus on some specific research areas - such as legume model development and waterlogging tolerance
		Wrap-up workshop	October 2015	Discussed project achievements and the way forward.
4.2	Conduct surveys	Analysis of potential constraints to and opportunities for short duration pulses followed by baseline survey	March 2012	Baseline survey was conducted in the project area. In the survey, varietal status, cultivation methods, input use by farmers, constraints of pulses, and potential niches for expansion of pulses were identified.
		Adoption survey	October 2015	Farmer adoption of project recommended varieties for Lentil (BARI Masur-6) and Mung (BARI Mung-6) was estimated. Project advocated management package (sowing time, insecticide and fungicide application) also became popular in mungbean and lentil. Relay sowing of lentil gained momentum in the area where it is applicable.
4.3	Conduct capacity building	Training visits of individual researchers to ICARDA & Australia	March 2014	Four scientists from PRC-BARI visited ICARDA - India. Three management-level officers (DG, BARI; IRRI rep. in Bangladesh; and project coordinator) visited UWA, Murdoch University, and CSIRO in WA, Australia.
		Farmer/NGO and extension study visit to relay sowing in Nepal		Eight pulse scientists from BARI and eight extension officers from DAE visited the relay cropping systems of lentil in Nepal.
		In-country training of farmers		A total of 3,564 mungbean and 4,015 lentil farmers were trained. Field Days were attended by a total of 8,585 farmers in mungbean and 17,960 farmers in lentil.

Objective 5: Activities to ensure impact during project extension to Sep-end 2016.

no.	activity	outputs/ milestones	completion date	comments
5.1	Communication & Dissemination: Farmers' training on lentil and mungbean quality seed production, preservation and milling	Six sessions of farmers' training conducted at PRC Ishurdi & Jessore, DAE Natore, Chuadanga, Jhenaidah and Magura	September 2016	A total of 132 farmers and 18 DAE officers received training on lentil and mungbean quality seed production and preservation.
		Brochure on seed production and preservation	September 2016	A brochure on seed production and preservation technology for lentil and mungbean was published and 5500 copies distributed.
	Monitoring & reporting of 67 lentil demonstrations conducted by DAE and PROVA in 2015-16 season	Report of lentil demonstrations available	September 2016	Detailed report of extension period including on-farm trials is available. In 2015-16 a total of 67 demonstrations were conducted and the overall increase of demonstration yields was 21.4% over farmers' yields.
5.2	Involvement of Private Sector in seed production:	Report on Private Sector involvement on pulse seed production available	September 2016	Private seed sector companies are unlikely to be interested in the pulse seed business with the existing varieties unless some exceptional situation arises, such as export possibilities for pulse seed.
5.3	Involvement of Private Sector in machinery service provision & milling: A survey	Report on Private Sector involvement in machinery service provision & pulse milling available		Lack of local service providers and skilled operators are two major constraints for mechanization of sowing of pulse crops. The demand of *dhal* (lentil) milling is high during harvest and then gradually declines over the year. Installing a *dhal* mill alone at farmers' level in a village is not economical, but is an economic proposition as a side-business to *dhal* millers.
5.4	Other activities	APSIM pea and lentil models available		Discrepancy between the simulation results and observed data were eminent. Further optimization of the model is in progress. Three manuscripts have been submitted to international journal and one is already published and other two are under review.

7 Key results and discussion

In this section only key results for the project objectives are presented and discussed including the extension period of the project. During the project a number of other small experiments were conducted to achieve project objectives: these are described in the annual reports.

Objective 1: Identify, test, and promote short-duration lentil in rice-based systems

We evaluated eighteen early-flowering lines in the 2011 winter seasons in three sowing dates (early, optimum and late). Sowing dates were selected to follow farmers' practice. Sowing date significantly ($P<0.05$) affected all measured parameters. Early-flowering lines flowered an average of 9-17 days earlier than the controls, irrespective of sowing date (Table 1.1).

Table 1.1. Average time to flowering, time to maturity and seed yield of 18 early-flowering lentil lines and two controls with sole cropping in 2011 at 3 sowing time (early optimum and late) (extracted from Malik et al 2016).

Traits	Sowing time	Control	Early-flowering	Overall	†Selected Early-flowering
Time to flowering (days)	Early	**59.0***	**34.6** ± 0.4	**35.8** ± 1.4	**33.7** ± 1.0
	Optimum	**59.0***	**36.9** ± 0.4	**38.1** ± 1.2	**36.0** ± 0.9
	Late	**58.0**	**39.2** ± 0.4	**40.2** ± 1.0	**38.3** ± 0.8
Time to maturity (days)	Early	**112.5***	**88.6** ± 0.7	**89.9** ± 1.4	**86.8** ± 1.8
	Optimum	**111.0***	**89.6** ± 0.4	**90.7** ± 1.2	**88.8** ± 0.8
	Late	**109.0***	**83.4** ± 1.2	**84.8** ± 1.8	**83.7** ± 0.6
Seed yield (kg/ha)	Early	**2045***	**1011** ± 66	**1065** ± 88	**1051**± 154
	Optimum	**1965***	**1070** ± 61	**1118** ± 74	**1021** ± 144
	Late	**2115***	**1188** ± 51	**1237** ± 68	**1203** ± 116

Values are the means of the means of two replicates of early-flowering lines and two cultivars for overall (±S.E, n=20), for early-flowering (±S.E, n=18), controls (S.E, n=2, or otherwise stated), selected early flowering (S.E, n=6). * One control was used in the experiment. †Selected early-flowering lines were chosen from result of 2010 experiment (extracted from Malik et al. 2016)

In 2011 and in 2012 relay cropping of selected early-flowering lines and controls was evaluated. There were significant differences in all the agronomic traits measured between the six early-flowering lines and the controls (BARI Masur-3 and BARI Masur-5) (Tables 1.2 and 1.3). Time to flowering was on average 17 days earlier for early-flowering lines (ranging 41-53 days for maturity) compared to control cultivars (Table 1.2). A similar

Table 1.2. Average time to flower and to maturity and seed yield of 6 early-flowering lentil lines and two controls under relay sowing in the 2011 and 2012. (Extracted from Malik et al 2016)

Entry names/Season	Time to flower (days)		Time to maturity (days)		Seed yield (kg/ ha)	
	2011	2012	2011	2012	2011	2012
Control mean	**65.7** ± 0.7	**52.5** ± 0.8	**111.8** ± 0.2	**106.7** ± 0.7	**1365** ± 120	**1893** ± 249
Early-flowering mean	**47.7** ± 1.8	**39.2** ± 1.3	**103.7** ± 1.3	**92.6** ± 0.9	**258** ± 84	**491** ± 118
Overall mean	**52.3** ± 3.2	**42.5** ± 2.4	**105.6** ± 1.6	**96.1** ± 2.4	**535** ± 193	**841** ± 250
l.s.d	2.1***	2.7***	3.3**	2.9**	196***	201***

trend occurred for time to maturity, which was on 14 February, after an average of 104 days for the early-flowering lines, and was about 9 days earlier in maturity than control cultivars (BARI Masur-3 and -5). However, early flowering lines did not achieve economically justifiable yield (Table 1.2).

Two strategies were evaluated to fit lentil into the short fallow between successive monsoonal (i.e., T. aman) and pre-monsoonal (aus) or irrigated rice (boro) crop: These were early-flowering sole-cropped lentil and relay-sown lentil into rice. Early-flowering lentils were evaluated as a way to intensify rice-based cropping. However they showed insufficient yield potential. We could identify no consistent advantage from their early flowering habit, because the reduced length of the reproductive period of the early-flowering lines was previously found to be highly dependent on temperature combined with photoperiod (Erskine et al. 1994). In some instances, the earlier maturity of early-flowering lines, compared with current cultivars, meant that they could fit into the rice cropping sequence (i.e. monsoon rice – lentil – rain-fed rice), but they failed to achieve an economic yield.

Table 1.3. Seed yield (kg/ha) for relay and conventional sown lentil cultivar BARI Masur on farmers' fields in 2011/12, 2012/13 2013/14 and 2014/15. (Modified from Malik et al. 2016)

Season	No of site	Yield (kg/ ha)		% yield advantage
		Relay	Conventional	of relay
2011/12	4	**1398** ± 116	**710** ± 113	**97**
2012/13	2	**1764** ± 164	**1134** ± 109	**57**
2013/14	4	**1495** ± 127	**1149** ± 142	**30**
2014/15	6	**1532** ± 69	**1233** ± 47	**24**

Considering the alternative strategy of relay-sowing into rice, sole-cropped lentil in farmer's fields - sown from 28 November to 9 December – yielded an average of 710 to 1233 kg/ha in the different years (Table 1.3). Relay-sown lentil, which was sown earlier between 8 to 27 November, annually yielded from 1398 to 1764 kg/ha on average. This was consistently - 24 to 97% - and significantly ($P < 0.05$) more than conventional sole-cropped practice on-farm over the years (Table 1.4).

