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// 1 Acknowledgments

As is often the case with completing large, multi partner research and development activities, all project team members have contributed to finalising this report well beyond what was originally anticipated or agreed. The persistence and ongoing contribution by all team members to ensuring the project delivers the best possible results is gratefully acknowledged.

The project team also acknowledges Gavin Tinning and Peter Regan, NSW Department of Primary Industries, who coordinated the successful completion of this report.

2 Acronyms

2WT	Two Wheel Tractor
4WT	Four Wheel Tractor
AARES	Australian Agricultural and Resource Economics Society
ACIAR	Australian Centre for International Agricultural Research
AusAID	Australian Agency for International Development
BCD	Broadcast Dry
BCR	Benefit Cost Ratio
BCW	Broadcast Wet
CARDI	Cambodian Agricultural Research and Development Institute
CaSAMNet	Cambodian Society for Agricultural Machinery Network
CAVAC	Cambodia Agricultural Value Chain Program
CCA	Cambodian Country Almanac
CDRI	Cambodian Development Resource Institute
CIM	Crop Improvement and Management (ACIAR)
CIMMYT	International Maize and Wheat Improvement Center
CLEAR	Cambodian Land and Environment Agricultural Resource
CSE	Cropping Systems and Economics (ACIAR)
CW	Complete Weeding
DAS	Days After Sowing
DAT	Days After Transplanting
DS	Dry Season
DSR	Dry Seeded Rice
EWS	Early Wet Season
FFGD	Farmer Focus Group Discussion
FFS	Farmer Field Schools
FP	Farmer Practice
FT	Full Tillage
GDA	General Directorate of Agriculture
HW	Hand Weeding
ICE	Integrated Crop Establishment
iDE	International Development Enterprises
IREC	Irrigation Research and Extension Committee
IPM	Integrated Pest Management
IRRI	International Rice Research Institute
IWM	Integrated Weed Management
MAFF	Ministry of Agriculture, Forestry and Fisheries
MRR	Marginal Rate of Return
NGO	Non Government Organisation
NPV	Net Present Value
NSW DPI	New South Wales Department of Primary Industries
NV	Net Value
PDA	Provincial Department of Agriculture
PPE	Personal Protection Equipment (PPE
RAEM	Russeykeo Agricultural Equipment Manufacturer
R,D&E	Research, Development and Extension
RUA	Royal University of Agriculture
SMCN	Soil Management and Crop Nutrition (ACIAR)
ToT	Training of Trainer
TPL	Transplanted
UCA	United Cambodia Agri
UNE	University of New England
UniSA	University of South Australia
WSR	Wet Seeded Rice
ZT	Zero Tillage

3 Executive summary

Rice remains the cornerstone of Cambodian agriculture. Over the last few years production systems have undergone more radical change than in the last few hundred years. The major changes relate to the spread of direct-seeding, a significant increase in irrigated rice, and the uptake of mechanisation to replace animal draught for land preparation.

The project successfully completed a large number of field experiments and demonstrations as well as socio-economic surveys and database development. These activities have produced a large volume of useful new information which, if adopted, will improve rice crop establishment, productivity and profitability in Cambodia.

Direct seeding and integrated weed management

The first emphasis of this project was improvements in direct-seeded rice production, predominantly into dry paddies. Common constraints to achieving higher productivity in both dry and wet-seeded rice involve delays in land preparation leading to late crop establishment, excessive weed infestation, uneven crop emergence and poor water control.

The project analysed, adapted and developed capacity for the use of new machinery options which were shown to provide farmers with the capacity to better establish direct-seeded rice. The widespread adoption of direct seeding in rice-based systems has led to greater pressure from weeds, which the majority of Cambodian farmers are now more efficiently controlling by using herbicides.

The project has evaluated an integrated weed management (IWM) strategy which includes options for rotation of herbicides to delay the onset of herbicide resistance and combination with manual/mechanical secondary weed control. Documentation has been prepared for presentation to policy makers on the need for an IWM strategy for effective weed control as well as a National Herbicide Resistance Management Strategy. Development of such a strategy will require improvements to the national listing of registered pesticides and complete engagement with farmers, retail outlets, herbicide distributors and importers.

Mechanisation

Another focus of the project was on refining suitable options for mechanisation, both in wet and dry-direct seeded rice and in conservation or zero-tillage cropping. Improvement in rice establishment through mechanisation introduced by the project has provided options to reduce the burden of labour shortages in the rural communities in Cambodia.

A range of tyned and disc seed drill options have been evaluated and improved, and a Cambodian drill solution suitable for existing 2-wheel tractors was developed in cooperation with a private machinery manufacturer. Economic analysis has shown that the seed drill is a potentially good investment, subject to at least a 50% greater contract hiring rate or achieving 10% improved grain yields. Strong farmer interest in the technology to date demonstrates it represents a perceived useful solution. Commercial sales have commenced with interest shown by input suppliers to put machines on display at regional sales outlets. It is expected that the Cambodia seed drill designed by the project team will have a significant impact within the next few years. However, the machinery development is at a critical stage where technical support for technology modifications and improvements is needed to respond adequately to early adopting farmer feedback, and not risk commercial failure.

Costs of land preparation were shown to be reduced using zero tillage practices. However, further research is required to increase crop yields and overcome constraints related to degraded soils, management of crop residues and harvest management. Zero-tillage rice establishment requires specific drill technology and also increases the reliance on chemical weed control, with related people and environment safety issues.

Private sector engagement

The most likely and sustainable adoption pathway for project innovations is considered to be via agricultural input and tractor-machinery dealers. The likely future role of government research and extension agencies, who have little more than 1% of one-on-one contact with farmers, is the provision of unbiased technical information and training to commercial agronomists and input/machinery dealers. It is important for future research projects to engage directly with agricultural input and machinery dealers as well as with traditional government and/or institutional partners.

Farmer training will ultimately be delivered by retail outlets, so government agencies will need to recognise them as essential partners in the delivery of new technical information to farmers.

Crop intensification and on-farm trials

A third set of issues relates to the improvement of productivity and profitability of irrigated rice systems in Cambodia by intensification – growing two or three crops per year rather than one. The analysis of combined data sets from the integrated crop establishment (ICE) experimental program has enabled the development of evidence-based recommendations for establishment practices for different soil types, rice growing environments and crop seasons. Economic analysis of cropping systems, weed management and mechanised seeding options has enabled fully integrated technology recommendations to be produced.

Further work is required to identify the most suitable rice and non-rice crop sequences and, where supplementary irrigation is available, to determine the benefit/cost and farm level economics of different non-rice rotation options.

Farmer field schools were successfully completed and key information on weed management, machinery innovations, crop establishment and fertilizer application have been utilized by participating farmers. Data collected on-farm has enabled statistical and economic analysis of improved practices for: weed management; seeding rates; machine planting (drum and drill seeders) and optimum fertilizer rates and timing.

These analyses are in a format suitable for use in Training of Trainer (ToT) programs for capacity building and effective out-scaling of technology via Provincial Departments of Agriculture (PDA), Non-Government Organisations (NGOs), one-stop shop retail outlets and leading farmers. Project technologies are already being rolled out by United Cambodia Agri (UCA), a large input supplier with qualified agronomists providing post-sales technical support to farmer clients.

Economic analyses

The project enabled the refinement and economic analysis of best bet technology recommendations according to topographical differences in water and soil environments and crop seasons. The options have been highlighted in tabulated form to make it easier to tailor technology packages for the different topo-sequence scenarios.

Economic analysis has been integrated into the technology recommendations. This has helped greatly in the interpretation of the project findings with regard to production gains. Gross margin and partial budgeting analysis has provided key insights as well as contradictions to popular farmer beliefs. For example economic analysis does not support the use of high seeding rates (greater than 150 kg/ha) to suppress weeds.

Translating agronomic data into farmer recommendations was a challenge for the Cambodian socio-economics team and despite the capacity building activities that took place under the project, there is a need for further training of professional staff in basic agricultural production economics.

The basis for inclusion or exclusion of labour in economic analyses was debated within the project team and considerable time and effort was invested to ensure representative analysis techniques were applied. The project was conceived on the basis that changes in cropping practices, mechanisation and herbicide use were driven by the declining availability of labour in the rural workforce. All experimental treatments involved different levels of family and hired labour input, and labour as a “cost that varies” between treatments must be included in economic analysis of experimental agronomic data. Further capacity building in the basics of agricultural production economics is required.

Project impacts

The project is already making scientific and community impacts. The project has made a significant contribution to defining and refining best practice recommendations for crop establishment, weed management and cropping systems which will underpin new technology packages. Rapid changes in practices occurred in the target districts between 2010 and 2013. Adoption of best practice in farming systems, lower seeding rates, better weed management, yield-targeted fertilizer application and improved machine seeding options, are likely to be adopted in the next 5 years as a result of the project.

A significant repository of baseline information and data has been collected and is available in the Cambodian Land and Environment Agricultural Resource (CLEAR). This provides an accessible database to support agricultural development and is available to over 350 people in Cambodia. However, a mechanism to maintain and update such a resource has yet to be put in place.

Institutional roles

One of the key outputs of the project is that the different institutions in Cambodia have worked together in the development of agronomic options and as a result cooperation among the groups has been enhanced. While some sharing of resources occurred, it was evident however that this did not extend to multi-disciplinary sharing of facilities or sites. Overall project results across the different sites were excellent but the value of combined analysis of data was limited because the different organisations measured a different variety of crop development parameters and this severely limited analysis and interpretation of the crop yield data with regard to yield components.

In any future joint project opportunities, Cambodian Government institutions involved in the project could more effectively utilize and share their existing resources and facilities and, while effective inter-institution collaboration is always a challenge, this would strengthen project outputs for improvement of livelihood of smallholders. To ensure that this outcome is achieved, the parties should discuss and agree on the format of collaboration being very clear on roles and responsibilities, and implications for intellectual property sharing arrangements prior to commencement of the activities and sign off on these. This should especially include arrangements for sharing of common experimental sites and shared responsibilities for measurements and data recording according to the mix of technical expertise across the partners. The institutions should share and nominate leadership of aspects in proportion to their technical expertise with regard to soil management and crop protection.

Saline groundwater

With the increased use of saline groundwater in both Cambodia and Australia for rice irrigation, it was critical to determine whether water salinity or soil toxicities and other yield constraints affect the potentially higher yield of these irrigated systems. In Cambodia, there is a significant amount of work left to do with regard to integrating non-rice crops into the system. In Australia, a potential new model for the screening of rice cultivars for salinity tolerance is being explored which may have significant impacts for assessing salinity tolerance in all field crops.

This has been a large and successful project. It has brought together four Cambodian and three international project partners many of whom have not worked together before. It has identified that rice productivity in Cambodia can be increased by the adoption of more intensive cropping programs of two or even three crops per year, utilising mechanisation and better weed control. The project leaves a legacy of rice crop establishment, weed management, fertiliser management and mechanisation trial results, the CLEAR database, and improved skills of researchers in Cambodia in the conduct of socio-economic analysis of agricultural research trials. The impact of the project over time will be maximised by engaging and training the private sector.

4 Background

Cambodia

Rice accounts for over 80% of Cambodia's 3.42 million hectares of cropped area and 50% of the agriculture sector output, the production from which is mostly consumed domestically. 75% of Cambodian rice is still produced in the main wet season under rain fed systems. The Cambodian government has articulated a new rice policy to transform Cambodia into a "rice basket" and become a major rice exporting country, aiming for an annual paddy surplus of more than 4 million tons and milled rice exports reaching at least 1 million tonnes by 2015.

In 2010, Cambodia reported a 3.3 million tonne paddy surplus while almost a quarter of provinces typically face food deficit and 11% of all households (mostly in rural areas) are considered food insecure (rising to 18% during the dry season), with many facing a food deficit for 1–2 months each year. This new rice policy aimed to transform the country from a subsistence into a commercially oriented sector to improve national food security and reduce poverty, and is creating a momentum of development activities across the country.

Figure 4.1. Map of Cambodia showing the target provinces.

In the past decade, rural Cambodian labour required for transplanting rice has increasingly become limited due to rural-urban and abroad migrations. As a result, direct seeded rice via manual seed broadcasting has dramatically replaced transplanted rice in rainfed lowland systems.

While the incentives for adoption of seed broadcasting techniques are their rapidity and ease of implementation, low labour cost and a quick rice establishment in irrigated areas, some significant limitations are experienced including: high seed rate (high input cost), high losses to seed predation, poor establishment, and high weed burden due to uneven land levelling and non-uniform seedbed preparation, and generally a technique less adapted to rainfed systems. At the same time, there has been a tendency to further intensify rice production through double cropping with supplementary irrigation. In Cambodia, two distinct cultural practices exist for direct seeding of rice:

1. Dry direct seeding (or Dry Seeded Rice - DSR) is where dry seeds are manually broadcast onto a prepared seedbed and incorporated by harrowing, followed by irrigation or waiting for rainfall. Land preparation is typically poor and rice establishment rates are generally low and uneven, despite the use of high seeding

rates up to 400 kg/ha to compensate. The use of such high seeding rates is a major diversion of seeds from food use or sale. Weeds are a major problem in dry seeded rice as the crop and weeds emerge together, and early weed control is important to prevent substantial crop losses.

2. Wet direct seeding (or Wet Seeded Rice – WSR) is where pre-germinated seeds are sown into puddled fields which have been recently drained, or into standing water where there is adequate water drainage, and supplementary water is available. Pre-germinated seed is also commonly used in establishing nurseries for transplanting in the main wet season, in recession areas, or in large irrigated areas. As with DSR, WSR crop losses due to weed competition can be severe without timely and adequate weed control.

The project focussed on three provinces, namely Kampong Thom, Takeo and Kampot (Figure 4.1). Each province has varying degrees of mechanisation and covers a range of lowland rice ecosystems that are affected by seasonal rainfall and position in the topo-sequence. The annual average rainfall at Phnom Penh, positioned central to the target provinces, is 1407 mm (Figure 4.2).

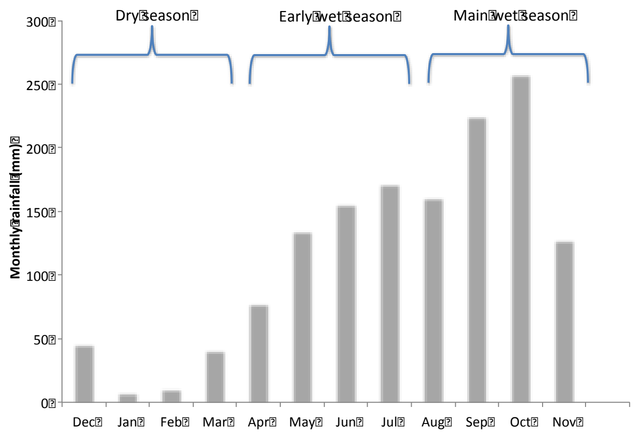


Figure 4.2. Rainfall distribution at Phnom Penh, Cambodia.

The Cambodian cropping calendar is conventionally divided into the dry season (DS) which extends from December to March, the early wet season (EWS) which extends from April to July and the main wet season (MWS) which extends from August to November (Figure 4.2).

In the dry season, rice can be grown if fully irrigated and, in recession areas rice and other crops can be established as main wet season flood waters recede and grown with supplementary irrigation. Rice can be grown in the early wet season with supplementary irrigation and rainfed rice is grown in the main wet season. The rice field topo-sequence (lower, middle and upper fields) influences, in particular, the dynamics of water and impacts when and how rainfed rice is established.

Coinciding with changes in crop establishment techniques in Cambodia is the growing use of farm machinery in rice production, replacing manual labour and animal draft power for tillage and transportation. The number of two wheel tractors (2WT) in operation has markedly increased since the early 2000s with a sharp rise observed over the last 3-4 years (Figure 4.3). In 2013, the official 2WT fleet numbered in excess of 150,000, which is equivalent to approximately 18% of the recorded number of ploughs or harrows in Cambodia. Two wheel tractors are primarily used for land preparation (disc ploughs, mouldboard ploughs, tine harrows and levelling boards). 2WT are also used for transportation, as power source for pumping irrigation water and for threshing crops. A similar trend in mechanisation is being observed with mechanised combine harvesters.

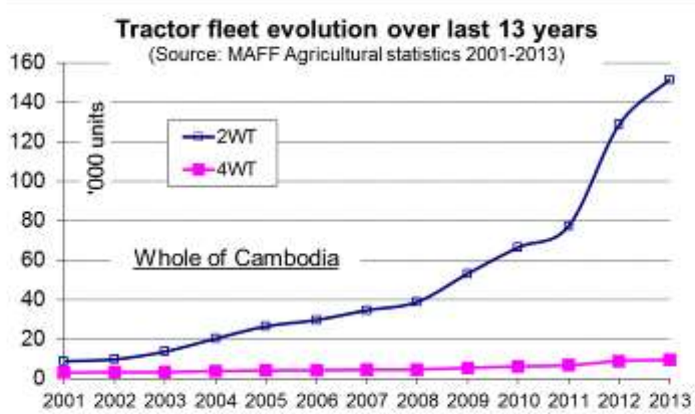


Figure 4.3. Trends in ownership of 2-wheel and 4-wheel tractors in Cambodia.

The timing of this project coincided with the launch of a strategic plan on agricultural engineering in Cambodia[1], with the objective of applying mechanisation as a major input in Cambodian agriculture and to serve as a catalyst for rural development, through supporting more land area in production, lessening drudgery of farm work, improving timeliness and efficiency of field operations, and providing entrepreneurship opportunities. A 70% and 5% level of mechanisation for land preparation and rice planting operation, respectively, are targeted by 2015 in the programme.

Changes in crop establishment and increasing availability of mechanical power raised three questions at the beginning of the project:

1. How can appropriate mechanisation help alleviate some of the constraints associated with manual wet and dry seeded seeding?
2. What management practices, including land preparation, crop protection and nutrition management, would be appropriate to optimise farmers' investment in mechanisation and improve rice productivity?
3. What constrains the successful adoption and integration of rice cropping technology options by farmers?

This project attempted to answer these questions and demonstrate the potential role of mechanisation in dry and wet direct-seeded rice production. In practice, mechanisation can facilitate increased cropping intensity and enable quick follow-up rice crop establishment or allow families greater flexibility in seeking off-farm or non-farm employment. Costs of land preparation can be further decreased if reduced tillage or zero tillage practices are employed, and this area was also investigated in the project.

The research project CSE-2009-037 was born as an outcome of a 2008 ACIAR/AusAID co-hosted workshop on “research priorities for future improvement of the productivity and profitability of rice-based farming systems in Cambodia” where improving rice establishment methods coupled with better agricultural machinery was highlighted as a high priority. The project started in 2010 following further consultations with MAFF and a series of field study visits during 2009 in collaboration with the then commencing *Cambodian Agricultural Value Chain Project* (CAVAC), which was an AusAID funded project promoting modern farming practices in the same three provinces as this project.

[1] *MAFF/GDA/DAEng (2011).* Strategic Plan for Agricultural Engineering in Cambodia: Shifting from subsistence agriculture to commercial agriculture*. September 2011, 44p*

Australia

All Australian rice is direct seeded either being aerially sown as pre-germinated seed into ponded water, broadcast as dry seed on dry soils, drill-sown as sod-sown rice into pasture or direct drilled into burnt rice stubble, or combine sown into a cultivated seed bed. Drought and consequent low irrigation water allocations between 2002 and 2010 resulted in changes to rice production approaches Australia. There was a move away from aerial sown rice with continuously ponded conditions throughout the rice growing season to drill-sown systems and the proportion of crops grown using saline groundwater also increased.

Good rice water management in Australia is achieved by land levelling using laser technology. The major soil types are duplex soils with a shallow clay loam topsoil underlain by a heavy clay subsoil, and heavy clay soils with high clay content throughout the profile, often with high levels of surface and/or subsoil sodicity. While these soils are well-suited to ponded rice culture, there are often severe limitations for the establishment of drill-sown rice: e.g. hard-setting/crusting of surface soils, dense sub-soils and poor internal drainage/aeration.

Spatial variability of rice establishment, growth and yield has been linked to exposure of hostile sub-soils when paddocks are land-formed. Data from rice crop variability studies clearly shows decreased establishment in heavily cut areas within fields. Growers report that in seasons when rice establishment on cut soils (exposed subsoil at the surface) is adequate, high N and P rates can allow highly satisfactory yields to be obtained. However, if establishment is below target levels (200-300 plants/m^2) then it is generally unlikely that high yields will be attained.

There has been a need to optimise rice crop establishment methods in Australia - for efficiency and reliability - in the context of variable surface soil conditions - following the cut and fill levelling operations in shallow duplex soils - and of the delayed permanent water rice growing systems being developed.

In Australia, most rice is grown using very fresh water (< 0.1 dS/m). However, there is a portion of the industry that relies on saline groundwater (1.2-1.8 dS/m) and this sector becomes important during years of very low surface water allocation. At these times, groundwater contributes well over 30% and up to 80% of the income generated from irrigated agriculture in the Australian rice growing regions of southern NSW. However, if rice growers are to avoid significant yield loss through irrigating with saline water, they need to know (1) which varieties are tolerant of salt and (2), what the threshold field water salinity is, above which yield loss will likely occur.

The most current Australian advice is now 10 years old (Beecher *et al.* 2004) and there have been new varieties released which whose salinity tolerance has not been tested. Consequently, there is a need to investigate the salinity tolerance of current Australian varieties for growers who irrigate with saline groundwater.

5 Objectives

The aim of the project was to enhance rice system productivity in rainfed and irrigated lowland systems (including direct seeded systems) through better matching of production systems to soil type and water availability/quality and through mechanisation. There were six objectives.

Objective 1: Assess the current and potential rice establishment methods used by farmers in at least the three targeted provinces, including their management practices, and use of agricultural machinery, to develop corresponding strategies to raise grower productivity.

Activity 1.1: Review existing secondary data, previous reports and available literature for greater information on production practices and households.

Activity 1.2: Initiate baseline surveys of farmers' current practices and trends in rice establishment methods, agricultural machinery use and productivity using a pre-tested instrument in each of the target areas.

Activity 1.3: Analyse the survey data, and evaluate opportunities for improved establishment options (including weed control, irrigation, land levelling, agronomy and machinery) by drawing on the most appropriate results from elsewhere. Define clearly the present and future rice establishment needs of the farmer, agricultural machinery trader and manufacturing communities. Use the data for updating project strategy through periodic learning and change workshops and publishing the results.

Activity 1.4: Initiate a follow-up survey near the end of the project, to note any changes in agricultural practices, knowledge, productivity and mechanisation use, either through the project and/or changes in farmer practices.

Objective 2: For use in better targeting rice establishment options at suitable locations in Cambodia, assemble spatial databases including survey results coupled with other databases including: soil fertility, moisture availability, land use, climate, socioeconomic, among many others to create a Cambodian Country Almanac (CCA).

Activity 2.1: Improve the existing CARDI soil science laboratory by provision of upgraded equipment and human capacity building. This will improve the accuracy of soil analyses for the spatial database inclusion in the CCA and for agronomic and germplasm interventions for this and other research projects. This capacity building activity will be contracted to Drs Graham and Nelly Blair (ex UNE, Armidale, Australia).

Activity 2.2: Develop a beta version of the Almanac using existing data bases for release and testing among GIS user groups. Training for this project's partners will enable their inclusion as 'GIS user groups.'

Activity 2.3: Populate the spatial database of CCA with newer data, including data obtained by CAVAC in 2009, while increasing the number of users and empowering a greater number of new users through training.

Activity 2.4: Release a first version of the Almanac and trial with Cambodian users, modify and release a second version while maximizing users through greater trainings.

Objective 3: Determine strategies and options that optimise rice establishment using direct seeding or other establishment methods on appropriate soils and rice ecosystem/farming systems, identify suitable weed management approaches, and develop training materials.

Activity 3.1: Evaluate rice establishment techniques (possibly comparative trials both on-station and on-farm) and demonstrate promising/potential technologies. Conduct adaptive research to optimise the performance. Implement innovative participatory methodologies for farmer/trader/manufacturer input in the rice establishment techniques early in the process.

Activity 3.2: Drawing on the survey data and experience gained elsewhere (e.g. ACIAR-India, The Philippines and IRRI), identify the best-bet weed management approaches that take account of a weed species shift likely to occur as a result of changes in management and establishment practice. Monitor effectiveness of weed management approaches and adapt these as appropriate.

Activity 3.3: Develop training modules on rice establishment for use in CAVAC extension activities and through them, NGOs, input supply dealers and machinery traders.

Objective 4: Identify agronomic practices specifically aiming to raise productivity by 25% for the emerging dry season, high-yielding irrigated rice system in Cambodia, and develop training materials.

Activity 4.1: Evaluate technically and economically innovative agronomic practices with defined technology options. Farmer/trader/manufacturer input, in a fully participatory approach early in the process, will allow quicker upscale and uptake by the farmer communities of rice establishment methods, agronomic recommendations and weed control practices.

Activity 4.2: Increase the capacity of private entrepreneurs (traders, agronomy and machinery input dealers, manufacturers, etc.) to access and provide accurate information to the grower communities.

Activity 4.3: Formulate training modules on successful dry season rice technology options and incorporate in CAVAC extension activities and through them, NGOs, input supply dealers, and machinery traders.

Objective 5: Increase the capacity of CARDI, GDA and RUA to lead adaptive research and demonstrations of rice establishment practices and associated technologies (including machinery)

Activity 5.1: Partner CARDI agricultural engineering program, agronomy and crop protection staff with that of GDA and RUA, private agricultural manufacturers and traders with farmers from site-specific locations and together demonstrate rice establishment techniques (may include new technologies such small horsepower diesel and electric irrigation pumps, tillage, herbicides, sprayers, seed drills, new full, reduced and zero tillage equipment, laser levellers). Capacity of private entrepreneurs will be supported by the CAVAC Agribusiness/Business component, in close collaboration with this project.

Activity 5.2: Build capacity of CARDI, GDA and RUA to utilise the Cambodia Country Almanac (Objective 2).

Objective 6: Australian component of the project will investigate current and predicted future problems with rice seedling establishment including cultural practices and soil type interactions and issues related to the use of groundwater.

Activity 6.1. Review literature and industry practice regarding rice crop establishment and rice seeding machinery. Explore the best way of matching seeding technologies to soil type and conditions for improved rice establishment under drill and aerial sowing.

Activity 6.2. Replicated field and glass house experiments will quantify the impact of water quality on the growth and yield of current and potential rice varieties.

6 Methodology

Objective 1: Assess the current and potential rice establishment methods used by farmers in at least the three targeted provinces, including their management practices, and use of agricultural machinery, to develop corresponding strategies to raise grower productivity.

Activity 1.1 Review of existing data, reports and literature

A review of existing data was conducted. This included grey/academic literature, previous study reports, methodologies used and the impacts of three related ACIAR projects that address direct seeding in rice-based systems - (SMCN 2003/011 (Philippines); CSE 2004/033 (India); and CIM 2007/215 (Thailand). This review information was used over time to assist the team with the conduct of the project activities, such as developing the benchmarking survey questionnaire and benchmarking trial programme, as well as selecting mechanised direct seeding technologies for rice establishment. The data were made available among the team and kept on a share drive directory at the University of South Australia.

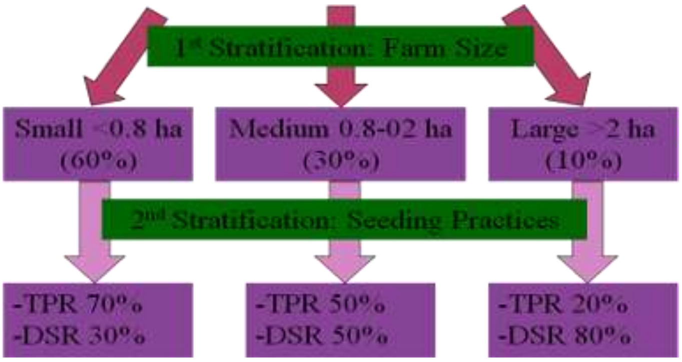
Activity 1.2 Initiate baseline surveys of farmers (2010)

A baseline survey of farmers in the three target provinces of Takeo, Kampong Thom and Kampot was conducted to benchmark current practices and establish future trends in:

- Rice establishment methods;
- Agricultural machinery use;
- Farm practices; and
- Productivity.

A detailed questionnaire was developed in March 2010 by the socio-economics team with input from all project staff. The questionnaire and interview methodology was pre-tested, on six farmers selected from two villages, one each in Takeo and Kampot provinces. Minor changes and amendments to the questionnaire were made based on the pre-test.

The Provincial Department of Agriculture (PDA) recommended communes and districts to be included so that survey information was collected from the range of representative agro-ecosystems. These included rain fed lowland, partially irrigated, and fully irrigated areas. Every attempt was made to have at least one commune to represent one agro-ecosystem. The study villages were selected based on personal conversation with local commune authorities. Participating farmers were randomly selected based on (1) farm size and (2) seeding practices (Figure 6.1).



(NB: TRP: Transplanting ; DSR: Direct seeding)

Figure 6.1. Stratification of farm size and seeding practice to select farmers for survey

The survey was carried out in August 2010 by the socioeconomic teams from CARDI, GDA and RUA with significant input from 10 students from RUA. Before undertaking the survey, training was provided to all enumerators by senior members of the socioeconomic team at CARDI.

Data were collected from 450 farmers (150 in each of Kampong Thom, Kampot and Takeo provinces) from 27 villages in 20 communes and 9 districts.

The district level survey report comprised the following modules:

- Demographic information – age, sex, civil status, education, farming experience;
- Household infrastructure – size and quality of housing, fuel, lighting, drinking water;
- Sources of income – from rice, other crops, supplementary activities on farm, agricultural labour, off-farm income;
- Farm size distribution – size, number of parcels, plots, soil type and elevation of rice farms;
- Irrigation – access to supplementary sources and method of irrigation, drought;
- Current practices and trends in rice establishment methods;
- Assets – current use of draft, farm power and other agricultural machinery;
- Liabilities – debt, amount borrowed, source, purpose, interest on borrowing;
- Rice farming practices and productivity, fertilizer management, plant protection;
- Extension and training support; and
- Farmer perceptions – issues and possible measures.