At the time of relay sowing, excess soil moisture and puddles on the soil surface are common features in puddled soil and lentil faces transient soil waterlogging from an early developmental stage. Poor germination in waterlogged soil is a major impeding factor for crop establishment (Ramakrishna et al. 2000). Initially we investigated waterlogging tolerance at UWA in contrasting pairs (seed size and origin) (Malik et al. 2015) of pea and lentil genotypes - compared to a grasspea, considered waterlogging tolerant (Purseglove 1968), control - in the period after germination to vegetative growth and during subsequent recovery in the glasshouse at UWA. Within the small sample studied, we found significant genetic variation in both pea and lentil in tolerance to waterlogging after germination and subsequent recovery (Malik et al. 2015). Following up also at UWA, we screened for waterlogging tolerance at germination a total of 127 lentil accessions - representatives of a world core germplasm collection from 11 major lentil producing countries [Afghanistan (12 accessions), Australia (11 cultivars), Bangladesh (17 acc.), Chile (7), Egypt (6), Ethiopia (8), India (12), Iran (17), Pakistan (12), Syria (9) and Turkey (16)] in the glasshouse at UWA. There was significant variation among genotypes, and genotypes originating from Bangladesh had the highest germination at 21.2% (Wiraguna et al. 2016).

We also explore the potential to increase lentil production in sole cropping. The Project recommended management package comprised (improved cultivar, Stemphylium disease control (iprodione fungicidal application), early sowing (~7 to 10 days earlier sowing than the farmers' practice). The overall yield advantage of the best management practice over adjacent non-demo yield was 28% over 436 demonstrations conducted over five cropping seasons. Over the years the yield gap between demo-farmers and control farmers plot yield decreased and comparing all years on average it was 28 % (calculated from Table 1.4). As a result cooperating farmers profited more than traditional-practice farmers. After meeting all production costs (seed, fertilizer, fungicides and labour) farmers made an average profit of 15,337 BDT/ ha (calculation was done following the price as Lentil= Tk.

60/kg, Urea = Tk. 16/kg, TSP = Tk. 22/kg, MOP = Tk. 15/kg, Gypsum = Tk. 10/kg and Boric acid = Tk. 80/kg, Rovral = Tk. 250/100 g, Labour wage for weeding and spraying fungicide & insecticides = Tk. 250/day/labourer (8 hours day)).

Using an across-season analysis by an unbalanced ANOVAs of individual factor effects, it was possible to identify the magnitude of individual factor effects in the package. Some districts were consistently higher yielding than others with district Chaudanga topping lentil yields (2.1 t /ha) and district Natore returning the lowest average yield (0.99 t/ha) over seasons. In general the higher yielding districts had lighter textured soil, to which lentil is adapted. Early sowing and the preceding crop did not have an affect on lentil productivity across seasons. Weeding increased yield significantly. Fungicidal application (iprodione) to manage Stemphylium blight also significantly increased yield with a single application imparting a 13% yield advantage and two applications giving a 39% advantage across seasons. This emphasizes the importance of blight management.

Table 1.4. Seed yield (kg/ha) for improved (project recommended) and conventional sown lentil cultivar BARI Masur on farmers' fields in 2011/12, 2012/13, 2013/14., 2014/15 and 2015/16.

Season	No of demonstrations	Yield (kg/ ha)		% yield advantage
		Improved	Conventional	of demos
2011/12	19	**1351** ± 64	**1003** ± 70	**35**
2012/13	124	**1733** ± 31	**1389** ± 31	**25**
2013/14	118	**1469** ± 60	**1192** ± 53	**23**
2014/15	108	**1573** ± 52	**1212** ± 45	**30**
2015/16	67	**1277** ± 62	**1013** ± 66	**26**

The demonstrations involved fungicidal application, and, responding to the severe Stemphylium epiphytotic in the first year of the project, we wanted to optimize fungicide use to reduce the applications to the minimum through improved disease predication as part of an integrated management system. For the purpose a series of experiments were conducted – as listed Section Methodology and a weather-based model 'Stempedia' was developed (Fig. 1.1, Moin et al. 2016). Three foliar applications of an efficient fungicide can provide an economical return. However this return is dependent on the timing of foliar application of fungicide. The best economic returns could be ensured if the first application of the fungicide is made on the first appearance of the disease in the early flowering stage (Fig. 1.2), followed by further application(s) if the disease-producing environment is expected (Moin et al. 2016). It was concluded that by calibrating under local conditions, the Stempedia model can be useful tool for tactical disease management (Moin et al. 2016).

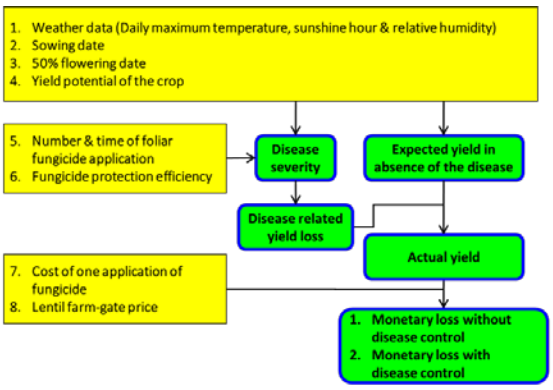

Fig: 1.1 Flow chart of the model Stempedia.

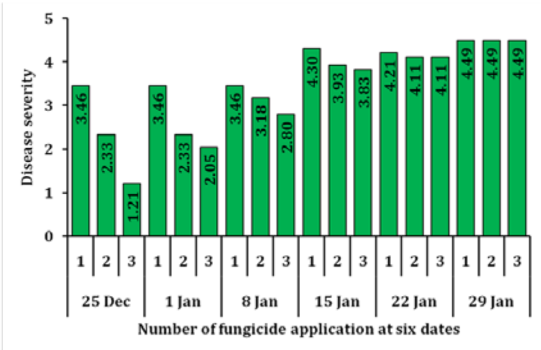

Fig: 1.2 Three fungicidal spray to control the Stemphyum blight disease of lentil starting at six different stage of development of the crop.

Objective 2: To test and promote short-duration mung bean in *kharif* 1 season within a cropping system of lentil/mustard/wheat - mungbean - T. *aman* rice in western Districts

Insect management is a key issue in mungbean. We evaluated different synthetic insecticides and botanicals in a field experiment in Ishurdi during 2011 and 2012 to develop management packages against mungbean insect pests. Over the two years of experiments, imidachloprid was the most economically effective insecticide identified against thrips, which is the major insect causing yield loss.

The effects of botanicals and other insecticides were non-significant (Table 2.1). A follow-up experiment was conducted during 2013 and 2014 using only synthetic insecticides available in the market (Table 2.2). Spraying of synthetic insecticides significantly reduced thrips, pod borer and stem fly infestation in mungbean flowers, pods and leaves,

Table 2.1 Effect of insecticidal management practices on net return of mungbean during *kharif*-1, 2011 and 2012.

Treatments	Yield (kg/ha)		Yield gain over control (kg/ha)		Return over control (Tk/ha)		Net return (Tk/ha)	
	2011	2012	2011	2012	2011	2012	2011	2012
Carbofuran	**1510**[bc]	**1618**[bc]	**95**	**67**	**5700**	**4020**	**3000**	**1320**
Carbofuran + Neem oil + trix	**1592**[abc]	**1728**[bc]	**177**	**177**	**10620**	**10620**	**3795**	**3795**
Carbofuran + Imidachloprid	**1752**[a]	**1960**[a]	**337**	**409**	**20220**	**24540**	**14220**	**18540**
Carbofuran + Fipronil	**1645**[ab]	**1736**[bc]	**230**	**185**	**13800**	**11100**	**8400**	**5700**
Imidachloprid	**1680**[ab]	**1830**[ab]	**265**	**279**	**15900**	**16740**	**12600**	**13440**
Fipronil	**1613**[ab]	**1727**[bc]	**198**	**176**	**11880**	**10560**	**9180**	**7860**
Untreated control	**1415**[c]	**1551**[c]	-	-	-	-	-	-

Carbofuran (Furadan 5 G), Neem (*Azadirachta indica*) leaves extract (Neem oil); Imidachloprid (Imitaf 20 SL), Fipronil (Regent 50 SC). For calculating return the following market prices were used: Neem oil = Tk. 250/litre, Trix = Tk. 140/litre, Furadan 5G = Tk. 115/kg, Imitaf 20 SL = Tk. 280/100 ml, Regent 50 SC = Tk. 200/100ml and Mungbean = Tk. 60/kg, Labour wage for spraying = Tk. 200/day/labourer (8 hours day). In a column, treatment means with different letters are significantly different (P>0.05).

respectively (Hossain 2015). Yield of mungbean varied significantly with the level of insect pest's infestation depending on the efficacy of different insecticides (Table 2.2). However in general, yield was higher in *kharif*-I of 2014 compared to 2013.