Activity 1.3 Analysis of survey data and identify opportunities for improvements to crop establishment

Initial analysis from the farmer field group discussions characterised key current practices and resource use, issues and prospects of mechanisation, crop intensification and adoption of innovative agronomic practices.

The survey results were used to identify trends and opportunities for improved crop establishment options (including weed control, irrigation, land levelling, agronomy and machinery), defining clearly the present and future rice establishment needs of the farmer, agricultural machinery trade and manufacturing industry. This information was incorporated into the design of Baseline Experiments and, following meetings in 2010-11, into the design of long-term systems trials for Integrated Crop Establishment (ICE). A report of the survey data is included as an attachment to the final report.

Activity 1.4 Follow up survey near to project end date

The final round of survey activity was conducted in August 2013 (Appendix 1) and collected information through both farmer focus group discussions and a farmer follow-up survey as follows:

1. 20 farmer group meetings with 217 farmers (8-22 farmers per group) were run targeting flood recession, fully irrigated dry season and early wet season rice ecosystems.
2. The farmer follow-up survey was conducted with 200 farmers from 22 villages in 18 communes of 8 districts.

Objective 2: For use in better targeting rice establishment options in Cambodia, assemble spatial databases to create a Cambodian Country Almanac (CCA).

Activity 2.1. Improvements to CARDI soil science laboratory

The CARDI soil science laboratory received an upgrade of equipment and a series of training workshops were provided to a limited number of staff to build their capacity to support soils research in the project and other soil-related activities in Cambodia.

The original version of this Cambodian Laboratory Manual was produced during two visits to the Cambodian Agricultural Research and Development Institute (CARDI), Soil and Water Sciences Division by Professor Graeme Blair and Dr Nelly Blair in 2008. These visits were sponsored by the Crawford Fund. This updated version was produced during another six week visit by Professor Blair and Dr Blair during February and March 2011. The manual was specifically prepared and edited by Dr Blair to suit the facilities and equipment at the CARDI Soil and Water Sciences and has been translated into Khmer.

In addition to development of the manual, the following equipment and materials were supplied to the laboratory:

- Reagents for soil analysis (pH, Electrical Conductivity, N, P, K, Organic Carbon, Particle Size Analysis);
- Materials and equipment for improving quality water supply to the lab (resin, filter, water distiller);
- Plastic/glassware and specific equipment for soil analysis (Electrical Conductivity, lamps for Atomic Adsorption Spectrophotometer).

Training was conducted during one visit to Cambodia. The training included:

- Operation and calibration of analytical equipment;
- Production of soil materials for analytical quality checks;
- Improved the understanding of glasshouse and field experiments.

A second proposed visit by the contracted Australian consultants to deliver further training was cancelled.

Activity 2.2. Develop a beta version of the CCA, now known as Cambodian Land and Environment Agricultural Resource (CLEAR)

The CLEAR database was developed by Aruna Technology and aWhere (USA) under contract to ACIAR. Phase 1 was developed from December 2010 to March 2011. The database was revised following testing and discussions with project partners.

Activity 2.3. Populate CLEAR with newer data

The second version of CLEAR was released in October 2012 and included over 30 new or updated data layers. This version was made available on DVD from Aruna and can be downloaded from http://clear.awhere.com/Homepage.aspx.

Activity 2.4. Release a first version of CLEAR and trial with and train users

Aruna Technology delivered training to 353 people from 16 institutions. In each training, the trainers offered skills and tools on how to capture specific data and how to present data on maps. Trainees were also provided with links on how to update further information and CDs of CLEAR which can be installed on their PC. There were other users who had access to the CLEAR website.

Training activities after 2012 did not continue following the cancellation of CAVAC support.

Objective 3: Strategies and options to optimise rice establishment practices
Objective 4: Identify agronomic practices to raise dry season, high-yielding irrigated rice system productivity by 25%

A common approach was used to address Objectives 3 and 4 to develop rice establishment options and related agronomic practices for improved productivity.

The project's agronomic program aimed to:

- Provide agronomic data on the performance of various options to optimize crop establishment and weed control (Activity 3.1 and 3.2);
- Identify options to raise productivity of irrigated dry season cropping (Activity 4.1);
- Build capacity through the development of training packages (Activities 3.3 and 4.3), publication of technical information sheets (Activity 4.2), and collaboration with and mentoring of CARDI, GDA and RUA staff to lead adaptive research (reported under Objective 5).

Experimental approach

Rice farming systems in Cambodia are complex and reflect the interaction of topo-sequence, soil type and hydrology. In order to address the increased productivity objective, it was first necessary to gain an understanding as to what the “best bet” agronomic options might be which the project team could test and assess. Initial discussions over a number of meetings in 2009 and 2010 were informed by the outcomes of Objective 1 (Literature Review and baseline socio-economic survey) and screened through the experience of the Cambodian and international project team members. A series of baseline studies benchmarked against farmer practice were conducted in 2010 to provide targeted agronomy information to help refine “best bet” agronomic management options for the range of topo-sequence, soil type and season combinations identified. The information generated by the baseline trials informed the development of a set of “best bet” agronomic recommendations which were incorporated into the ICE experiment conducted over consecutive seasons at five permanent sites.

Common constraints to achieving higher productivity in direct seeded rice were identified as 1) delays in crop establishment, 2) weed infestation, 3) poor or uneven crop emergence, 4) sub-optimal nutrition, 5) high costs and 6) poor water control on poorly levelled paddies. Agronomic questions relating to rice productivity included optimum seeding rates, effective weed control, appropriate crop nutrition and optimum crop protection. Technical questions related to mechanised seeding operation efficiency included land preparation, machinery suitability, operating cost, farmer skills, and operation "windows of opportunity". Activities were planned with the aim of emphasising mechanised options for direct-seeding using either dry or pre-germinated seeds at different times in the cropping calendar, under likely soil tillage systems and in areas with different hydrological conditions. The goal was to address labour and timeliness issues and determine practices that would maximise the crop establishment efficiency and reliability under existing windows of opportunity.

At the commencement of the project, experimental data available amongst the partners on the performance of agronomic practices on different soil types and seasons was very limited. Often data were only available for the areas where research stations were located. Information was lacking on questions such as:

- Optimum direct seeding rate;
- Direct seeding performance (wet or dry vs. transplanting reference);
- Opportunities for direct seeding with reduced or zero-tillage;
- Optimum crop nutrition for direct seeded crops;

- Cost-effective crop protection (insect and weeds);
- Mechanised row direct seeding versus broadcasting;
- Use of herbicides and/or mechanical rotary weeders vs hand weeding; and,
- Varietal choice for direct seeded rice crops.

Interactions of rice establishment, site hydrology, and season were additional areas of uncertainty. Better targeting of possible approaches was required to refine the number of options for rice crop establishment and to develop a strategy for implementation.

Baseline experiments

In 2010, a series of baseline experiments and demonstrations were carried out to establish initial recommendations around seeding rate, establishment method, weed control and crop nutrition. GDA, CARDI and RUA each took the lead in different provinces with different experiments according to their capacity and agreed priorities.

All experiments followed common experimental protocols co-developed by the project team, in which partners were encouraged to use improved sampling methodologies and collect relevant agronomic data such as plant density, crop growth and grain yield and, where relevant, weed score/ biomass by species. Partners undertook analyses of their respective trials with results presented and discussed at project review meetings.

Effect of establishment method, seeding rates and weed control methods on weed biomass and rice grain yield

Comparison of crop establishment methods (2010-2011)

A series of 17 experiments was carried out in 2010-11 to compare five establishment treatments with and without weed control. Nine experiments were carried out in the wet season and eight in the dry season.

Land was prepared by ploughing with a disc plough three times followed by harrowing once. The soil type was Prateah Lang which has a sandy topsoil less than 40 cm thick over a subsoil that has a loamy or clayey texture (White et al. 1997). Fertilizer inputs were cow dung at 3 t/ha, urea at 50 kg/ha, DAP at 25 kg/ha and KCl at 25 kg/ha.

The experimental design was a split plot with 3 replications repeated at 17 sites. Main plots were +/- weed control. The weed control treatment was a combination of herbicide (bispyribac sodium 25 g a.i. ha applied 7 days after sowing) and hand-weeding. The seeding rate treatments were wet-seed broadcast. Sub-plots comprised five planting methods:

1. Farmer direct seeding practice at 180 kg/ha;
2. Drum seeding at 60 kg/ha;
3. Drum seeding at 80 kg/ha;
4. Transplanting 1 seedling at 25 cm x 25 cm;
5. Transplanting 2-3 seedlings at 20 cm x 20 cm.

Assumptions for the economic analysis were as follows:

- Labour was costed at $5 per person day. Per hectare, transplanting required 46 person days ($230); broadcasting 3 person days ($15) and drum seeding 4 person days ($20);
- For calculation of transplanting seeding rate, it was assumed 1,000 seeds weighed 23 grams and that germination/emergence losses were 19%;
- Seed cost of wet season (aromatic) rice was assumed to be 3,200 riel/kg and seed of dry season (non-aromatic) rice was assumed to be 2,800 riel/kg;

- The farm gate price of wet season aromatic rice in January was assumed to be $300/t and for dry season (actually early wet season) the price in July was assumed to be $260/t.

A partial budget was used to compare the treatments based on the costs that varied between treatments (cost of seed and labour as shown above) and the income (yield * farm gate price as above). The net benefits or net return for each treatment was calculated by subtracting the total costs that vary from the income.

A dominance analysis was carried out by first listing the treatments in order of increasing costs that vary. Treatments achieving net benefits that are less than or equal to those of a treatment with lower costs that vary are said to be ‘dominated’ and are removed from further analysis.

The marginal rate of return was calculated by dividing the marginal net return by the marginal cost expressed as a percentage (CIMMYT 1988). It is generally assumed that the minimum rate of return acceptable to farmers should be a minimum of 50%, but more typically closer to 100% for likely technology adoption.

Effect of seeding rate of rice on weed suppression (2010-2011)

A series of 17 experiments was carried out in ACIAR Project CSE/2009/037 in 2010-11 to determine the effect of varying the seeding rate of rice for suppression of weeds under Cambodian conditions. Nine experiments were carried out in the wet season and eight in the dry season.

Land was prepared as per the previous experiment, with the same experimental design and weed control treatments. The seeding rate treatments were wet-seed broadcast.

Sub-plots were five planting methods and five seeding rates:

Treatment 2: Broadcast pre-germinated seed at 250 kg/ha;
Treatment 3: Broadcast pre-germinated see d at 200 kg/ha;
Treatment 4: Broadcast pre-germinated seed at 150 kg/ha;
Treatment 5: Broadcast pre-germinated seed at 100 kg/ha;
Treatment 6: Broadcast pre-germinated seed at 60 kg/ha.

Weed species present, weed biomass ,and rice grain yield were recorded.

Integrated crop establishment (ICE) experiments

In 2011, a systematic approach was developed to evaluate the sequencing of various crop establishment methods as a means to raise rice productivity per annum. The Integrated Crop Establishment (ICE) experimental design comprised four dual cropping and two triple cropping scenarios, designed in particular to maximise opportunities for dry season (including recession areas) and early wet season contributions to annual rice productivity.

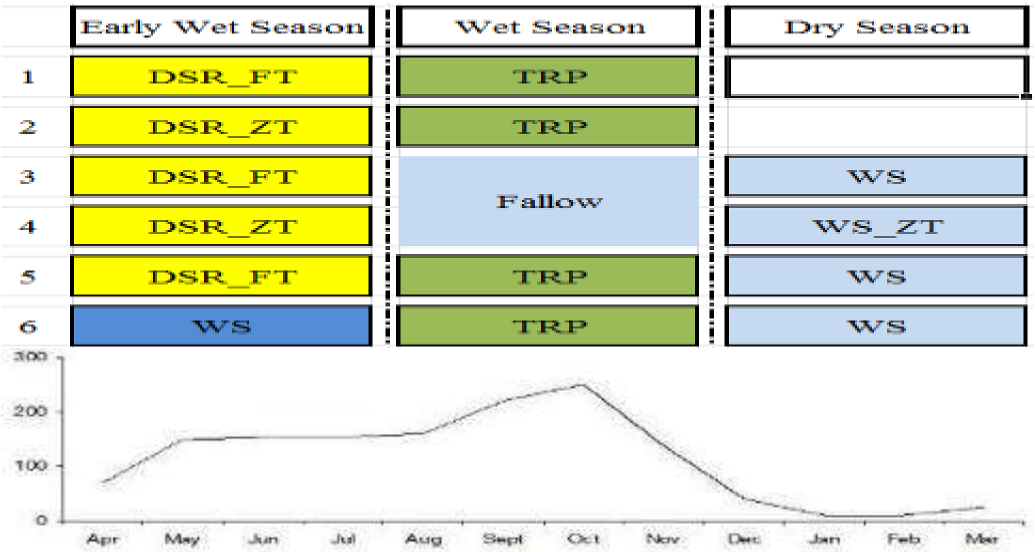
The objectives of the ICE experiments were to:

1. Determine the impact of establishment method and cropping sequence on agronomic performance and provide data from an evaluation of system productivity;
2. Determine the effects of establishment method and cropping sequence on weed populations and species shifts;
3. Serve as a farmer demonstration trial and a reference point (‘mother trial”) for complementary “daughter trials” to explore responses to various agronomic options in different rice environments.

Establishment treatments in each season (Figure 6.2) were:

- Main wet season: Transplanting (identified as the dominant practice in the benchmark survey) after soil puddling, or fallow (stubble after EWS rice crop);

- Dry season: Mechanised wet seeding (drum seeding practice highlighted in benchmarking trials) after either soil puddling or zero-tillage (recession rice opportunity); and
- Early wet season: Mechanised dry seeding (two wheel tractor drill technology) into a cultivated seedbed or under zero-tillage conditions.



- *DSR_FT = full/conventional tillage; mechanised dry seeding*
- *DSR_ZT = zero tillage; mechanised dry seeding*
- *WSR = mechanised wet seeding (drum seeder) with pre-germinated seeds after soil puddling*
- *WSR_ZT = mechanised wet seeding (drum seeder) with pre-germinated seeds without any prior tillage but following application of glyphosate to control rice regrowth and weeds.*
- *TRP = transplanting rice seedlings in rows after puddling soil*

Figure 6.2. Crop establishment sequencing simulated in the ICE experiments.

Treatments T1 to T6 were sub-divided into two weed control levels to allow cumulative data to be collected on weed growth and species succession in relation to crop establishment sequencing and cropping intensity (Activity 3.2). The experimental design comprised four replications and was conducted at five permanent sites across three provinces, namely: CARDI research station, Takeo (GDA Bati research station), Kampot , Kampong Thom (PDA station), and RUA campus, from the 2011 wet season onwards, to gather data on rice productivity and weed management impact over a two year period (7 consecutive seasons).

Sub-plot treatments for weed management were:

- CW - Complete weeding = herbicide treatment + one follow up hand weeding;
- HW – Hand weeding = one hand weeding at 30 days after seeding / transplanting.

Best bets for weed management were a key part of the ICE trials. The key steps in this process included:

- Weed identification - what weeds, where and at what crop stage;
- Understanding weed ecology and integrated control options;
- The weed management impacts were then examined across the ICE trials in each different rice ecosystem.