All the insecticides were effective against insect pest and economic return was variable (Table 2.2). Considering two years average yield Thiamethoxam + Chlorantraneliprol provided the highest yield although it has the highest input expense. The best economic outcome was demonstrated by Fipronil (7.4-fold higher) followed by Imidachloprid and Dimethoate (5.5-fold higher) over each unit investment.

Table 2.2 Effect of insecticidal management practices on net return of mungbean during *kharif*-1, 2013 and 2014

Treatments	Yield (kg/ha)		Yield gain over control (kg/ha)		Return over control (Tk/ha)		Net return (Tk/ha)	
	2013	2014	2013	2014	2013	2014	2013	2014
Cypermethrin	**1355**[bc]	**2077**[b]	**189**	**376**	**11340**	**22560**	**8040**	**19260**
Chlorpyrifos + Cypermethrin	**1321**[c]	**1842**[d]	**155**	**141**	**9300**	**8460**	**5550**	**4710**
Lambda Cyhalothrin	**1300**[c]	**1877**[cd]	**134**	**176**	**8040**	**10560**	**5340**	**7860**
Dimethoate	**1483**[a]	**2188**[ab]	**317**	**487**	**19020**	**29220**	**15270**	**25470**
Thiamethoxam + Chlorantraneliprol	**1452**[ab]	**2347**[a]	**286**	**646**	**17160**	**38760**	**11460**	**33060**
Emamectin Benzoate	**1524**[a]	**2195**[ab]	**358**	**494**	**21480**	**29640**	**15780**	**23940**
Fipronil	**1570**[a]	**2097**[b]	**404**	**396**	**24240**	**23760**	**21390**	**20910**
Imidachloprid	**1448**[ab]	**2047**[bc]	**282**	**346**	**16920**	**20760**	**13995**	**17835**
Untreated control	**1166**[d]	**1701**[d]	-	-	-	-	-	-

Cypermethrin (Ripcord 10 EC), Chlorpyrifos + Cypermethrin (Nitro 505 EC), Lambda Cyhalothrin (Reeva 2.5 EC), Dimethoate (Tafgor 40 EC), Thiamethoxam + Chlorantraneliprol (Voliam flexi 300 SC), Emamectin Benzoate (Wonder 5 G), Fipronil (Regent 50 SC), Imidachloprid (Imitaf 20 SL). For calculating return the following market prices were used: Ripcord 10 EC = Tk. 140/100 ml, Nitro 505 EC = Tk. 170/100 ml, Reeva 2.5 EC = Tk. 100/100 ml, Tafgor 40 EC = Tk. 85/100 ml, Voliam flexi 300 SC = Tk. 600/100 ml, Wonder 5 G = Tk. 300/100g, Regent 50 SC = Tk. 220/100 ml and Imitaf 20 SL = Tk. 230/100 ml and and Mungbean = Tk. 60/kg. Labour wage for spraying = Tk. 200/day/labourer (8 hours day). In a column, treatment means with different letters are significantly different (P>0.05).

The outputs of the insect pest management package were also disseminated among farmers through 439 demonstrations. Optimum cultivation technology (i.e. short-duration variety, line sowing, need for sowing irrigation, timely weeding and insecticidal application) for the cultivation of mungbean were the other components of the demonstration package. Project recommended technology with best management practice (i.e. improved cultivar, disease control) yielded significantly higher ($P < 0.001$) (Table 2.3) and the yield advantage ranges from 17 to 27%. Over the years the yield gap between demo-farmers and control farmers plot yield decreased and comparing all years on average it was 23 % (calculated from Table 2.3). As a result cooperating farmers profited more than traditional-practice farmers. After meeting all production costs (seed, fertilizer, fungicides and labour) farmers made an average profit of 7802 BDT/ ha (calculation was done following the price as : Urea = Tk. 16/kg, TSP = Tk. 22/kg, MOP = Tk. 15/kg, Gypsum = Tk. 10/kg and Boric acid = Tk. 80/kg, Ripcord 10 EC = Tk. 140/100 ml, Nitro 505 EC = Tk. 170/100 ml, Reeva 2.5 EC = Tk. 100/100 ml, Tafgor 40 EC = Tk. 85/100 ml, Voliam flexi 300 SC = Tk. 600/100 ml, Virtako 40 WG = Tk. 140/10g, Wonder 5 G = Tk. 300/100g, Regent 50 SC = Tk. 220/100 ml and Imitaf 20 SL = Tk. 230/100 ml. Labour wage for spraying insecticides = Tk. 250/day/labourer (8 hours day). Pod picking cost = Tk 9.10/kg pod (i.e. Tk. 13/kg seed), 100 kg pod equal to 70 kg seed).

Table 2.3. Seed yield (kg/ha) for improved (project recommended) and conventional (farmers' practice) sown mung cultivar BARI Mung 6 on farmers' fields during *kharif* 1 of 2011, 2012, 2013, 2014 and 2015.

Season	No of demonstrations	Yield (kg/ ha)		% yield advantage
		Improved	Conventional	of improved technology
2011	19	**1498** ± 118	**NA**	**NA**
2012	105	**1448** ± 42	**1137** ± 41	**27**
2013	104	**1344** ± 38	**1070** ± 55	**26**
2014	104	**1395** ± 40	**1167** ± 46	**20**
2015	107	**1450** ± 61	**1243** ± 58	**17**

NA= not available

Across-season analysis showed consistent differences among districts with average yields highest in Jessore (1.66 t/ha) and lowest in Rajshahi (1.13 t/ha). This variation among districts was lower than the spread for lentil of 2.1 to 0.99 t/ha among districts from Chaudanga and Natore. In the mung demonstrations delayed sowing reduced yields. Part of this was associated with the significant effect of the preceding crop on yield, because with wheat - the preceding crop giving lowest mung yields – a late wheat harvest typically delayed mungbean sowing and this rotation is common in Rajshahi and Rajbari, the lowest yielding mung districts. Part also was associated with mung cropping within mango orchards producing low yields in Rajshahi. As anticipated the number of insecticidal applications had a significant effect on mung productivity in the demonstrations: A single application yielded 1292 kg/ha (SE 83.5) and in comparison two, three, four, and five applications yielded 9, 11, 20 and 28% respectively more yield on average over seasons. The number of harvests also significantly affected mean yield over seasons with a single harvest giving 1147 kg/ha and two and three harvests giving 12 and 29% respectively more yield.

Objective 3: To identify, test and promote short-duration pea in rice-based systems in Western Bangladesh

At the start of the project, pea was by far least explored in Bangladesh of the three project legumes. We started experimentation with two options for pea: Cropping for early dry seed production and for green vegetable production. On-station experiments on cropping system intensification negated the possibility of dry pea harvest in the dominant cropping pattern of T. *aman* and *boro* because of the extended duration of the dry seed pea crop. However, the green vegetable pea crop showed great potential on-station which was then tested on-farm as a fallow replacement. Two possibilities for the green vegetable pea crop were tested: sole cropping between successive rice crops and relay sowing into the standing T. *aman* rice.

To compare the relay versus sole cropping options, ten genotypes selected from germplasm evaluation under relay cropping into monsoonal rice were used in field experiment in Bangladesh. Contrasting genotypes, BARI motorshuti-3 (BM-3) Natore local-2 (NL-2) and Kaspa (Australian cultivar), were evaluated in three waterlogging treatments (drained control, 4 and 8 days waterlogging at germination) in the glasshouse at UWA. Conspicuous variation in waterlogging tolerance at germination was observed in the field (Fig 3.1) and confirmed under controlled conditions. In relay sowing in 2012 germination was severely affected (12 plants m^{-2}) compared to sole sowing (37 plants m^{-2}).

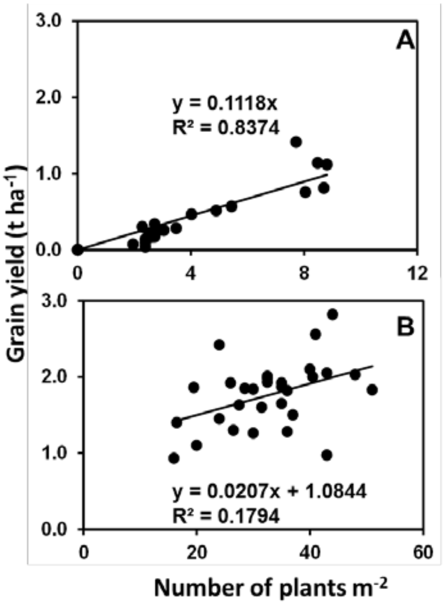

Fig. 3.1 Relationship between seedling plant density (plant m^{-2}) and seed yield (t ha^{-1}) in relay sowing in 2012 (A) and 2013 (B) cropping seasons.

Additionally, among genotypes BM-3 had 6 plants m^{-2} at germination which later died, whereas germination was 2-fold higher (13 plants m^{-2}) in NL-2 with all plants surviving. Presumably, waterlogging caused lowering the plant density in relay as seeds that had been waterlogged for an extended period reduced germination in pea (Crawford 1977), narrow-leaf lupin (*Lupinus angustifolius* L.) (Sarlistyaningsih et al. 1995) and pigeon pea (*Cajanus cajan* (L.) Millsp.) (Kumutha et al. 2008). Soil waterlogging also reduced the plant population during the vegetative stage as we found reduced plant population at harvest compared to at emergence (4.3 plants m^{-2} at harvest from 12 plants m^{-2} at emergence in relay cropping and 25 plants m^{-2} from 30 plants m^{-2} in sole sowing on Nov 1st) (Fig. 3.1). In the following season, during 2013, the plant population at emergence and at harvest of the sowing treatments were almost similar. However, there were genotypic variation in response to excess water during germination during relay sowing. In the glasshouse there was 14% germination in BM-3, 40% in NL-2 and 55% in Kaspa after 8 days of waterlogging. Such conspicuous differences in waterlogging tolerance at germination in the model pea are the first reported and illustrate prospects for its selection to improve adaptation to relay sowing in South Asia. This finding and the report by Malik et al. (2015) prompted us to screen a total of 120 pea accessions from 49 countries for waterlogging tolerance in a pot soil system at germination at UWA. There was significant variation among accessions in response to soil waterlogging, which was associated with geographic origin.

Turning to the evaluation of sole cropping peas squeezed into the fallow window between rice crops, we explored the whole cropping system to intensify with pea as sole crop. Six pea cultivars were evaluated for their suitability as a green vegetable with lentil as check in the cropping sequence trial in the first year (Fig 3.2). Our approach during 2011-12 was to identify pea cultivars to replace the short fallow between rainfed monsoon rice and irrigated spring rice. Selected cultivars were incorporated in subsequent experimentation (2012-13 and 2014-15) on-station. Extending to farmers' fields the comparison of green vegetable pea with fallow was also done.

While the main focus of experimentation was on legume options, we also examined different rice possibilities (short and long duration rice cultivars) in order to assess farm productivity in the cropping sequence trial. The early harvest of short duration rainfed monsoon rice cultivars (such as BRRI dhan33) allowed a longer gap (open the window) for land preparation for legume cultivation compared to the long duration BRRI dhan49 (Fig 3.2).

To fit peas into the rice-rice cropping sequence the green-pod stage of development must be complete by the third week of January to allow a timely transplant of irrigated spring

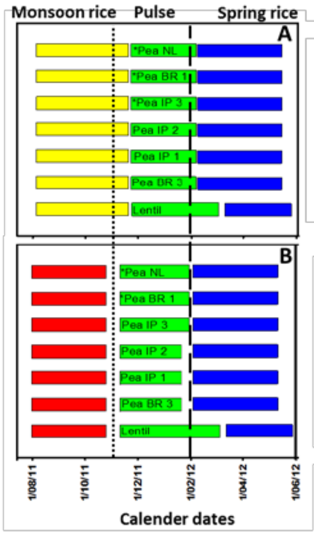

Fig. 3.2. Crop duration for monsoon rice, pulse and irrigated spring rice during 2011- 12 season. Horizontal length of bars represent duration of crop - yellow denote rice cultivar BRRI49 (full season) (A), red denote rice cultivar BRRI33 (short-season) (B), blue denote irrigated spring rice BRRI28. Pea cultivar (green) NL= Natore local, BR= BARI, IP = IPSA. *= up-rooted before harvest to make land available for timely transplant of irrigated rice. Dotted line represents optimum sowing time for pulse and dashed line represents optimum transplant time for irrigated spring rice

rice by early February. During 2011-12, among the six test lines pea cultivars, BARI3, IPSA1 and IPSA2 had reached this stage of development following the harvest of both long duration rice cultivar BRRI dhan49 and short-duration cultivar BRRI dhan33 (Table 3.2). Pea cultivar IPSA3 reached to a similar developmental stage only following the harvest of short-duration rice cultivar BRRI dhan33 (Fig 3.2). The other cultivars were too late. To confirm these findings, pea cultivars BARI3 and IPSA3 were included in 2012-13 and 2014-15 experiments. However, IPSA3 could only allow 1 to 3 days land preparation time for following irrigated rice (Table 3.1).The inclusion of an extra crop, pea as green pod vegetable, increased farm productivity (measure by Rice Equivalent Yield) by 1.4-fold over the dominant cropping sequence (rice - fallow - rice) and farm net income by four-fold. The study highlighted the advantages in total system productivity, monetary return and equivalent energy yield of crop intensification with the inclusion of a pea crop between successive rice crops instead of a fallow period (Table 3.1).

Equivalent grain energy yield, eliminate confounding effects of large inherent differences in the amounts of biomass of economic output and the fluctuating market price of the

Table 3.1 Yields of rainfed monsoon rice (BRRI dhan49, BRRI dhan 33), different pulses (pea and lentil) and irrigated spring rice (BRRI dhan 28) in crop sequence trial at Bangladesh Rice Research Institute (BRRI) Rajshahi during 2011-12, 2012-13 and 2014-15.

Year	Rainfed monsoon rice		Pulse		Irrigated spring rice (BRRI dhan28)	Grain energy yield (GJ ha-1)
	Cultivar (BRRI dhan)	Yield (t ha^{-1})	Name/Cultivar	Yield (t ha^{-1})	Yield (t ha^{-1})	
2011-2012	49	**4.2** ± 0.47	Pea/BARI3	**2.7** ± 0.32	**5.5** ± 0.31	**176.8** ± 7.41
	33	**3.6** ± 0.52	Pea/BARI3	**2.5** ± 0.16	**5.6** ± 0.28	**168.1** ± 13.06
	49	**4.3** ± 0.44	#Lentil/BARI6	**1.7** ± 0.30	**5.2** ± 0.51	**161.8** ± 9.52
	33	**3.4** ± 0.41		**1.7** ± 0.25	**5.0** ± 0.39	**145.9** ± 14.28
2012-2013	49	**5.0** ± 0.24	Pea/BARI3	**2.2** ± 0.12	**5.8** ± 0.76	**188.3** ± 14.00
	33	**4.3** ± 0.32	Pea/BARI3	**2.2** ± 0.07	**5.9** ± 0.56	**179.2** ± 11.79
	49	**5.1** ± 0.27	Fallow		**5.8** ± 0.51	**157.0** ± 4.36
	33	**4.1** ± 0.19	Fallow		**5.9** ± 0.47	**145.3** ± 9.35
2014-2015	49	**5.1** ± 0.20	Pea/BARI3	**3.2** ± 0.33	**5.7** ± 0.26	**201.8** ± 1.18
	33	**4.2** ± 0.20	Pea/BARI3	**3.0** ± 0.11	**5.6** ± 1.02	**184.2** ± 16.14
	49	**5.5** ± 0.22	Fallow		**5.3** ± 0.66	**156.1** ± 12.39
	33	**4.3** ± 0.20	Fallow		**5.0** ± 0.88	**134.6** ± 9.97

*NH = Not harvested (Uprooted as they did not mature). #Lentil= dry weight of seed

economic output, were used to compare the productivity of cropping sequences (Table 3.2). Fallow replacement by a pea crop gave significantly ($P<0.001$) higher productivity. However, long duration rainfed monsoon rice cultivar BRRI dhan49 produced higher yield than the short duration rainfed monsoon rice cultivar BRRI dhan33 and contributed to higher grain energy yield from the cropping sequence with the control fallow period (Table 3.2). Thus, pea cultivar IPSA3 is an option, if farmers change to shorter duration rice.

The long-term increasing trend for post monsoon rain (i.e. during November) is an issue for crop production (Hossain et al. 2014). Over three years of experimentation we experienced one such event during 2012-13 season. Following monsoon rice harvest farmers require a 'gap period' of 2-3 weeks for soil drying and cultivation prior to legume sowing. Any delay from unseasonal rains leads to a knock-on effect of late sowing/transplant. These projections, however, are often uncertain due to the number of different climate models available. While methodologies exist to downscale climatic projections to spatial and temporal scales more relevant to agricultural production (Corney et al. 2010) and to help identify the most suitable models to use (Smith & Chandler 2010), these methods still produce projections with a large range of variability and uncertainty.

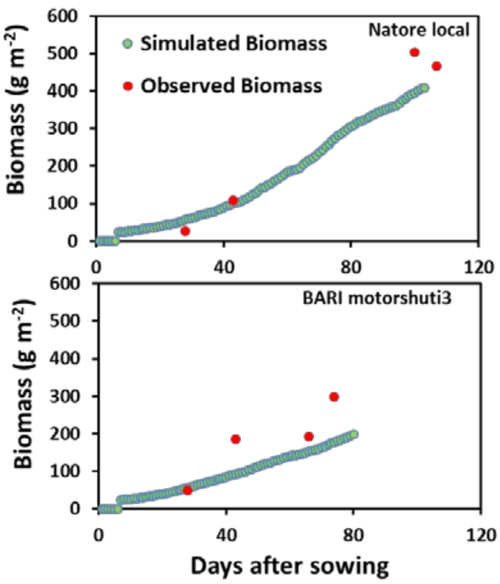

Fig. 3.3: Simulated and observed biomass accumulation for long and short duration pea Natore local and BARI motorshuti3.