The main plots were 8 m x 4 m and sub-plots 4 m x 4 m, with 20 crop rows per plot with WSR (using drum seeder); DSR (using Rogro seed drill), TRP (hand transplanting in rows). Fertiliser was applied using site specific recommendations from CARDI.

The data were analysed using IRRISTAT 5.0 (IRRI 2000). A detailed description of the statistical analysis is provided in Appendix 6.

Weed management

A total of 21 weed management focus trials were conducted during the project, using drum seeding establishment methods.

Non-replicated benchmark trials were undertaken in 2010 wet season and 2011 dry season with the following treatments:

- T1: Farmer practice;
- T2: Herbicides (metsulfuron-methyl + chlorimuron-ethyl at 15 DAT at 1 g/8L H_2O for 100 m^2 and 2,4-D at 25 and 40 DAT 10 mL/6 L H_2O for 100 m^2);
- T3: Non weeding;
- T4: Cono rotary weeder (30 DAT and 45 DAT).

Based on the early results from these trials, treatments were modified from 2011 onwards:

- T1: Farmer practice;
- T2: Drum seeder + rotary weeder;
- T3; Drum seeder + herbicide (pretilachlor + safener at 1 L/ha at 2 DAS + 2,4-D 0.5 kg/ha at 18 DAS);
- T4: Hand broadcasting + herbicides (pretilachlor + safener at 1 L/ha at 1 DAS + 2,4-D at 0.5 kg ai/ha at 18 DAS).

26 drum seeders (From Vietnam) and 24 x 2 push-type rotary-weeders (2 types, cono-style and cylinder type - manufactured by GDA) were acquired by the project during 2010 to equip the Cambodian team for implementing trials and farmer demonstrations, including PDA partners in the 3 provinces. Three hydro-tillers were also imported from the Philippines to evaluate opportunities for rapid soil puddling and faster rice establishment in dry-season recession areas. See Figure 5.3.

Figure 6.3. Drum seeder, push-type cono-weeder and hydro-tiller acquired by the project

Cropping sequences, establishment method and weed control

Weed management strategies were developed to complement the rice establishment methods being evaluated in Activity 3.1. Trials began in the 2010 wet season. A total of 38 systems trials were conducted over 7 consecutive seasons. The objectives of these trials were to:

1. Determine the impact of establishment method and cropping sequence on agronomic performance and provide data from an evaluation of system productivity;

2. Determine the effects of establishment method and cropping sequence on weed populations and species shifts.

Mechanised dry seeding evaluation and adaptive research

The concept of evaluating and promoting simple drill implements adapted to the existing and expanding two wheel tractor (2WT) power source was adopted in the project as a key strategy to improve crop establishment quality under dry direct seeding contexts. It was anticipated that a range of possible cropping system benefits would result, such as:

- Accurate seed placement at optimum depth to maximise field establishment rate;
- Row seeding to facilitate mechanical/manual weeding;
- Limited or no predation risks with buried seeds;
- Limited or no lodging relative to surface established crops;
- Time and cost saving when used as zero-till to direct sow into residue;
- Possibility to establish rice using stored moisture in rainfed systems;
- Opportunity to place fertiliser in the seed row for better nutrient use efficiency.

Additionally, a staged approach was adopted, consisting of:

1. A more readily adoptable ‘entry level’ mechanisation with drill technology suited to sowing into a prepared seedbed; and
2. A ‘blue sky’ mechanisation with technologies suited to zero-till direct seeding into unploughed rice paddies, providing the maximum cost-saving and timeliness.

A selection of mechanised dry seeding equipment was identified and purchased in 2010-11 to equip the respective partners (see also Figure 6.).

Figure 6.4. Seed drills selected and evaluated in the project (from left to right: Thai disc drill, Cambodia-made Rogro tine/press-wheel drill, Chinese rotary till drill 2BFG-100).

These included:

- Three two wheel tractors (Thai-made Siam Kubota);
- An existing tine and press wheel drill concept (Rogro drill) developed as part of a previous ACIAR project CSE/2007/027, manufactured to a limited extent in Phnom Penh and now available commercially from China at a much reduced cost (US $450 ex-works 2011);
- A contrasting disc drill (Thai drill, cost US$400 ex-works 2011) recently developed by the Ministry of Agriculture in Thailand offering an improved performance over the Rogro drill under some conditions;
- A rotary till drill from China (2BFG-100, cost US$450 ex-works 2011) with its DF12L Chinese two wheel tractor, as an improved drill concept for zero-till application in heavy residue;
- Knapsack equipment with multi nozzle boom and low drift nozzles acquired from Australia.

Mechanised seeding trials

There were four components to the work done regarding mechanisation options for rice seeding by the project partners:

1. Capacity building (Activity 4.2 and 5.1 – reported under Objective 5);
2. Replicated trials to demonstrate the applicability of using mechanised drill technologies under both full till and zero till conditions in the early wet season and dry season (reported under ICE trials);
3. Adaptive research to refine the field performance of mechanised dry seeding and develop recommendations around the types of machinery and preferred conditions of use by season agro-ecosystem (soil type, and topo-sequence);
4. Seeder development activities and adaptive research trials aiming to develop local machinery solutions for Cambodian conditions and eco-systems:
   4.1. Development/adaptation of the Rogro-style seeder;
   4.2. Introduction of the Drum Seeder to the provinces and its incorporation into on-station and district trials;
   4.3. Development of a Cambodian made disc drill for two wheel tractor.

Mechanised dry seeding trials and demonstrations conducted by the project partners included:

- Performance of mechanised dry/wet seeding options compared with broadcast seeding and/or transplanting (farmer practice);
- Reduced tillage drum seeding optimization trials;
- Comparative evaluation of seed drill options under full till and no-tillage conditions;
- Drill sowing window after soil wetting under cultivated soil conditions;
- Safe levels of combined fertiliser application with drill seeding of rice;
- Demonstration of dry seeding with Rogro style drill under tillage and no-tillage;
- Optimising weed management options for drill sown rice under zero-tillage;
- Evaluation of the performance of a new Cambodian disc planter prototype;
- Demonstration of Cambodian drill under farmer-led dry sowing of rice.

Economic assessment of mechanisation

An economic assessment of mechanisation in the lowland rice ecosystems of Takeo province was conducted. The objective was to assess the practical reality and the constraints associated with best bet agronomic options. To estimate the potential benefits, the study considered five base-case scenarios (non-mechanised) and two best-bet scenarios (mechanised), outlined in Table 6.2. A partial budgeting approach was used to capture changes in the annual costs and benefits of mechanisation and intensification at the farm scale.

There were two components to the methodology - farm level analysis and farm level benefit cost analysis. The farm level analysis measured the on-farm impact of mechanisation and intensification to identify financial benefits arising from productivity gains, improvements in grain quality, changes to cropping rotations, lower production losses, and reductions in costs and labour. Benefit cost analysis was used to measure the return on investment in on-farm mechanisation. The criteria used were the Net Present Value (NPV) of mechanisation and the Benefit-Cost Ratio (BCR). Sensitivity analysis was undertaken to demonstrate the effect of change of yield, discount rate seed on returns. Data and key assumptions used in the analysis are provided in

Table 6.1.

Table 6.1. Data and key assumptions used in the farm level benefit cost analysis

Farm size	2 ha	**Fuel consumption**	**L/hr**
Interest/ discount rate	30% pa	Ploughing	1.2
Accounting period	10 yrs	Harrowing	1.1
		Seed drill	1.1
Machinery repairs & maintenance (% of capital cost)	2-7%	Pumping water	0.9
		Lubricants used (%of total fuel)	7%
Time for different operations			
Using animal draught power	*days/ha*	*Using motorised power (2WT)*	*hrs/ha*
Ploughing	6-7	Ploughing	5.5
Harrowing	4-5	Harrowing	4.0
broadcast/transplant		Drill seeding	5.5
Levelling	12	Levelling	48
		Cost of levelling - every 4 yrs	$120/ha
No. of irrigations (supplementary)		**No. of irrigations (fully irrigated)**	
Rice in EWS	4	Rice in dry season	12
Rice in MWS	2	Mungbean in dry season	3
Pumping time per irrigation	**hrs**		
Rice	21-25	Water source - Channel water	
Mungbean	6	Pumping of water - Power tiller	

Note: Value of farmer's time for operating machinery was not considered in the analysis. All costs are in 2013 US dollars,

Table 6.2. Description of the seven scenarios examined in the benefit cost analysis (Scenarios 1 to 5 are base case scenarios and 6 and 7 are best case Scenarios)

<table>
<tr><th>Key</th><th>Season</th><th>Seed source & variety</th><th>Sowing</th><th>Operations</th><th>Supp. Irrigat.</th><th>Fert inputs Level</th></tr>
<tr><td>1</td><td>Main wet season only</td><td rowspan="5">own seed, traditional</td><td rowspan="2">Transplant</td><td rowspan="5">Animal draught power
1 ploughing +
1 harrowing for each respective crop</td><td>None</td><td rowspan="5">Low</td></tr>
<tr><td>2</td><td>Main wet season only</td><td>2</td></tr>
<tr><td>3</td><td>2 crops annually (EWS & MWS)</td><td rowspan="2">EWS -broadcast
MWS - transplant
–</td><td>None</td></tr>
<tr><td>4</td><td>2 crops annually (EWS & MWS)</td><td>4 EWS
2 MWS</td></tr>
<tr><td>5</td><td>2 crops annually (EWS & DS)</td><td>EWS -broadcast
DS - broadcast</td><td>4 EWS
Full DS</td></tr>
<tr><td>6</td><td>2 crops annually
(EWS & MWS)</td><td>EWS - new variety
MWS - traditional</td><td>EWS – drill seed
MWS - transplant</td><td rowspan="2">Motorised power (2WT)
2 ploughings and 1 harrowing for each respective crop in levelled field</td><td>4 EWS
2 MWS
??</td><td rowspan="2">CARDI rec's</td></tr>
<tr><td>7</td><td>2 rice crops (EWS & MWS) and 1 mungbean crop in DS annually</td><td>EWS - new variety
MWS – traditional
DS – short duration mungbean</td><td>EWS – drill seed
MWS – transplant
DS – drill seed</td><td>4 EWS
3 DS</td></tr>
</table>

Drum seeder adoption

The objective of this assessment was to test the financial feasibility of on-farm adoption of drum seeding for direct drilling rice in the Cambodian context of rain fed lowland rice.

More specifically, the objectives of the study presented here were to:

1. estimate potential financial benefits to farmers of drum seeding compared to the current practices of planting rice;
2. estimate the costs of on-farm adoption of drum seeding;
3. compare the annual benefits and costs of adoption of drum seeding;
4. identify constraints to adoption of the drum seeding.

The economic analysis involved a partial budgeting approach in which the additional and foregone annual costs and benefits associated with drum seeding were compared to estimate the net annual gains from adoption of the new technology. The analysis was carried out from a financial perspective. The potential annual benefits and the costs (in nominal terms) of using the drum seeder were estimated for a 2 ha farm growing rice in both the EWS and the DS, as per a rice cropping intensification scenario identified and evaluated in the project systems trial (Treatment 6), noting that additional use may be applied during the main wet season subject to appropriate conditions. It was assumed that the farmer has time and capacity to use the drum seeder for contract work during EWS and DS, to earn extra income.

Total annualised costs, including depreciation, interest on capital invested and expenditure on repair and maintenance of the drum seeder were considered in the analysis. The potential annual benefits and the costs of using the drum seeder were estimated over the current practice of manual broadcasting-wet of rice in both the EWS and DS and the criterion used in assessing the financial merit of adoption of the drum seeder was the net value (NV) of the annual benefits in nominal terms of drum seeding.

Scenarios for the potential use of the drum seeder

Scenario 1 A farmer uses a drum seeder for direct drilling rice in both the EWS and the DS on his 2 ha farm only (4 ha per year);

Scenario 2 In addition to using the drum seeder on his own farm, the farmer also uses the drum seeder for direct drilling an extra 4 ha of rice, i.e. 2 ha of rice in each of the EWS and the DS (total 8 ha per year);

Scenario 3 In addition to using the drum seeder on his own farm, he also uses the drum seeder for direct drilling 8 ha of rice i.e. 4 ha of rice in each of the EWS and the DS (total 12 ha/year).

Assumptions and data

Drum seeders have been tested in the lowland rice ecosystems over the past 4 years, both within the ICE systems trials and on a limited area of farmers' fields each year. In general, there is a lack of consistent information on the costs involved in using a drum seeder for direct drilling rice, potential yield and other benefits of this technology for a typical rice farm. Therefore the value of the potential benefits and costs of drum seeding were estimated using the results of the research to date, together with farmer data and estimates by project staff to fill data gaps.

The key data and assumptions used in the analysis are given below.

Capital cost of a drum seeder (2.4 m 12 row, imported)	$90
Potential economic life of a drum seeder when used on:	
Own farm only	5 years

Own farm plus 4 ha of contract work	3 years
Own farm plus 8 ha of contract work	2.5 years
Residual value of a drum seeder (value of plastic)	0%
Interest rate on borrowing (pa)	30%
Operational size of farm	2 ha
Depreciation	linear
Speed of planting @ 4 hours / ha	2 ha/day
Custom hiring rate (drum seeder + operator)	$14 /ha

The custom hiring rate of $14/ha includes $10/ha for custom hiring machine plus $4/ha to cover the cost of hiring an operator. The farmer who owns a drum seeder is assumed to operate it for contract work and his time is costed at a skilled rate of $8 per day compared with the wage of an unskilled farm worker hired at $5/day.

Repair and maintenance assumptions:

- 5% of the capital cost of the drum seeder per annum where it is used on his own farm only;
- 10% where the drum seeder is used for 4 ha on contract in addition to its use on own farm; and
- 15% of the capital cost of drum seeder when used on own farm plus 8 ha of contract work per annum.

Yield of drum seeded rice:

In the Integrated Crop Establishment (ICE) experiment, crop yields obtained from drum seeded rice have been both higher and lower than the yields obtained with broadcasting wet, depending on locations, . Therefore in the initial analysis, it is assumed that the grain yield obtained from drum seeded rice is at par with the yield obtained from rice planted by broadcasting wet.

Farmer reference yields for broadcast-wet rice in Bati, Takeo were 3.5 t/ha in the EWS and 4.8 t/ha in the DS.

Seeding rates were:

- EWS: 150 kg/ha for broadcast wet and 70 kg/ha for drum seeder;
- DS: 175 kg/ha for broadcast wet and 80 kg/ha for drum seeder.

Broadcasting wet requires 6 hours per ha overall skilled labour for seed preparation e.g. soaking/incubating/air drying whereas in the case of drum seeded rice seed preparation was estimated to require 4 hours per ha, due to the lesser quantities involved.

Gap filling post-emergence to redress poor establishment, predation and misses was estimated at 3-5 labour days for broadcasting wet (particularly under to lower seed rate). and 1-2 labour days after drum seeding (Table 8.28).

All the other inputs and management practices are the same as were being used in rice broadcasting-wet.