An alternative method of assessing crop production under future climates is to use the range of possible climatic variables within a biophysical modelling framework to assess the resilience or sensitivity of agricultural production to scaled changes in climatic variables (Cullen et al. 2012). With that aim we have collected growth and yield data on two contrasting pea cultivars (long, Natore local and short duration, BARI motorshuti3) to assess how well APSIM simulates their growth and development under local conditions. Simulations of biomass accumulation (i.e. above ground dry mater, green pod weight) for Natore local and flowering time agreed well with observed data (Fig. 3.3). However, the model overestimated the duration of grain filling and underestimated biomass accumulation in BARI motorshuti3. This discrepancy is presumably due to the different growth habit of the two contrasting cultivars and further adjustment of cultivar-specific parameters is necessary. Then we aim to model the effects of possible future climate scenarios for the replacement of fallow by a green vegetable pea crop.

8 Impacts

8.1 Scientific impacts – now and in 5 years

The project aimed to intensify the rice based cropping system in Western Bangladesh by including the pulses, lentil, mungbean and pea. The project developed optimum cultivation technology for lentil and mungbean, and also successfully demonstrated replacing fallow by green pea as a vegetable crop between most dominant cropping pattern in Bangladesh, rainfed monsoon rice (T. *aman*) and irrigated spring rice (*boro*). The project also selected the best cultivar for these new niches to exploit the management x cultivar interaction and increase productivity. All these components have already positively impacted on pulse production in the project districts and will continue to grow the scientific impact in the broader aspect in Bangladesh. We anticipate scientific impact will also spill-over across the border in particular to West Bengal where rotations with pulses are similar.

The project recommended relay sowing of lentil into standing T. *aman* rice to avoid late-sowing lentil and low yields. This follows up the on-station research of Ali (2011) and represents the first use of on-farm relay on lentil in Bangladesh. Relay sowing into standing T. *aman* (~2 weeks earlier than the sole-cropped lentil sowing time) and recommended management practice has been taken up by farmers in the project area (see economic impact). Furthermore, project recommended improved technology for sole cropping of lentil has also been taken up and could be substantiated by the area and production increase (see economic impact) in the all 9 districts where 70% of the lentil are grown in Bangladesh.

Similar to sole crop lentil, project recommended improved cultivation technology of mungbean has been taken up by the farmers as evident be the increase in cultivation area and production (see economic impact) in the all 9 districts. Adoption survey showed that traditional varieties of mungbean have been replaced by improved varieties. Among the improved varieties, BARI Mung-6 was adopted at the highest level (64–70%). However 86% of the demo farmers and 79% of the non-demo mungbean farmers used spray to control pod borers in mungbean. Higher input use, timely sowing, and pest control practices certainly helped to produce higher yield and this also indicates a change in farmers' practice.

UWA scientists and the project coordinator worked closely with national scientist to jointly develop the project's experimental program; implementation was predominantly a national scientist activity, and writing-up the research results was a joint affair. As a result six scientific articles in international journals and one book chapter have been already been published and two journal articles were submitted and under review. Topics range from agronomy to crop physiology. These publications will and/or have attracted wider scientific community. For example, Malik et al. 2016 is already cited by an article in *Nature Plants*, a reputed science journal.

8.2 Capacity impacts – now and in 5 years

Project activities contributed to capacity development of farmers, extension officers in DAE and scientists. Farmers were exposed to crop specific training and field days organised by national scientists. Scientists and DAE personals were engaged in international educational tours, workshops and specific trainings. Scientists from different countries also received formal educational training (i.e. MSc and PhD).

Throughout the duration of the project crop see economic impact)-specific training sessions were organised for farmers. A total of 3,564 mungbean and 4,015 lentil farmers participated in day-long training on optimum pulse management practices. Furthermore,

Fig. 8.2.1 Women participants in field days.

8,585 mungbean and 17,960 lentil farmers participated during field days of which ~20 % participants were women (Fig 8.2.1). The impact of the training and participation in the field days are confirmed by the decreasing trend of the yield gap between demo farmers and non-demo farmers (Tables 1.3, 1.4 and 2.3).

Eight DAE personnel and eight BARI scientists attended a study visit to Nepal, a major regional lentil-producing country with a well-developed lentil relay-cropping production system. The National Grain Legume Research Program (NGLRP) of Nepal also has a well-connected outreach activity. Through the visits scientists from both countries benefited and fostered research collaboration. As a result, for example, as Stemphylium is becoming a major problem in Nepal, the Stempedia model research included a Nepali co-author. Similarities were identified to build collaboration as both countries are focused in increasing legume production by reducing rice-fallow cropping pattern. Sole cropping of lentil led to late sowing causing yield penalty in Nepal and in Bangladesh. Nepal is also focusing in increasing cropping intensity by introducing three crops in a year, for example, rice-lentil-mungbean. Four senior scientists of PRC-BARI visited the Indian Institute of Pulses Research (IIPR) in Kanpur and the Indian Agricultural Research Institute (IARI) in Delhi and also ICARDA activities in India. These visits exposed them to Indian pulse research and scientists and contributing to their capacity to solve common problems.

The project contributed to the development of the scientific practice and science communication of the national pulse program scientists. The project has raised the science communication ability of the scientists through writing of the research results into international scientific publications (see above 8.1 and publication list) and summarised the results as oral presentations for yearly progress report and wrap-up workshop. Furthermore, John Allwright fellow Md Shashin uz Zaman, Scientific officer, Pulse Research Centre, BARI is now in his 2nd year of PhD at UWA. His research focuses on waterlogging tolerance of pea at germination. Mr. Zaman ensuing expertise on physiological responses as well as genetic control waterlogging tolerance of pea at germination. He would be able to use the expertise to other crop as well as pulses upon returning to Bangladesh.

Scientists from Iraq, Indonesia and Cambodia have completed their MSc degree at UWA, after undertaking thesis research project within the project. The results have been published as theses and in international journals. These scientists are now contributing in their respective countries.

The project contributed to the planning and implementation of national pulse improvement in Bangladesh. Particularly noteworthy were the links built between BARI scientists and extensionists in the Department of Agricultural Extension (DAE) especially in the sector of dissemination of scientific output at the farmers' field level. We anticipate this relationship will continue and will be implemented for other crops in the future.

8.3 Community impacts – now and in 5 years

8.3.1 Economic impacts

Pulse area and production have increased significantly in the nine project districts (Fig: 8.3.1). DAE data show that lentil area increased by 46% from 91,993 ha in 2010-11 to 129,631 ha in 2014-15 and production by 63% from 119,639 t to 173,886 t, while in adjacent districts lentil area and production increased by only 16% and 13%, respectively, over the same period. Similarly, mungbean area increased by 41% from 30,233 ha in 2010-11 to 42,732 ha in 2014-15 and production by 37% from 39,471 t to 53,998 t within the same period. The area and production for mungbean in adjacent project districts was declined (area by 15% and production by 6%). In monetary terms, the price of these (i.e. lentil and mung) increased production is about AUS$68.1 million at AUS$912/t lentil and AUS$1180/t mungbean.

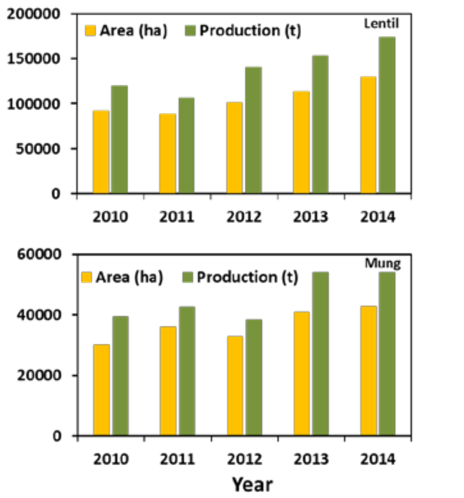

Fig 8.3.1: Area (ha) and Production (ha) of Mung bean and Lentil in all 9 project districts since 2010 to 2014 (DAE, 2015). In project districts during kharif 1 a total of 439 and during rabi season a total of 436 demonstrations. Each demonstrations were only 1ha.

Rabi season: Project recommended optimum cultivation technology (BARI cultivar, fungicidal application to control *Stemphylium* blight and line sowing) demonstrated lentil cultivation to farmers in 436 demonstrations. The project-recommended management package for lentil yielded on an average 28% higher compared to farmers' practice (local cultivar, traditional broadcast sowing and management). As a result cooperating farmers profited more than traditional-practice farmers. After meeting all production costs (seed, fertilizer, fungicides and labour) farmers made an average profit of 319 AUS$/ha. Furthermore, in some areas relay sowing of lentil on standing rainfed aman rice was appropriately done, yielded on an average 51% higher compared to neighbouring farmers' practice that gave an extra income of 491 AUS$/ha. For example, at Atgoria in Pabna the demonstration area was 2 ha 2012-13 season (Yr2) in that region 27 ha as under relay sowing. In 2014-15 the relay area had doubled from previous season and is ~ 150 ha with the unprompted involvement of ~600 farmers. The conservatively calculated value of this relay crop is AUS$ 0.18 M.

For green pea, farmers are very enthusiastic about the short-duration variety BARI Motorshuti 3 as it can be harvested for green pods within 60 days allowing a succeeding crop of irrigated boro rice – effectively replacing a fallow period. Total on-farm rice production (i.e. rainfed monsoon rice + irrigated spring rice) averaged 11.5 t/ha (calculated from on farm data discussed in Section 7, objective 3) where there was a fallow period between two rice crops. By contrast, replacing the fallow with modern pea cultivar BARI3 gave rice equivalent yield of 16.3 t ha-1, increasing farm productivity by 1.4-fold. This higher productivity gave more than a 4-fold increase in net return when farmers invested an extra AUS$ 856 (with green pod-picking as the major expenditure) over the usual cost of AUS$ 2,802 to raise two rice crops (Fig. 8.3.2).

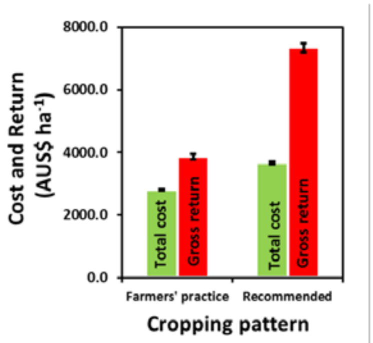

Fig 8.3.2: Total cost and gross income (AUS$) of farmers' practice and recommended cropping sequence. Values are the means of three locations standard errors.

Kharif 1: Project recommended optimum cultivation technology (short-duration BARI variety, line sowing, sowing with irrigation, timely weeding and insecticidal application) demonstrated mungbean cultivation to farmers in demonstrations. The project-recommended management package for mungbean yielded on an average 19 % higher compared to farmers' practice (local cultivar, traditional broadcast sowing and management) (Calculated from Table 2.3). As a result cooperating farmers profited more than traditional-practice farmers. After meeting all production costs (seed, fertilizer, insecticides and labour) farmers made an average profit of 300 AUS$/ha. From adoption survey we concluded that 83% of the demo farmers and 64% of the non-demo farmers has taken up project recommended technology. (i.e. modern cultivar BARI Masur-6, because for its high yield performance and disease tolerance).

8.3.2 Social impacts

Rabi season: Economic benefits slowly convert into social impacts. Lentil is a vital source of protein, with a mean content of 28.3% ranging from 15.9 to 31.4% (Grusak, 2009), especially for the poor, who cannot afford animal products. Lentil seed also contains high amounts of macro- and micro-nutrients (Ca, Fe, K, P and Zn), vitamins (Ascorbic acid, Inositol, Niacin and Vitamin A), fibre and carbohydrates for balanced nutrition (Bhatty, 1988; Savage, 1988). Adoption survey respondent farmers mentioned that their pulse consumption increased due to increased production of pulses. The statement came more from lentil farmers compared to mungbean farmers. The additional production of 54,247 t/an. of lentil represents additional local production of ~15,000 t of high quality dietary protein with ramifications into health. During the lifetime of the project (2011 to 2016) we estimate that ~ 112,914 farmers (each ha is cultivated by ~3 farmers) taken up lentil cultivation as an additional 37,638 ha came under lentil area. Conservatively calculated, from this extra lentil area ~ 564,570 people have benefited (average family size 5 person) in the form of extra income and/or dietary protein.

Green pod harvest of pea as a vegetable is developing into a major market opportunity from last year's demonstrations. It has created new opportunities for work in green pod harvesting by women and the preparation and marketing of resulting produce for transport to urban areas. Farmer interest had created a demand for pea seed. One farmer (Mr. Md Mintu) spontaneously insisted on converting his demonstration of green pod production into a seed increase during 2013-14 and sold seeds bulk (~100 kg) to neighbouring farmers at the start of next season. Mr. Mintu and his wife Ms Rehnuma Begum both were engaged in this enterprise (Fig. 8.3.2a). They made higher (1.6- fold, i.e. AUS$110 more) profit compared to selling green pod as vegetable without any further inputs. For lentils, project recommended relay-sowing yielded ~21% higher compared to the traditional way of sole-cropping. Lentil growers are enthusiastic to take up the technology and have started doing this in some areas following demonstrations (see Economic impacts Rabi season).

Fig 8.3.2a: Ms. Rehnuma Begum (farmer's wife) preparing pea seeds for market ready (left) and Mr. Md Mitu (farmer) showing pea seeds to visitors and farmers.

Kharif 1: In regions of western Bangladesh where the cropping pattern had a fallow (March to June) there is limited scope for income generation in the area at this time. Men migrate seasonally, but women often are unable to do so. Introduction of *kharif* 1 mungbean cultivation in the fallow period in *kharif* 1 has opened opportunities for

Fig. 8.3.2 Girls and women are engaged in mungbean pod harvest (top), woman processing harvested mungbean for market ready (bottom left) and woman buying cloths from mobile vendor on bicycle with extra income.

employment in the area during the lean period. Women and youth are involved in mung pod harvest (Fig 8.3.2) and can earn up to AUS$ 2.5 day^{-1}; they are also involved in post-harvest preparation of the produce to be ready for the market (Fig 8.3.2). Activities recommended by the project during the lean period have generated a social movement towards engagement in crop intensification through an extra crop between rice crops. The yield gap between demonstration plots and farmers' practice demonstrated decreasing trend, (was 31% in 2012 and 20% in 2015), possibly due to the exposure of farmers to previous demonstrations.

During the lifetime of the project (2011 to 2016) ~ 37,497 farmers (each ha is cultivated by ~3 farmers) taken up mung bean as an additional 12,499 ha came under mung bean area. Conservatively calculated, from this extra mungbean area ~ 187,485 people has been benefited (average family size 5 person) in the form of extra income and/or dietary protein.

8.3.3 Environmental impacts

The inclusion of pulse crops typically benefits succeeding crops by improving soil health as a result of biological nitrogen fixation and other rotational effects. Lentil, mungbean and pea - all fix atmospheric nitrogen in association with their Rhizobia. We anticipate knock-on improvements in soil health from the increases in pulse cultivation.

Project advocated to plough harvested mungbean haulm as green manure. For both lentil and mungbean most of the root systems remain in the field. Available research suggests that N associated with nodules and roots may contribute 30% to 60% of the total N accumulated by legume crops (Peoples et al. 2009). The amount of N fixed by legumes varies from 0 to 192 kg total N/ha around a mean of 80 kg total N/ha (Quinn, 2009). Most fixed N is removed as grain, with only a small percentage remaining in the soil. The carry-over of N, for example, from lentil is low at 23–45 kg N/ha. Furthermore, Ladha et al. (1996) reported that legume residues incorporated into the soil supplied N to rice and produced benefits comparable with that of 25 to 50 kg fertilizer N. Increased yields and protein contents of cereals grown in rotation with lentil and other grain legumes, in comparison to continuous cereals have been reported (Quinn, 2009). During the travelling workshop several mungbean farmers commented their saving of fertiliser inputs into their succeeding T. *aman* rice crop following project recommendation of ploughing harvested green mungbean haulm into the soil. During the lifespan of the project, the legume cultivation area increased by 50,000 ha (Fig. 8.3.1) and assuming a middle point (25 kg N/ha) for N fixation by these extra crop a total of 1250 t N was fixed by the crop which potentially replaced chemical N application.

8.4 Communication and dissemination activities

Communication and dissemination activities were conducted through training programmes and field days; and were organised to include researchers, NGOs, agriculture extension field level workers and farmers to implement and achieve project objectives (see Section 8.2). To ensure project impact, five brochures in Bangla (see publication list 10.2) were produced on different project technologies and distributed during the project and its extension.

Communication and dissemination activities bring the success of the project. Yearly programme implementation workshop for Scientists and DAE personnel's build a strong partnership between BARI and DAE. This partnership now has become the model for other agricultural activities in Bangladesh to take the scientific output to the farmers' field. The reduced yield gap between demonstration plots and farmers' fields showed the effectiveness of the communication and dissemination activities. A large number of farmers became interested in cultivating short-duration lentil and mungbean due to the availability of improved variety seed, higher yield, less cultivation cost and financial benefit. More than 70% lentil and 60% mungbean farmers responded during the adoption survey that project had a positive impact on the expansion of pulses area in project districts.