Economic evaluation of 2WT drill seeder technology

A partial budgeting approach was used for financial analysis of the on-farm adoption of the 2-wheel tractor (2WT) drill seeder, to estimate the potential benefits and costs of on-farm adoption of drill seeders for direct drilling rice in both the early wet season and dry season

Assumptions

- A farmer who buys a drill seeder already owns a tractor;
- He has capacity to use his tractor for direct drilling rice:

  - on his 2 ha own farm and
  - contract direct drill 5 ha of rice in the EWS and 5 ha in the DS
- The current market custom hiring rate is $30/ha for hiring drill seeder, 2-wheel tractor and driver
- In the analysis, annualised costs for both drill and tractor for 14 ha (2 ha own + 5 ha custom hiring in both the EWS and DS) are used.
- Total cost of drill seeder and only operating costs of tractor were considered while estimating the annualised costs of using drill seeder.
- Current seeding practices (Farmer practice, FP)
  - Broadcasting-wet in both the EWS and DS
- Potential use of drill seeder
  - Direct drill rice in the EWS and DS

Scenarios considered

Scenario 1: Yield obtained from drill seeded rice was at par with the yield obtained from the rice grown with the current FP (broadcasting wet).

In the integrated Crop Establishment trials, undertaken within the ACIAR project, in some locations, crop yields obtained from the drill seeded rice were higher than the yields obtained from the rice being grown using farmers' current seeding practice of broadcasting wet. Whereas in some other locations, the yields from drill seeded rice were lower than the FP rice broadcasted wet. In the financial analysis, the study has assumed that farmers will be able to achieve yields of drill seeded in both the EWS and DS, at par with the yields being obtained from the rice broadcasted wet.

Scenario 2: Yield obtained from drill seeded rice was 10% higher than the current FP rice yield in both the EWS and DS

Scenario 3: 10% increase in crop yield in both the EWS and DS but with no contract work available

Objective 5: Increase the capacity of CARDI, GDA and RUA to lead adaptive research and demonstrations of rice establishment practices and associated technologies (including machinery)

A variety of formal training and research mentoring activities were conducted by project partners to improve the knowledge and capacity of farmers in the three target provinces, staff and students from CARDI, GDA and RUA, and staff from PDA, iDE and the private sector. Capacity building activities fell under four objectives:

Develop training packages on rice establishment (Activity 3.3.) and dry season rice technology (Activity 4.3.)

A range of training materials was produced in the 2010-2012 collaboration with CAVAC, developed from the results of early weed management, rice establishment and mechanisation activities in the project. Many of the training materials were translated into Khmer. Section 10.2 provides a full listing of project publications and training materials.

Increase farmer capacity to improve rice productivity in target provinces (GDA)

GDA established farmer field schools (FFS in Kampong Thom, Takeo and Kampot provinces over the period from 2011 to 2013. Farmer Field Schools (FFS) are "schools without walls" where 25-30 farmers meet half a day each week for a full cropping season. The primary objective for GDA in running these schools was to increase the capacity of local farming communities and, specifically, to:

- Reduce farmers' dependence on agricultural chemicals, especially pesticides, in order to minimize hazards to human health, animals and environment;

- Develop the capacity of farmers so they are able to identify problems and find appropriate solutions by themselves;
- Educate farmers about crop eco-systems and develop their skills in monitoring and analysing field situations so they can manage their crops more effectively.

The approach taken by GDA in running their FFS was a participatory one, with discovery-based and experiential learning following the education paradigm "learner learning rather than teacher teaching". The learning process was based on an adult learning cycle, with farmers learning by doing simple experiments that were designed to allow participants to discover answers to their own questions. Apart from field experiments, other methods used in the FFS included introductions to special topics, large and small group discussions and brainstorming. At the end of each FFS, a field day was organized to present the results and to discuss and share knowledge and experiences between trained and non-trained farmers (50-60 farmers).

At each FFS, a crop was grown as a field study activity for local farmers to observe and analyse, and discover the dynamic relationship between plants, pests, natural enemies, nutrients, soil, and water. In general, local Farmer Practice was compared to a "best management" or Technical Plot (Table 6.3).

The core activity of each FFS was Agro-Ecosystem Analysis. After thoroughly analysing the field trial, farmers and facilitators discussed their findings and together made decisions about crop management. Often special topics were set based on problems observed in the field. These were flexibly decided by facilitators and participants and focused mainly on areas related to crop physiology, crop protection and production, field ecology and economic analysis

Table 6.3 Practices used in FFS technical plots compared to farmer practice

Technical Plot	Farmer Practice
Using good rice seed	Using farmer saved seed
Two time land preparation with good land levelling	One time land preparation without proper levelling
In dry season, using drum seeder for planting with seed rate of 80-100 kg/ha	In dry season, hand broadcasting with the seed rate of 200-250 kg/ha
In wet season, transplanting in line with young seeding (15 days) and 1-2 seedlings/hill	In wet season, randomly transplanting with old seeding (25-30 days) and 5-7 seedling/hill
Using fertilizer based on the technical recommendation according to soil type	Using fertilizers based on traditional practice and information from sellers
Controlling weeds properly by selecting targeted herbicides based on weed type	Controlling weeds by using a mixture of herbicides told by sellers
Controlling insect pests and diseases based on agro-ecosystem analysis and field observation with joint decision making of facilitators and participants.	Controlling insect pests and diseases by setting spraying calendar and following advice from pesticide sellers.

Increase the capacity of private entrepreneurs (Activity 4.2)

The project interacted early on via CAVAC with a number of input dealers supplying herbicides and fertilisers, but the scale and scope of this activity ceased when ACIAR withdrew from CAVAC, with the opportunity to collaborate on information dissemination to the private sector reduced.

In its activities, the project collaborated with a number of private entrepreneurs such as:

- BvB Machinery Ltd (Importer of farm machinery) who benefited from exposure to 2WT drill technologies and related training and engaged in some limited promotion with farmers.

- Russeykeo Agricultural Equipment Manufacturer (RAEM) (Mr Ouchhoeun Larano and Mr Pen Nouv) in Phnom Penh) who benefited from exposure to new seeder technology and adopted some of this technology on both small and larger scale drills. The interaction over the project duration resulted in the ordering of 470 seed metering units from China to facilitate the commercial supply of 2 and 4 wheel tractor seeders, the development in 2012-13 of the 1st disc drill for 4WT made in Cambodia - with two 14 row drills made to date, and finally the development of a small scale disc drill for 2 wheel tractors. This active collaboration extended to the manufacturing workshop at the GDA Department of Agricultural Engineering whose is able to commercially manufacture the same range of rice and other crop seeders, effectively increasing local supply capacity.
- iDE-Cambodia with knowledge sharing and training on aspects of mechanised seeding and enabled engagement widely with suppliers and farmers in two additional provinces (Prey Veng and Svay Reng).
- The Cambodian Society for Agricultural Machinery Network (CaSAMNet) networking among stakeholders related to agricultural machinery to improve the use and effectiveness of agricultural machinery in Cambodia. An early collaborative activity with CAVAC included developing and conducting an agro-tool supplier survey aiming to document the baseline situation of machinery supply chain in the 3 provinces and Phnom Penh. A report was finalized by the contracted agent DAC Consulting (http://dacgroupkh.com) and made available to CaSAMNet – see http://casamnet.org/wp-content/uploads/docs-cam/DAC%20ReportCambodia%20%20Agro-tool%20Market%20Survey%20July2011.pdf
- A presentation on the project and survey results was made to industry in 2012 at one of the regular CaSAMNet meetings and direct support was given by Scott Justice to enable the development of a website (http://casamnet.org/) as a platform for information dissemination to Industry.

Develop agronomic recommendations and upscale demonstrations to extend advice to private sector.

Activities included:

- Machinery seed drill calibration, pre-testing & field establishment data;
- Weed management via safe & effective use of herbicides;
- Improved weed management for rice;
- Safe and effective operation of seed drill technology;
- Weed Identification and herbicide application.

The development of a project strategy and the experimental approaches used were based team discussions involving all the main partners. The ICE experiment was developed over several such meetings and an analysis of the constraints posed by season, hydrology and soil and opportunities presented by new ideas, methods and collaboration. The result was a fairly sophisticated experimental design with multiple objectives. The experiment served it purpose well and Dr Ouk Makara, Director of CARDI, said is the first time the Cambodian researchers had come together and used such a systematic approach to the problem. Developing the experimental plan and conducting the experimental provided a tremendous learning opportunity.

Formal training and mentoring activities in seeder machinery calibration and field operation; trouble shooting, trial design, implementation and data sampling were conducted by Dr Jack Desbiolles (Uni SA) over 2011-14 with translation/facilitation by Pao Sinath (CARDI), Chea Sovandina (GDA) and Chuong Sophal (RUA). These included:

- Feb 2011: at the CARDI station: Technology awareness and seed drill calibration and pre-testing, attended by 10 CARDI, GDA and RUA staff and students
- July-Aug 2012: Field trial implementation at the CARDI Station and Takeo/Kampot field sites to an extended CARDI team of 6 trainees.
- July 2012: Field trial implementation at the GDA Tonle Bati station and Takeo - Bati field site to an extended GDA team of 4 trainees.
- July-Aug 2012: Field trial implementation at the RUA Campus and Takeo field site to 5 participants from the RUA team and students.
- 2013-14: Various mentoring activities in field performance improvement and Cambodian drill prototype development in collaboration with industry partner and CARDI Agricultural Engineering staff.

Additionally, Mr Scott Justice conducted a formal mechanisation training:

- April 2012 at the CARDI station, with 22 participants from CARDI/GDA/RUA partners/PDA staff/iDE on "setting up and safe operation of rotary-till - strip till and full till - seed drill technology"

Overall, a total of 45 students were involved in project trials at RUA and CARDI over the course of the project. These projects trials were managed as undergraduate project components, with students exposed to innovative technologies and best practice research and management. Activities included direct involvement in:

- agronomy trial implementation, data collection and analysis, report writing;
- machinery trial design, implementation, data sampling and analysis, report writing;
- survey design, pre-testing and implementation, data basic analysis and reporting.

Objective 6: Australian component - investigate current and predicted future problems with rice seedling establishment including cultural practices and soil type interactions and issues related to the use of groundwater.

Activity 6.1 Identification and review of literature and replicated glasshouse and field experiments

Over three seasons, numerous experiments were conducted in the controlled temperature head and poly houses and also in the field at multiple locations with different soil types. The field experiments were used to confirm findings obtained in the controlled environment experiments.

Year 1 - 2010-2011 Season

Head house experiment

This experiment was designed to determine if different seed treatments impacted on seedling establishment. Three current rice varieties and three soil types common in the rice growing area were used.

- 4 replications of 3 varieties (YRM 69 (Sherpa), Rieziq & Amaroo) on 3 soil types
- seed treatments (dry seed, water 12hr seed soak, water 24hr seed soak, Gibberellic Acid (GA) 12hr seed soak, GA 24hr soak & indo-butyric acid (IBA).

Field experiments

Experiments were conducted at two sites with different soil types using both drill and aerial sowing methods. The seed treatments tested in the head house were also tested in the field in these experiments.

Conducted at Yanco Agricultural Institute Leeton Field Station

- 4 replications of 2 sowing methods (aerial & drill)
- seed treatments (dry seed, water 12hr seed soak, water 24hr seed soak, GA 12hr seed soak, GA 24hr seed soak & IBA)
- In the drill method, a Zn seed coat and DAP replaced the two seed soak treatments

A third field experiment was conducted at the McCaughey Institute.

- 3 replications of 2 sowing methods (aerial & drill), 2 varieties (YRM 69 (Sherpa) & Langi), using 2 seed rates (75 and 150 kg/ha) and 2 seed treatments (zero & GA 10)

At an additional site in the Murray Valley GA seed treatments were also tested in the field using both aerial and drill sowing methods with two varieties and two seeding rates.

Year 2 - 2011-2012 Season

Head house experiments

Experiment 1 - Seeds of one variety were sown 4 cm deep in the one soil type to test if the addition of Zn seed coat or the commercial product “seed boost” affected speed of establishment and/or the number of seedling established.

- 4 replications of 3 treatments (control, Zn & Seed Boost)

Experiment 2 - Seeds of four current commercial rice varieties were treated with three rates of Gibberellic Acid (GA) before being sown at two depths in two soil types to determine if emergence and seedling establishment are improved.

- replications of 4 varieties (Sherpa, Langi, Kyeema & Illabong) on 2 soil types (red & grey) at 2 sowing depths (4, 6 cm) using 3 GA rate treatments (GA 0, GA 20, GA 40)

Experiment 3 - Same treatments as experiment 2 but with only one sowing depth (4 cm) as few plants emerged from the deeper sowing depth in experiment 2.

- replications of 4 varieties (Sherpa, Langi, Kyeema & Illabong) on 2 soil types (red & grey) at 1 sowing depth (4 cm) using 3 treatments (GA 0, GA 20 & GA 40).

Slant-board experiments

Two experiments were conducted with seeds germinating and growing on slant boards so that shoot and root lengths could be measured after treatments were applied to the seed.

Experiment 1 – 3 reps of 2 varieties using 3 Treatments (dry seed, GA & 12hr water soak)

Experiment 2 - 3 reps of 10 varieties using 5 Treatments (dry seed, water soak, GA soak, GA spray (low) & GA spray (high)).

Field Experiments

- 3 reps of 8 treatments (Control, Single super, Triple super, 50N, Triple super +50N, T. super +50N +Zn seed coat, Triple super +100N, MAP + 50N, Granulock Z +50N).

Two experiments located on cut and no cut areas of a district rice field to assess the effect of P and Zn on plant growth and grain yield in land-formed fields.

Year 3 - 2012-2013 season

Polyhouse experiment

This experiment was designed to look at the effect of removing topsoil on plant growth and yield. Lime was applied to increase the soil level of carbonate and then a range of Zn rates were applied to counteract potential Zn deficiency that can occur at high soil carbonate levels.

- 3 reps with 3 soil depths (0-10, 20-30 & 40-50 cm) using 11 treatments (control, lime 2.5, lime 10, lime 20, lime 40, Zn 2.5, Zn 10, Zn 20, Zn 40, 2 x Zn 40 & 4 x Zn 40)

Field Experiments

Leeton Field Station

This field experiment was designed to increase the soil carbonate level by adding lime and then seeing if the zinc treatments have an effect on establishment and survival after permanent water applied.

- 3 replications using 4 treatments (control, 20t/ha lime, 20t/ha lime + Zn seed coat & 20t/ha lime + Granulock Zn).

Nine experiments were established in farmers fields across both valleys. In the drill sown experiments levels and types of phosphorus and zinc sown with the seed were assessed while different forms and application methods of Zn were tested in the aerial sown experiments.

Three drill sown experiments on district farmer fields

- 2 replications using 6 treatments (control, MAP, Single super phosphate (SSP), SSP+Zn seed coat, Granulock Z 10P, Granulock Z 30P).

Six aerial sown experiments on district farmer fields.

- 2 replications using 6 treatments (control, Zn coated seed, Un coated seed, $ZnSO_4$ spray 5 kg Zn/ha, $ZnSO_4$ spray 10kg Zn/ha, surface spread $ZnSO_4$ 10 kg Zn/ha)

Activity 6.2 Replicated field and glass house experiments will quantify the impact of water quality on the growth and yield of current and potential rice varieties

The following field trials and glasshouse experiments were conducted by NSW DPI (Sam North and Don Griffin) at Deniliquin in the Murray Irrigation district of southern NSW.