9 Conclusions and recommendations

9.1 Conclusions

The project aimed to sustainably increase the cropping intensity with pulses in the dominant rotation in Bangladesh, which is rainfed monsoon rice followed by irrigated spring rice. Cropping patterns are highly dynamic in Bangladesh and the replacement of short fallow between rice crops was the focus of such changes. We addressed two different seasons, *rabi* (i.e. November to February) and *kharif* 1 (March to June), with three legumes, lentil, mungbean and pea. As a consequence several research outputs have resulted in impressive impacts within the lifespan of the project with the overall additional value of AUS$ 68.1 million.

Among the legumes, lentils are grown in the eastern Gangetic plain where monsoonal rice dominates cropping (Miah and Rahman, 1993; Islam et al., 2013) and are the most favoured pulse nationally. To intensify cropping, focus was given where double rice cropping in a year is the pattern and two approaches were tested. Firstly, sole-cropped early-flowering lentil lines were too low yielding to replace fallow. The second approach of using relay sowing of lentil into rice before its harvest was found promising and is now being adopted instead of fallow to intensify the system. This opened a potential rotation niche for lentil between two successive rice crops in the eastern Gangetic plain.

Lentil production in the nine Western project districts, which comprise ~70% of the national lentil area, has risen by 63 % (54,247 t) worth AUS$ 49.4 million. Compared to the non-project districts where production rose by only 13 % during the project. Much of this can be attributed to the effect of the project. This is due to the transfer of the technologies of cultivar, Stemphylium blight management and relay sowing.

The mungbean national production is concentrated in Southern Bangladesh. Unlike for lentil, the nine project districts in western Bangladesh comprise only 26 % of the country's mungbean area, where production rose by 37 % (16,527 t) worth AUS$ 18.7 million compared to adjacent non-project districts where production fell by 6 %. Again much of this can be attributed to the effect of the project. This is due to the transfer of the technologies of cultivar, sowing date and method and integrated pest management.

Pea contrasts with the two pulses, lentil and mungbean, in that the project research output of a technology package for green pod production (comprising cultivar and associated management practices) was only just starting to be translated into adoption and impact by the end of the project. But the prospects are excellent for green vegetable pea to replace the fallow between aman and boro rice as it was found highly beneficial from agronomic, economic and energy perspectives. An estimated 5-7 % or ~ 100,000 ha of the 1.8 million ha of land under this rotation has upland soil suited for pea production (Ahmad 2013). Vegetable peas have a ready market in nearby metropolitan Dhaka with its population of ~17 million.

9.2 Recommendations

Technology transfer

Project activities aimed to intensify rice-rice cropping with a pulse. To ensure a pathway to impact strong links were established between BARI research scientists and DAE extensionists. DAE is the agricultural institution with the widest rural coverage in Bangladesh. As a result of BARI/DAE links, project-developed technologies were rapidly up-scaled through demonstrations to a wide range of stakeholders across the nine districts. The early establishment of these links during the project cycle was crucial to the success of dissemination leading to technology adoption and project impact. This is a lesson for other projects.

Looking ahead for lentil and mungbean the transfer of technology should be deepened by DAE with BARI support in the nine project districts and broadened to suitable areas beyond the nine target project districts. Part of this will occur in the Barisal Division within the planned project CIM/2014/076.

With the package of technology for green pod production developed, its dissemination now needs a focused campaign to move the potential as a project output into adoption and impact. Candidate institutions for this role include DAE and other research/development projects. A key unaddressed issue especially for green pea production is the limited seed availability. During the project's extension phase we canvassed the private seed industry's interest to enter the pulse sector. Under current circumstances they are uninterested. Encouraging local entrepreneurs such as those mentioned in Section 8.3.2 is among approaches to be explored in the informal seed sector (McGuire and Sperling 2016).

Research

Lentil cultivars with resistance to Stemphylium blight: In the project we developed and extended a package to manage Stemphylium blight based on fungicidal application optimized with the Stempedia model. Elsewhere in South Asia the disease has increased in prominence in both Eastern India and the western Terai of Nepal recently. In the project we also identified sources of host plant resistance to Stemphylium blight, offering for the longer term the prospect of cultivars with higher levels of resistance than those currently available. To this end, a regional program is required to breed lentil cultivars with resistance to Stemphylium blight with ICARDA and national programs for the longer term.

Lentil late sowing technology package: Approximately 35-40% of the lentil area nationally is late sown because it succeeds a late-harvested T. aman rice crop. The project started to address the issue of modifying lentil production technologies developed for optimum sowing time to suit these late-sowing conditions. On the genotype side we found that the existing cultivars BARI Masur-4, -5, and -7 and BINA Masur-5 produced higher yields under late planting condition than short duration lines and may be used for late planting. Research on agronomic practices to complete the technology package for late-sowing is now required to move this thrust forward.

Mungbean – The management of pests is the key issue for mungbean production in Bangladesh. The project experimented with botanicals without success and integrated pest management (IPM) hinges on insecticidal application. Further research on IPM is required - some of which will be possible within the new project CIM/2014/076.

Mechanization through zero tillage planting is to shorten the crop turnaround time after rice and wheat in mungbean and also in green pea production (see below). A survey on mechanization was conducted during the project extension. The widespread availability of suitable equipment and operators was considered a major problem to be overcome.

Peas: The novel strategy toward intensification of relay sowing of lentil and of green pea suggests other avenues for investigation to shorten the crop turnaround time between successive rice crops:

- The crop model for pea needs to be completed in order to test the technology package for green pod production against a range of climate futures.
- A cultivar of early pea for green pod production adapted to relay sowing is now required.
- Waterlogging tolerance is needed in both pea and lentil

10 References

10.1 References cited in report

Ali, M. O. (2011) Enhancing lentil (*Lens culinaris* Medik.) production through relay cropping in transplant aman rice in medium low lands of Bangladesh. PhD Thesis, University of Rajshahi, Rajshahi, Bangladesh.

Bakr, M.A., Ahmed, F. (1992) Development of Stemphylium blight of lentil and its control. Bangladesh Journal of Plant Pathology 8: 39-40.

Bhatty, R. S. (1988) Composition and quality of lentil (*Lens culinaris* Medik.): a review. Canadian Institute of Food Science and Technology 21: 144–160.

Corney, S. P., Katzfey, J. J., McGregor, J. L., Grose, M. R., Bennett, J. C., White, C. J., Holz, G. K., Gaynor, S.M., Bindoff, N. L. (2010) Climate Modelling. Climate Futures for Tasmania: Climate Modelling Technical Report. Hobart, Tasmania: Antarctic Climate & Ecosystems Cooperative Research Centre.

Crawford R.M.M. (1977) Tolerance of anoxia and ethanol metabolism in germinating seeds. New Phytologist 79:511–517.

Cullen, B. R., Eckard, R.J., Rawnsley, R. P. (2012) Resistance of pasture production to projected climate changes in south eastern Australia. Crop and Pasture Science 63:77–86.

Erskine, W., Hussain, A., Tahir, M., Baksh, A., Ellis, R.H., Summerfield, R.J. and Roberts, E.H. (1994) Field evaluation of a model of photothermal flowering responses in a world lentil collection. Theoretical and Applied Genetics 88: 423-428.

FAO. 2010. FAOSTAT Statistical database of the United Nations Food and Agriculture Organization (FAO), Rome.

Grusak, M. A. (2009) 'Nutritional and health-beneficial quality'. Pages 368–390 in W. Erskine, F. J. Muehlbauer, A. Sarker, & B. Sharma (Eds.), The lentil—Botany, production and uses, Wallingford, UK: Comm Agric Bureaux.

Islam, S. Q. M., Miah, M. A., Zaman, A. M. U. & Hossain, S. (2013). Baseline survey on introduction of short duration pulses into rice-based cropping systems in western Bangladesh. In: Zaman, S.M., Hossain M. A., Khaleque, A. M., Ali, O. M., Hossail, A.M., Haque, M. A. H. M., Khalaquzzaman, K. M., Islam, M. M., Hossain, M. A. (Eds.), Annual Research Report, Pulses Research Centre, BARI, Ishwardi, pp. 175-184. Pabna, Bangladesh.

Kumutha, D., Sairam, R.K., Ezhilmathi, K., Chinnusamy, V., Meena, R.C. (2008) Effect of waterlogging on carbohydrate metabolism in pigeon pea (*Cajanus cajan* L.): Upregulation of sucrose synthase and alcohol dehydrogenase. Plant Science 175: 706–716.

Ladha JK, Kundu DK, Coppenolle A-V, G M, Carangal VR, Peoples MB, Dart PJ. 1996. Legume Productivity and Soil Nitrogen Dynamics in Lowland Rice-Based Cropping Systems. Soil Science Society of America Journal 60: 183–192.