Salinity at vegetative stage

- Glasshouse pot experiment using recirculated water in 2012-13
- Salinity applied from 3-5 leaf stage to panicle initiation (PI)
- 20 varieties: Amaroo, Dongarah, Illabong, Kyeema, Langi, Opus, Quest, Reiziq, Sherpa, YRF209, YRW4, IR45427 & Amber33 (2 tolerant checks), IR29 & IR58 (2 sensitive checks), basmati, Phka Rumduol, Padang Wangi 7, Hom Mali Niaw, Hom Nag Neung.
- 2 soil water salinities – fresh (0.4-0.5 dS/m), saline (8.0-9.5 dS/m).

Salinity at reproductive stage

- Glasshouse pot experiment in 2011-12;
- Salinity applied from PI to physiological maturity;
- 15 varieties across two experiments: Amaroo, Doongarah, Illabong, Quest, Reiziq, Sherpa, Opus, IR45427 (tolerant check) and IR58 (sensitive check) common to both plus Langi, YRF209 and YRW4 in Expt 1 and IR29, Sen Pidao and IR66 in Experiment 2;
- 2 soil water salinities – fresh (2 dS/m), saline (8 dS/m in Experiment 1 and 4.5 dS/m in Experiment 2).

Salinity from establishment to harvest

- Blocked, split-plot design field trial using fresh channel water and saline groundwater (3.8 to 4.5 dS/m) in 2010-11;

- Salinity applied for whole season from 3-5 leaf stage to plants grown on a red chromosol in bays 20 m by 12 m;
- Varieties – Amaroo, Doongarah, Illabong, Quest, Reiziq, Sherpa salinities – fresh channel water (0.1 dS/m) and target bay water salinities of 1.5, 2.0, 2.5 and 3.0 dS/m.

Apart from measures of growth (tiller number, shoot biomass, leaf area, grain yield, 1000 grain weight, harvest index), data has been collected to assess salinity by variety treatment effects on:

1) transpiration and the interaction with leaf area and biomass accumulation in a pot-in-bucket (Hunter and Mitchell et. al. 2012) glasshouse trial in 2013;
2) leaf stomatal resistance and the interaction with the crop environment (temperature, relative humidity and vapour pressure deficit);
3) chloride, sodium and potassium accumulation in whole shoots.

7 Achievements against activities and outputs/milestones

Objective 1: Assess the current and potential rice establishment methods used by farmers in at least the three targeted provinces, including their management practices, and use of agricultural machinery to develop corresponding strategies to raise grower productivity.

Activities	Outputs/ milestones	Completion date	Output progress and comments
Activity 1.1: Review existing secondary data, previous reports and available literature for greater information on production practices and households.	Bibliography assembled with supporting documents to be a component for the inception/planning meeting and survey CAM (IRRI, CARDI, GDA, RUA) AUS (I&I NSW, ISST)	12/2010	Relevant literature compiled, shared among partners and stored in a shared site hosted at the University of SA. Alternative arrangements needed to make outputs accessible and effective for Cambodian partners in the future Access to e-copies can be developed however IT issues restrict Cambodian staff
Activity 1.2: Initiate baseline surveys of farmers' current and trends in rice establishment methods, agricultural machinery use, practices and productivity using a pre-tested instrument in each of the target areas.	Workshop involving all project collaborators held in Dec 2009; Survey pretested during Jan-Feb 2010 and widely implemented by CARDI,GDA and RUA and completed by July 2010 CAM (IRRI, CARDI, GDA, RUA) AUS (I&I NSW, ISST)	12/2009 7/2010	Design, pretesting and conduct of survey completed with direct contribution from all partners One baseline survey across 3 provinces with 150 farmers/province and all project partners, completed Aug 2010 More focus group discussion and targeted survey may have led to greater insights and understanding
Activity 1.3: Analyze the survey data, and evaluate opportunities for improved establishment options (including weed control, irrigation, land levelling, agronomy and machinery) by drawing on the most appropriate results from elsewhere, defining clearly the present and future rice establishment needs of the farmer, agricultural machinery trader and manufacturing communities and use the data for updating project strategy through periodic learning and change workshops publishing the results.	1. Initial Survey data analysed by Sept 2010 2. Project strategy devised in September 2010 to incorporate farmer defined priorities 3. Results of the survey will be compiled in a report and subsequently developed for local publications and peer-reviewed journals CAM (IRRI, CARDI, GDA, RUA) AUS (I&I NSW, ISST)	3/2013 Not delivered 10/2013	Preliminary analysis completed for all 3 provinces, with presentations, 3 reports and typologies developed and used in design of project work An extensive dataset has been established Benchmark survey of agro-tool industry in Phnom Penh and 3 provinces was conducted in collaboration with CAVAC, guiding the machinery strategy and complementing the outputs of the baseline survey Full report on analysis and synthesis of survey findings and data implications completed end 2014. The loss of El Sotheary and Mr Piseth from CARDI affected progress of data analysis and results Initial survey results discussed with PDA Extension Officers in 2011. Comments incorporated to fine tune the results. Contributed conference paper to AARES 57th Annual Conference in Feb. 2013 Sydney (see 10.2)

Activities	Outputs/ milestones	Completion date	Output progress and comments
Activity 1.4: Initiate another survey near the end of the project to note any changes in agricultural practices, knowledge, productivity and mechanisation use either through the project and/or changes in farmer practices.	Data collected and analysed for noting any changes in baseline survey areas CAM (IRRI, CARDI, GDA, RUA) AUS (I&I NSW, ISST)	12/2013	Farmer survey - 200 farmers from 22 villages in areas where project team experiments were conducted. **Additional activity** Farmer focus groups - 20 farmer group meetings, 217 farmers to strengthen understanding in key rice establishment systems. The survey datasets were obtained in Australia in January 2014 and analyses completed in September 2014. Biometrical support was provided by NSW DPI. Full analysis has been completed and included in the final report. Key current practices and resource use, issues and prospects of mechanisation, intensification and adoption of innovative agronomic practices, are presented in 'Farmers Focus Group Discussions (FFGD) with farmers growing rice in different eco-systems in Cambodia - Case study: Recession rice in Kampong Thom and Takeo.' The exit survey and results were analyzed and included in the final report. **Training** was provided to the Socio-economic team (CARDI, GDA and RUA) on using gross margins and partial budgeting technique for financial analysis of on-farm research.

Objective 2: For use in better targeting rice establishment options at suitable locations in Cambodia, assemble spatial databases including survey results coupled with other databases including: soil fertility, moisture availability, land use, climate, socioeconomic, among many others to create a Cambodian Country Almanac (CCA).

Activities	Outputs/ Milestones	Completion date	Output progress and comments
Activity 2.1: Improve the existing CARDI soil science laboratory by provision of upgraded equipment and human capacity building to improve the accuracy of soil analyses for the spatial database inclusion in the CCA and for agronomic and germplasm interventions for this and other research projects. Contracted to Drs. Graham and Nelly Blair (ex UNE).	Equipment purchased, upgraded, and service initiated There will be HR capacity building of soil laboratory staff in terms of skills and experience in conducting soil analyses CAM (CARDI, Blair)	6/2012	Lab equipment was purchased. Lab manuals (Appendix 3) translated into Khmer. Initial training conducted: Visit 1 completed Visit 2 planned but not conducted. Training was limited due to lack of staff at the laboratory. Sampling constrained by ongoing training likely to be necessary to maintain and build capacity for staff to manage the laboratory.
Activity 2.2: Develop a beta version of the Almanac using existing data bases for release and testing among GIS user groups. Training for this project's partners will enable their inclusion as 'GIS user groups.'	200 beta copies will be delivered with training on its use. Contribution of data to the CCA will provide an immediate acknowledgement of individuals contributions and allow immediate dissemination of data and information to others. CAM (Contractor, CAVAC)	6/2010	CLEAR has been assembled with a full version of the beta version (200 copies delivered with training) a full version released in October 2011. Training delivered at first release in 2011. 22 training sessions and 9 demos delivered for first release. 500 registrations have built up over the life of the project. Feedback to ARUNA continued over the life of the project.
Activity 2.3: Populate the spatial database of CCA with newer data including data obtained by CAVAC in 2009 while increasing the number of users while empowering a greater number of new users through training.	Databases will increase including socioeconomic and other relevant spatial data. CAM (CARDI, CAVAC)	2/2011	Data were incorporated in 2009 and 2010 in version 2 of CLEAR. Further updates are unlikely without support from a commercial or government partner.
Activity 2.4: Release a first version of the Almanac and trial with Cambodian users, modify and release a second version while maximizing users through greater trainings.	300 users will be further trained on CCA v.1 expanded capabilities and databases CAM (CARDI, GDA, RUA, IRRI, CAVAC)	3/2012	353 people from 16 organisations trained in use of CLEAR (see Table 7.12 in Results section). Second version released in August 2012 with 30 new/updated layers and made available in October 2012. On DVD from ARUNA or at http://clear.awhere.com/Homepage.aspx User license expired Feb 2014.

CAM = Cambodia, AUS = Australia

Objective 3: Determine strategies and options that optimise rice establishment practices using direct seeding or other establishment methods on appropriate soils and rice ecosystem/farming systems, to identify suitable weed management approaches, and to develop training materials.

Activities	Outputs/ Milestones	Completion date	Output progress and comments
Activity 3.1: Evaluate technically and economically rice establishment techniques (possibly comparative trials both on-station and on-farm) and demonstrate economically and promising / potential technologies. Adaptive research will be conducted to optimise the performance. Innovative participatory methodologies will be implemented for farmer/trader/manufacturer input in the rice establishment techniques early in the process.	Targeted adaptive trials (50 in total –sites x season) implemented progressively on rice establishment techniques and associated practices and options Agronomic recommendations reviewed in the light of adaptive trial results including economic assessment. CAM (GDA, CARDI, RUA, IRRI) AUS (I&I NSW, ISST)	9/2010 9/2011 9/2012 9/2013 9/2011 9/2013	15 benchmarking trials completed. ICE trials designed to address Objective 3 & 4 and fulfil Milestones. 6 BMP trials completed. 19 machinery and student trials completed. 6 soil water/puddling trials completed. 38 conducted by RUA. 68 conducted by GDA (incl. ICE). Statistical and economic analysis completed on trial data. ICE trial combined analysis completed with assistance from Neil Coombes, Biometrician, NSW DPI. Seeding rates for broadcasting and drum seeding have been optimised (biological and economic). Mechanised dry/wet establishment options defined with regard to topography, soil type, tillage and season. Whole team workshops were conducted in June and September 2014 to document group and individual experience, learning. These workshops enabled the development of rigorous, evidence-based recommendations for establishment practices for topo-sequence, soil type and season. Due to the cancellation of CAVAC links in early 2012, out-scaling activities (drum seeders, FFS) occurred at a more limited scale than planned New direct private sector linkages have been established to promote both drum and drill seeders.
Activity 3.2: Drawing on the survey data and experience gained elsewhere (e.g. ACIAR-India, The Philippines, and IRRC), identify the best-bet weed management approaches that take account of a weed species shift likely to occur as a result of changes in management and establishment practice. Monitor effectiveness of weed management approaches and adapt these as appropriate.	Targeted adaptive trials (20 in total –sites x season) implemented progressively on weed implications of rice establishment integrated with above trials Nature of weed problems in respect to management described; and response options developed. CAM (GDA, CARDI, RUA, IRRI) AUS (I&I NSW, ISST)	9/2010 9/2011 9/2012 9/2013 9/2011 9/2013	38 targeted adaptive trials in ICE trials in total –sites x season ICE completed. Best bet recommendations for fertiliser and weed control have been tested and included in the final report. Full analysis of site by season by establishment enabled patterns to be identified and recommendations for farmers to be compiled. Weed types have been identified and described. Development of IWM recommendations including herbicide resistance management drafted.

Activities	Outputs/ Milestones	Completion date	Output progress and comments
Activity 3.3: Develop training modules on rice establishment for use in CAVAC extension activities and through them, reach farmers, NGOs, input supply dealers, and machinery traders.	At least 2,500 modules published and trainees educated on improved rice establishment Modules reviewed in "light of results/ experience" CAM (CARDI, GDA, RUA, CAVAC, IRRI) AUS (I&I NSW)	9/2011 9/2013	Training materials developed and delivered for: • Drum seeder use and seed drill calibration and field setting (translated into Khmer); • Manuals for machinery troubleshooting and operation (translated) not yet published; • Whole farm family (CAVAC); • 44 farmer field schools for 1130 farmers (550 women); • Weed identification and management (in Khmer) to PDA, GDA CARDI staff, RUA students (270, 92 women); • Mentoring to machinery dealers and manufacturers and facilitate exchanges with farmers and attendance at machinery field days. These materials have been reviewed and updated by partners as part of an ongoing process during the project. Post CAVAC, outreach and extension is being tested with direct engagement of one-stop-shop input and machinery outlets.

CAM = Cambodia, AUS = Australia

Objective 4: Identify agronomic practices specifically to raise productivity by 25% for the emerging dry season, high-yielding irrigated rice system in Cambodia, and to develop training materials.

Activities	Outputs/ Milestones	Completion date	Output progress and comments
Activity 4.1: Evaluate technically and economically innovative agronomic practices with defined technology options. Farmer/trader/manufacturer input, in a fully participatory approach early in the process, will allow quicker upscale and uptake by the farmer communities of rice establishment methods, agronomic recommendations, and weed control practices.	Targeted adaptive trials (50 in total –sites x season progressively implemented on improved agronomic practices in irrigated dry season rice on farm and on station. Agronomic recommendations reviewed "in light" of experience including economic assessment.. CAM (CARDI, GDA, RUA, ,IRRI Justice) AUS (I&I NSW, ISST)	9/2010 9/2011 9/2012 9/2013 9/2011 9/2013	38 ICE trials (sites*season) dry and wet seeded options. 5 on station (CARDI 2, RUA 1, GDA 2) and PDA (Tng Bati) and 2 on-farm (Takeo and Kampot). Completed at end of wet season (Nov 2013) except 1 ongoing at CARDI. Best bet agronomic recommendations were compiled for machinery and weed control. The project team workshop in Sept 2014 enabled collation of agronomic recommendations based on trial results and experiences in the project. Agronomic data were subjected to rigorous economic analysis to produce farmer recommendations.
Activity 4.2: Increase the capacity of private entrepreneurs (traders, agronomy and machinery input dealers, manufacturers, etc) to access and provide accurate information to the grower communities.	Technical information sheets are available on fertilisers, herbicides, pumps, machinery and subsequently revised based on project findings.. CAM (CARDI, GDA, RUA, IRRI, CAVAC) AUS (I&I NSW, ISST)	9/2011 9/2013	Technical information sheets available since 2012 on fertiliser, herbicide, irrigation pumps, machinery and soils. These were produced by CAVAC as part of their extension role in the project up until 2012. Revision of these technical sheets is now possible after completion of the analysis of the full trial data set. Production manuals were published in 2011 (the blue book) including fertiliser use, dry seeding, crop care. Development of the Cambodian drill seeder in close partnership with industry
Activity 4.3: Formulate training modules on successful dry season rice technology options and incorporate in CAVAC extension activities and through them, reach NGOs, input supply dealers, and machinery traders.	At least 2,500 modules published and trainees educated on raising dry season rice crop productivity. CAM (CARDI, GDA, RUA, CAVAC, IRRI, Justice) AUS (I&I NSW, ISST)	9/2011 9/2013	Modules developed in weed management, establishment options, pest management, drum seeder.

CAM = Cambodia, AUS = Australia

Objective 5: Increase the capacity of CARDI, GDA and RUA to lead demonstrations of rice establishment techniques and agricultural equipment

Activities	**Outputs/ milestones**	**Completion date**	**Output progress and comments**
Activity 5.1 1.Partner CARDI agricultural engineering program, agronomy and crop protection staff with that of GDA, RUA, private agricultural manufacturers, traders and farmer groups. 2. Capacity of private entrepreneurs will be supported by the CAVAC Agribusiness/Business component, in close collaboration with this project.	1. CARDI, GDA and RUA will work together in development of agronomic recommendations after options are evaluated in on-station and on-farm demonstration. 2. Capacity of private entrepreneurs in upscale of demonstration will be supported by CAVAC on a cost-sharing basis CAM (CARDI, GDA, RUA, IRRI, CAVAC, Justice) AUS (I&I NSW, ISST)	5/2010 9/2011 9/2012 9/2013	3 Cambodian partners conducted replicated WS, DS and early WS experiments each year (see activities 3.1, 3.2 and 4.1). The project successfully engaged with machinery manufacturers and retailers and during the 6 month extension with a new one-stop-shop input supplier, now located in Battambang.
Activity 5.2: Build capacity of CARDI, RUA, and GDA to lead demonstrations on agricultural innovations and utilize the Cambodia Country Almanac (Obj 2).	Partners increasingly take leadership in demonstrating agricultural innovation developed within the project. Manual and training on CCA uses will be provided to CARDI, GDA, RUA and others CAM (CARDI, GDA, RUA, CAVAC)	9/2011 9/2013 3/2012	IRRI conducted 3 weed workshops (management and control) for Cambodian scientists from CARDI (5) GDA (8) CAVAC (5) RUA (5) and PDA (6). UniSA mentored CARDI, GDA and RUA partners on machinery trial activities, developing their capacity to design, implement and sample machinery trials as well as interpret field results. CARDI management of on-farm-replicated trials has improved capacity to manage activities in other ACIAR projects (LWR2008/019, 2009/046 & CARF). CARDI researchers use CLEAR database for R&D.

CAM = Cambodia, AUS = Australia

Objective 6: Australian component of the project will investigate current and predicted future problems with rice seedling establishment including cultural practices and soil type interactions and issues related to the use of groundwater.

Activities	Outputs/ Milestones	Completion date	Output progress and comments
Activity 6.1 Review literature and industry practice regarding rice crop establishment and rice seeding machinery. Explore the best way of matching seeding technologies to soil type and conditions for improved rice establishment under drill and aerial sowing. Replicated field experiments investigating the use of a range of seeding and fertiliser rates in areas of adverse soil conditions in farmer's fields would be undertaken using drill or aerial seeding at locations across the rice growing region. Soil characterisation, crop establishment, crop growth and final biomass and yield measurements would be taken. Replicated glasshouse experiments on the effectiveness of soil amendments (gypsum, organic matter, polyacrylamides) and seed coating/priming using phosphorus amendments and GA / IBA treatments will be undertaken. Depending upon the success of these glasshouse experiments field experiments would be undertaken.	Literature review assembled and reviewed by external reviewer AUS (I&I NSW, ISST) Experiments completed, data collated and analysed Results presented to growers, R&D groups Determine whether seed dressings/seed coating or soaking solutions offer improvements in plant establishment in cut and/or sodic soils. Determine whether physical soil tilth is a limitation or are there interactions with nutrition AUS (I&I NSW),RRAPL	12/2010 9/2013 9/2013 9/2011 9/2012 9/2013	Rice literature review incorporated as part of Activity 1.1 including a focus on crop establishment techniques with some seeding machinery considerations. Initial literature review assembled Sept 2010, made available on share site at the University of South Australia, with additional papers collected over the project duration. Literature and consultation with UniSA used in identifying machinery opportunities for improving rice crop establishment in heavy stubble, and guide selection and operation of equipment used in field trials conducted by Rice Research Australia. Several replicated field experiments have been conducted over 3 years of the project. Many of the experiments have been located on farmers' fields across all southern NSW rice growing areas and included both drill and aerial seeding methods. Seed treatments and fertilisers have been tested and crop establishment, growth and yield measurements collected. Several replicated glasshouse experiments have been conducted to determine the effectiveness of seed coating and priming using GA and IBA treatments and numerous Zn seed coats and sprays. Some of these seed coat treatments have also been tested in experiments in the field. Results have been presented to farmers, commercial agronomists and R & D groups at several field days, pre-season meetings, research meetings, radio interview, IREC farmers newsletter article and direct contact with growers and consultants.

Activities	Outputs/ Milestones	Completion date	Output progress and comments
6.2 Replicated field and glass house experiments will quantify the impact of water quality on the growth and yield of current and potential rice varieties. The experiments will be undertaken in a complementary fashion, with the applicability of glasshouse results confirmed by field trials: i) Rice varieties will be grown in pots irrigated with water of a given ECiw in glasshouse based pot experiments ii) Appropriate rice varieties will be sown in replicated agronomy field trials which will be irrigated with saline groundwater.	Field plot experiments on bay water salinity threshold and salinity tolerance of 6 common Australian varieties undertaken	Apr 2011	Confirmation of bay water salinity threshold recommendations for current main Australian rice varieties. These recommendations are somewhat conditional because of the damage that mice did to the grain yield in this trial.
	Relative salinity tolerance of all current semi-dwarf Australian varieties assessed at reproductive stages in pot trials in the Deniliquin glasshouse along with two unreleased Australian varieties, two IRRI “check” varieties, and two common Cambodian varieties	Apr 2012	Determination of relative salinity tolerance of current main Australian varieties at reproductive stage. Quest appears the most tolerant line.
	District field demonstrations to confirm outcomes of small plot and glasshouse experiments undertaken.	Apr 2013	Differences in development between the salt and fresh treatments resulted in differing impact on the treatments from cold damage. Data from these sites was only used to support data from other trials.
	Two glasshouse experiments conducted to: 1) assess salinity tolerance of 20 lines (Australian and IRRI) during vegetative growth, and 2) determine the effect of water salinity on the relationship between transpiration, leaf area and shoot chloride accumulation.	May 2013	Determination of relative salinity tolerance of current main Australian varieties at vegetative stage. Quest and Doongarah appear the most tolerant lines. Transpiration rates differed between varieties and salinity reduced transpiration in all lines. There is a relationship between transpiration, leaf area, biomass and chloride accumulation.
	Growth chamber experiment to assess salinity tolerance at seedling stage of 15 varieties and effect of root zone salinity on shoot ion (Cl, Na, K) accumulation Analysis for shoot chemistry completed. Statistical analysis and report writing completed	Feb 2014 Mar 2014 Sept 2014	Growth chamber and shoot chemistry experiments completed. The main Australian cultivars (Sherpa, Reiziq) appear as tolerant as during the vegetative stage as tolerant Asian lines. Illabong, Kyeema and Amaroo appear the most sensitive Australian lines at the vegetative stage. Quest and Doongara were the least affected by salinity while Basmati was the most affected. Data is undergoing statistical analysis for reporting by journal publication.

PC = partner country, A = Australia

8 Key results and discussion

8.1. Objective 1: Assess current and potential rice establishment methods

Review of existing data, reports and literature

The information obtained provided a useful reference for the team in the early stages of the project to help guide the project direction and clarify knowledge gaps and opportunities for innovation. The information was shared among partners and is currently in a repository held in a University of South Australia share drive, with password access to registered individuals from UniSA, NSW DPI, CARDI, GDA, RUA, CAVAC, ACIAR. There is an opportunity to update the repository and distribute it more widely as an e-copy (CD) for easier and more effective access, especially for students, but issues of copyrights may need to be clarified.

Farmer practices within the scope of this project include rice establishment methods, use of agricultural machinery, irrigation methods and agricultural inputs. The surveys conducted showed that the capacity of Cambodian farmers to adopt new technologies is affected by the availability of irrigation, access to inputs, access to extension advice and access to credit.

In the study area, over 80% of the farms were less than 2 ha in size. Most of these farms were fragmented into 2-7 parcels, each with different soil types, topography, location and suitability for rice. Mostly, the separate parcels had different levels of access to irrigation water.

Results of farmer focus group discussions

Recession rice is grown on large areas in both in Kampong Thom and Takeo. The size of farms owned by the participants in the four focus group discussions in each of these provinces is summarised in Table 8.1 and Table 8.2.

Table 8.1: Farm size distribution in Takeo

Village	Commune	District	No. of farmers	Proportion in each farm size (%)		
				< 1 ha	1-2 ha	> 2 ha
Bro Chreal	Ang Prasat	Kirivong	10	90	10	0
Krang Tromung	Ta O	Kirivong	8	67	17	17
Phnom Borey	Phtol	Angkor Borei	11	78	22	0
Toul Sangkor	Angkor Borei	Angkor Borei	11	55	45	0

Table 8.2: Farm size distribution in Kampong Thom

Village	Commune	District	No. of farmers	Proportion in each farm size (%)		
				< 1 ha	1-2 ha	> 2 ha
Bantaychas	Thnoth Chum	Baray	18	78	11	11
Banok	Baray	Baray	22	41	41	18
Snengkrobie	Kampongkrobao	Steoung Sen	14	16	50	14
Orkunter	Orkunter	Steoung Sen	15	40	33	27

Key findings from the discussion groups showed the following similarities and differences within and between the different provinces.

Similarities

- A single cultivation using power tillers and combines are used for harvesting rice;
- Inefficient arrangements for custom hiring of machinery;
- Broadcasting (direct seeding) IRRI varieties of rice;
- Farmers use their own seed or buy it from neighbours;
- Micro finance advancing loans at competitive rates;

- Awareness among farmers on importance of fertilisers and chemical plant protection;
- Lack of quality extension support;
- Rice sold to village collectors.

Differences

- Prices of fertilisers vary both within and across provinces;
- Significant differences in input use, farming practices - both inter- and intra-regional;
- Ownership of power tillers vary greatly across districts and provinces;
- Treatments and their timing, practices and resources that are used in different areas.

In the 2010 benchmarking survey conducted across the three target provinces, 67-77% of the 450 surveyed farmers owned an animal drawn trailer/plough, with only 3-10% owning 2-wheel tractors. A later survey (2013) of farmer focus groups in the recession areas of the more mechanised province of Takeo, 83.4% farmers use 2-wheel tractors, with 42% as owners. An analysis of trends occurring between 2010 and 2013 is presented at 7.1.3

Baseline survey economic analyses (2010)

Seeding practice

Farmer practices for seeding rice were transplanting (TPL), broadcast wet (BCW) and broadcast dry (BCD). Seeding practices differed between the three Provinces (Figure 8.1). In Kampot (Chhouk) transplanting was the predominant method in all seasons: early wet season (EWS), main wet season (MWS) and dry season (DS). Some BCW was practiced in the EWS and DS. In Takeo (Bati) BCW was the predominant method in the EWS and DS with TPL the main method in MWS. BCW and BCD was also done in the MWS. In Kampong Thom (Steung Sen) BCW was the predominant method in all seasons.

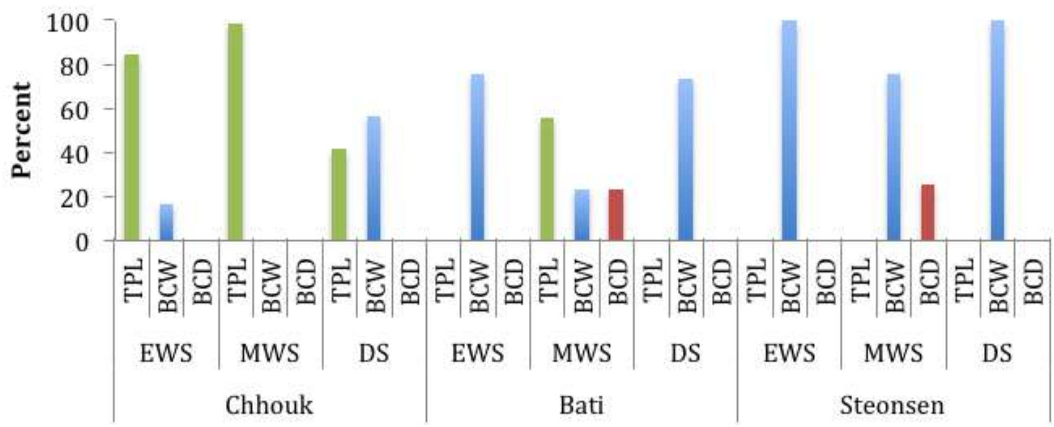


Figure 8.1 Seeding practices in the target Provinces in 2010.

Across the three Provinces, the cost of seeding by transplanting per ha was $177 compared to $42 for broadcast seeding when the cost of labour was included (Figure 8.2). However, the broadcast seeding rate was much higher in Kampong Thom (272 kg/ha average) compared to 80 kg/ha or less in Takeo and Kampot.

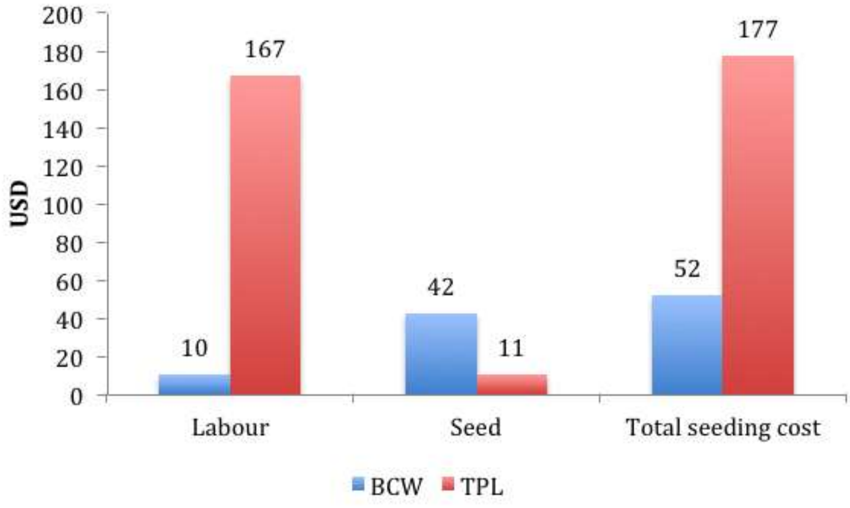


Figure 8.2. Cost comparison between transplanting and broadcasting.

Fertilizer use

The fertilizer use pattern was similar for Kampot and Takeo with higher rates being applied in the EWS and MWS compared to the DS.