Malik, A.I., Ailewe, T.I., Erskine, W. (2015) Tolerance of three food legume species to transient waterlogging. AoB Plants. DOI: 10.1093/aobpla/plv040

McGuire, S., Sperling, L. (2016) Seed systems smallholder farmers use. Food Security 8: 179–195.

Miah, A.A. & Rahman, M.M. (1993). Agronomy of lentil in Bangladesh. In: Erskine, W., Saxena, M. C. (Eds.), Proceedings of the Seminar on Lentil in South Asia, 11-15-March 1991, New Delhi, India. pp. 128-137. ICARDA, Aleppo, Syria.

Peoples MB, Brockwell J, Herridge DF, Rochester IJ, Alves BJR, Urquiaga S, Boddey RM, Dakora FD, Bhattarai S, Maskey SL, Sampet C. Rerkasem B., Khan DF., Hauggaard-Nielsen H., Jensen ES. 2009. The contributions of nitrogen-fixing crop legumes to the productivity of agricultural systems. Symbiosis 48: 1–17.

Purseglove JW (1968) Tropical Crops Dicotyledons. Longman, London UK.

Quinn, M. A. (2009) 'Biological nitrogen fixation and soil health improvement.' Pages 229–247 in W. Erskine, F. J. Muehlbauer, A. Sarker, & B. Sharma (Eds.), The lentil—Botany, production and uses, Wallingford, UK: Comm Agric Bureaux.

Ramakrishna A, Gowda C.L.L., Johansen C. (2000) Management factors affecting legumes production in the Indo-Gangetic Plain. (In) Legumes in rice and wheat cropping systems of the Indo-Gangetic Plain-constraints and opportunities. ICRISAT, Patancheru, Andhra Pradesh, pp 156–65.

Sarlistyaningsih, L., Sivasithamparam, K., Setter T.L. (1995) Influence of waterlogging on germination and survival of lupin seeds (*Lupinus angustifolius* L. cv. Gungurru) coated with calcium peroxide and streptomycin. Animal Production Science 35, 537–541.

Savage, G. P. (1988), 'The composition and nutritive value of lentils (*Lens culinaris*).' Nutr. Abs. Rev. (Series A), 58, 320–343.

Zareen S, and Johansen C (2010) Sub-sector Analysis of Lentil in Bangladesh. A Project Report of ACIAR Project LWR/2005/001 Addressing constraints to pulses in cereal-based cropping systems, with particular reference to poverty alleviation in north-western Bangladesh.

10.2 List of publications produced by project

Journal Publications:

Malik, A.I., Ali, M.O., Zaman, M.S., Flower, K., Rahman M.M., Erskine, W. (2015) Relay sowing of lentil (*Lens culinaris* subsp. *culinaris*) to intensify rice-based cropping. Journal of Agricultural Science. 154, 850-857. DOI:10.1017/S0021859614001324

Malik, A.I., Ailewe, T.I., Erskine, W. (2015) Tolerance of three food legume species to transient waterlogging. AoB Plants. DOI: 10.1093/aobpla/plv040

Wiraguna, E., Malik A.I., Erskine, W. (2016) Waterlogging tolerance in lentil (*Lens culinaris* Medik. subsp. *culinaris*) germplasm associated with geographic origin. Genetic Resources and Crop Evolution. DOI:10.1007/s10722-016-0385-0.

Hossain, A. (2015) Efficacy of some insecticides against insect pests of mungbean (*Vigna radiata* L.). Bangladesh Journal of Agricultural Research. 40, 657-667.

Hossain, A. (2015) Development of insecticide-based management package against insect pests of mungbean (*Vigna radiate* L.). Bulletin of Institute of Tropical Agriculture Kyushu University. 38, 55-63.

Salam, M.U., Day, T.K., Ahmed, A.U., Nessa, B., Haque, A.H.M., Subedi, S., Malik, A.I., Rahman, M.M. and Erskine, W. (2016) Stempedia: A weather-based model to explore and manage the risk of lentil *Stemphylium* blight disease. Australasian Plant Pathology. 45:499–507. DOI: 10.1007/s13313-016-0434-3.

Malik, I.A., Nasim, M., Flower, K., Hossain, M.A., Rahman, M.S., Anwar, B., Ali, M.O., Rahman, M.M., Erskine, W. (Submitted) Cropping system intensification in the Eastern Gangetic Plain: Vegetable pea can replace fallow between rainfed monsoon rice and irrigated spring rice. Journal of Agricultural Science.

Zaman, M.S.U., Malik, A.I., Kaur, P., and Erskine, W. (Submitted) Genotypic variation for waterlogging tolerance of pea at germination. Functional Plant Biology

Edited book Chapter:

Erskine, W., Upadhyaya, H.D., Malik, A.I. (2014) Challenges and examples: Salinity. In: Jackson M., Ford-Lloyd B. & Parry M. (eds.) Plant Genetic Resources and Climate Change – a 21st Century Perspective. CABI, UK. Pp 236-250.

Conference Publications:

Ali, O., Zuberi, M.I., Sarker, A. (2012) Lentil relay cropping in the rice-based cropping System: An innovative technology for lentil production, sustainability and nutritional security in changing climate of Bangladesh' Poster at 1st Asian Food Security Association (AFSA) Conference 15-17 September 2012, Osaka Prefecture University, Osaka, Japan.

Malik, A.I., Ailewe, T.I., Zaman, M.U.Z., Ali, O., Flower, K., Rahman, M.M., Erskine, W. (2013) Growing pea and lentil in rice-based cropping system. Invited presentation at 11th Conference of International Society for Plant Anaerobiosis (ISPA), 6-11 October 2013, IRRI, Philippines.

Ali, O., Sarker, A., Kumar, S., Matiur, R., Erskine, W., Malik A. I. (2014) Advances of Lentil Research and Development in Bangladesh. Poster presentation at 6th International Food Legume Conference (IFLRC VI), 8-10 July 2014, Saskatoon, Saskatchewan, Canada.

Rahman, M.M., Malik, A.I., Flower, K., Ali, O., and Erskine, W. (2014) Lentils in conservation agriculture: Relay cropping in Bangladesh. Poster presentation at 6th International Food Legume Conference (IFLRC VI) 8-10 July 2014, Saskatoon, Saskatchewan, Canada.

Malik, A.I., Ailewe, T.I., and Erskine, W. (2014) Variation in physiological responses in pea and lentil to soil waterlogging. Invited presentation at 6th International Food Legume Conference (IFLRC VI) 8-10 July 2014, Saskatoon, Saskatchewan, Canada.

Rahman, M.M., Erskine, W., Siddique, K.H.M., Thavarajah, P., Thavarajah, D., Zaman, M.S., Materne, M.A., and McMurray, L.M. (2014) Selenium biofortification of lentil in Australia and Bangladesh. Invited presentation at 6th International Food Legume Conference (IFLRC VI) 8-10 July 2014, Saskatoon, Saskatchewan, Canada.

Ali, O., Rahman, M.M., Erskine, W. Malik, A.I. (2014) Pea as relay crop in between monsoon rice and summer rice: a Resource Conservation Technology. Poster presentation at International Conference on Conservation Agriculture for Smallholders in Asia and Africa, 7-11 December 2014, Mymensingh, Bangladesh.

Malik, A.I., Wiraguna, E., Zaman, M.S.U., Erskine, W. (2016) Waterlogging tolerance in lentil and pea associated with geographic origin. Invited presentation at 12th Conference of The International Society for Plant Anaerobiosis conference (ISPA), 5-8th September 2016, Denmark.

Malik, A.I., Ouk, A., Erskine, W. (2016) Selection for salinity tolerance in lentil. Poster presentation at Australian Pulse Conference, 12-14th September 2016, Tamworth.

Production technology brochures:

Rahman, M.M., A. Hossain, Ali, O. (2013) মুগ ডাল উৎপাদন প্রযুক্তি (Mungbean production technology: a leaflet in Bangla). ACIAR, Rice-Pulse Project.

Rahman, M.M., Ali, O., Haque, M.M., Dey, T.K. (2013) মসুর ডাল উৎপাদন প্রযুক্তি (Lentil production technology: a leaflet in Bangla). ACIAR, Rice-Pulse Project.

Rahman, M.M., Ali, O. (2014) অমন ধানের সাথে মসুরের সাথী ফসলের চাষ. (Relay lentil technology: a leaflet in Bangla). ACIAR, Rice-Pulse Project.

Rahman, M.M., Ali, O. (2015) অমন-বোরো ধানের মাঝে মটরশুঁটি চাষ (Cultivation of green pea in between T. aman and boro rice: a leaflet in Bangla). ACIAR, Rice-Pulse Project.

Rahman, M.M., A. Hossain, Ali, O., Alam, J (2016) মসুর ও মুগের মান সম্পন্ন বীজ উৎপাদন প্রযুক্তি (Quality seed production technology for lentil and Mung bean: a leaflet in Bangla). ACIAR, Rice-Pulse Project.

11 Appendixes

11.1 Appendix 1:

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