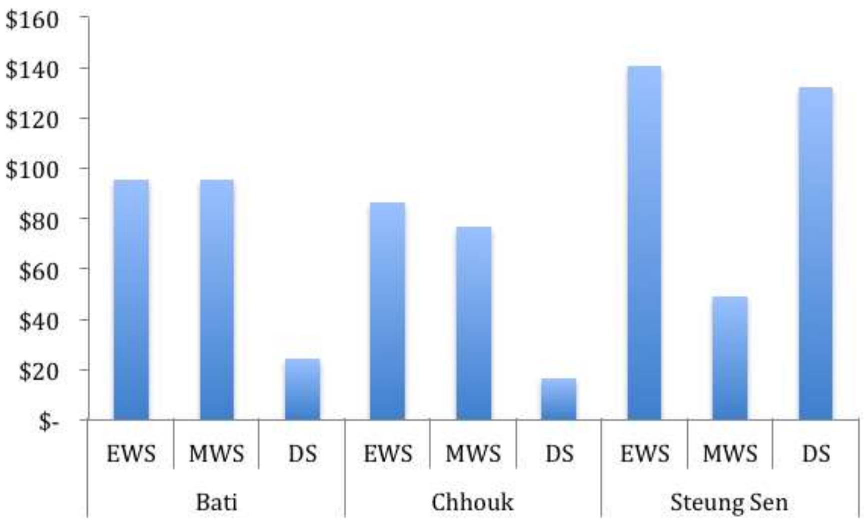


Figure 8.3: Fertilizer input costs.

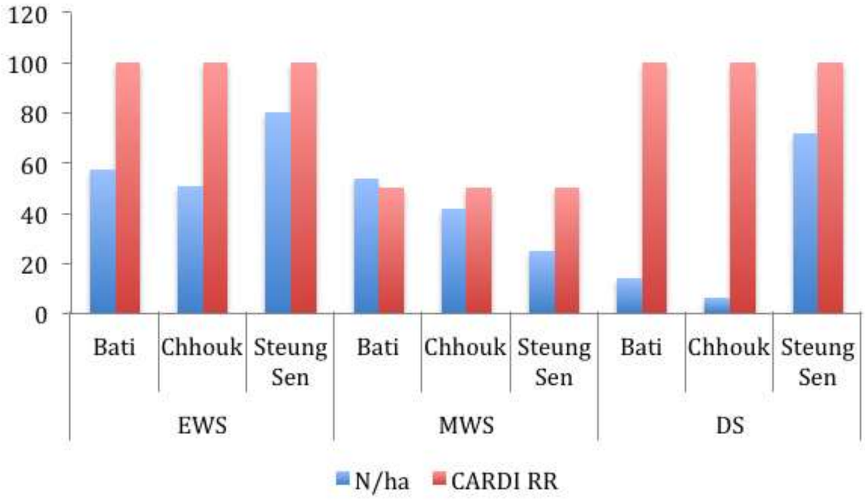


Figure 8.4: Rates of N applied to rice in three Provinces according to season.

The rates of N-equivalent fertilizer were consistently less than the CARDI recommended rates of N for Prateah Lang soil. This was particularly the case for EWS and DS crops.

Recommendations

Recommendation 1. Following the CARDI fertilizer application package should be a key extension message arising from the project.

Weed control

Weed control was predominantly by herbicide and it was assumed some hand weeding was carried out following herbicide application. Weed control expenditure didn't vary much between Provinces but greater amounts of hand weeding were done in the EWS and DS (Figure 8.5).

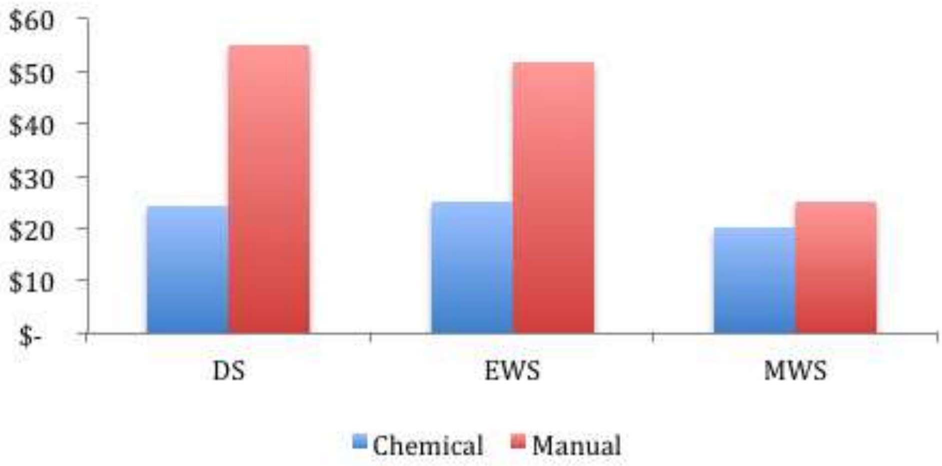


Figure 8.5: Chemical vs manual weed control costs.

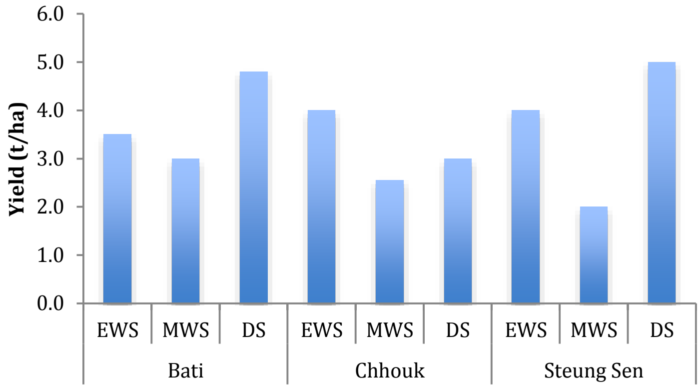


Figure 8.6: Rice paddy yields across seasons in three Provinces.

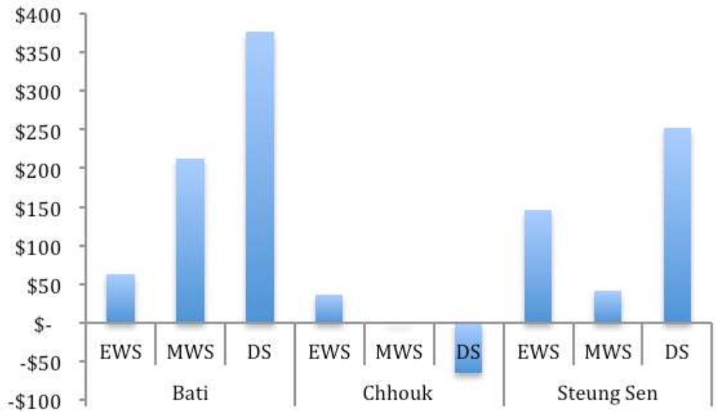


Figure 8.7: Gross margins for three sowing times in three Provinces.

Harvesting

Harvesting was by machine in all seasons at Bati and in the EWS and DS at Steung Sen. Harvesting was done manually in all seasons at Chhouk.

Paddy yield

The average rice paddy yield was 4.0 t/ha in the EWS and DS and 2.3 t/ha in the MWS. The MWS yield was the lowest at all sites (Figure 8.6). These are farmer estimates and should be read in that context.

Gross margins varied between sites and seasons (Figure 8.7, Table 8.3). The result indicates that farmers in Chhouk are actually losing money growing rice and this is related to the high dependence on manual labour for production.

Table 8.3. Gross margin analysis for the baseline survey, 2010.

Activity	Input	Bati (EWS)	Bati (MWS)	Bati (DS)	Chhouk (EW	Chhouk (MV	Chhouk (DS)	Steung Sen	Steung Sen	Steung Sen
Land preparation	Land levelling	$15.00	$15.00	$ -	$15.00	$15.00	$15.00	$15.00	$15.00	$ -
Land preparation	1st ploughing	$37.50	$37.50	$37.50	$37.50	$37.50	$37.50	$37.50	$37.50	$37.50
Land preparation	2nd ploughing	$37.50	$37.50	$37.50	$37.50	$37.50	$37.50	$37.50	$37.50	$37.50
Land preparation	Harrowing	$25.00	$25.00	$25.00	$25.00	$25.00	$25.00	$50.00	$25.00	$25.00
Sowing	Seed	$18.05	$16.07	$16.53	$6.09	$9.41	$6.61	$74.23	$76.02	$60.33
Sowing	Labour	$10.00	$160.00	$10.00	$170.00	$170.00	$10.00	$10.00	$10.00	$10.00
Fertilizer	Urea	$52.64	$43.24	$14.10	$42.77	$33.37	$6.58	$63.45	$20.21	$54.99
Fertilizer	DAP	$22.11	$42.21	$ -	$33.50	$33.50	$ -	$67.00	$18.76	$67.00
Fertilizer	KCL	$10.88	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Fertilizer	Application	$10.00	$10.00	$10.00	$10.00	$10.00	$10.00	$10.00	$10.00	$10.00
Irrigation	Pump	$25.00	$12.50	$75.00	$25.00	$12.50	$75.00	$25.00	$12.50	$75.00
Irrigation	labour cost for irrigation	$20.00	$10.00	$60.00	$20.00	$ -	$60.00	$20.00	$10.00	$60.00
Weed control	Herbicide	$12.50	$11.50	$9.38	$4.00	$11.50	$5.00	$5.50	$5.00	$6.00
Weed control	Application	$17.50	$17.50	$17.50	$17.50	$17.50	$17.50	$17.50	$17.50	$17.50
Weed control	Manual weeding	$55.00	$25.00	$55.00	$55.00	$25.00	$25.00	$55.00	$25.00	$55.00
Insect control	Insecticide	$10.00	$10.00	$10.00	$10.00	$10.00	$10.00	$10.00	$10.00	$10.00
Insect control	Application	$35.00	$35.00	$35.00	$35.00	$35.00	$35.00	$35.00	$35.00	$35.00
Disease control	Fungicide	$10.00	$10.00	$10.00	$10.00	$10.00	$10.00	$10.00	$10.00	$10.00
Disease control	Application cost (contract)	$35.00	$35.00	$35.00	$35.00	$35.00	$35.00	$35.00	$35.00	$35.00
Other pest control	Other Pesticide	$5.00	$5.00	$5.00	$5.00	$5.00	$5.00	$5.00	$5.00	$5.00
Other pest control	Application cost (contract)	$17.50	$17.50	$17.50	$17.50	$17.50	$17.50	$17.50	$17.50	$17.50
Harvesting	Manual	$190.00	$ -	$ -	$188.00	$187.50	$187.50	$ -	$ -	$ -
Harvesting	Machine		$100.00	$100.00				$100.00	$100.00	$100.00
Transport	Hand tractor	$ -	$20.00	$ -	$ -	$17.00	$ -	$ -	$13.33	$ -
Loan		$80.54	$82.26	$69.60	$95.92	$89.37	$75.68	$84.02	$65.50	$87.40
Variable costs		**$751.72**	**$767.78**	**$649.61**	**$895.29**	**$834.15**	**$706.38**	**$784.20**	**$611.33**	**$815.72**
Rice yield		3.50	3.00	4.80	4.00	2.55	3.00	4.00	2.00	5.00
Price		$232.75	$326.56	$213.75	$232.75	$326.56	$213.75	$232.75	$326.56	$213.75
Income		**$814.63**	**$979.69**	**$1,026.00**	**$931.00**	**$832.73**	**$641.25**	**$931.00**	**$653.13**	**$1,068.75**
Gross margin ($/ha)		**$62.90**	**$211.91**	**$376.39**	**$35.71**	**-$1.41**	**-$65.13**	**$146.80**	**$41.80**	**$253.03**
Break-even yield		3.23	2.35	3.04	3.85	2.55	3.30	3.37	1.87	3.82
Break-even price		$214.78	$255.93	$135.34	$223.82	$327.12	$235.46	$196.05	$305.66	$163.14

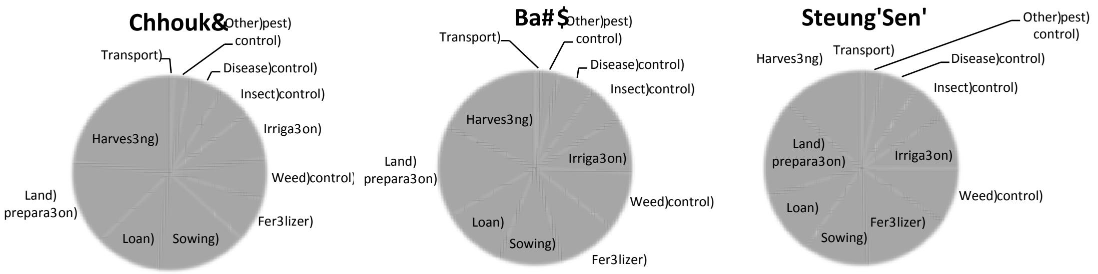


Figure 8.8. Input costs for rice production in three Provinces.

The largest input allocations for rice production in the survey of Cambodian farms were for 'primary' inputs: loan, land preparation, sowing and harvest (Figure 8.8). This was greatest in Chhouk which was the most dependent on hand operations.

The result also agrees with observation that perhaps 'secondary' inputs such as fertilizer and herbicide are applied too little and too late. It should be noted that the crop loan is typically the third or fourth biggest input cost. Farmer education about loan options should be a high priority with regard to input purchase decisions.

Key findings

1. Cambodian farmers have addressed the problem of lack of and cost of labour by:
    a. Switching to direct seeding which significantly reduces the cost of crop establishment compared to transplanting;
    b. Adoption of herbicides which are substantially cheaper than hand-weeding;
2. Farmer-practice fertilizer application rates are substantially less than the CARDI recommended rates;

3. Farmers in the survey appeared to be 'risk-averse' by applying 'primary' crop inputs of land preparation, seed and harvesting but under-investing in 'secondary' inputs such as nutrition and crop protection which generally minimises returns;
4. Farmers relying on traditional methods of transplanting and hand weeding (eg Chhouk) had minimal or zero gross margins.

Discussion

The comparison of input allocation in the Cambodian rice crop compared to Australia suggest that rice productivity in Cambodia is being held back by lack of and poor timing of 'secondary' inputs especially relating to nutrition and weed management (Figure 8.9). Key differences were the higher amount spent on 'primary' inputs of land preparation and sowing in Cambodia compared to Australia. This agrees with the observations by Smith et al. (2011) in Lao PDR especially with regard to the amount and timing of weed control and fertilizer inputs.

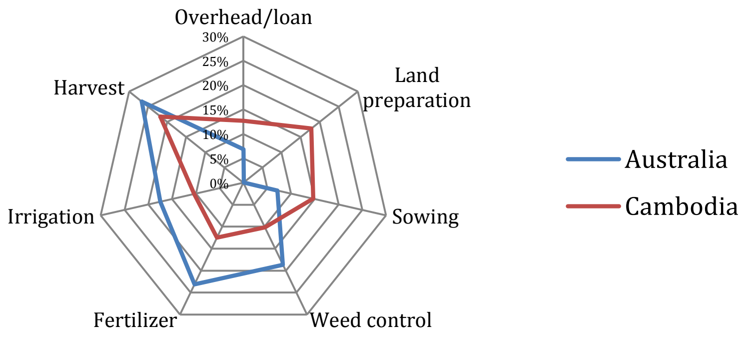


Figure 8.9. Allocation of input resources: Cambodia vs Australia.

Extension programs could focus on reduced or no-tillage and drum/drill seeding recommendations arising from the project. Savings made here could be spent on additional fertilizer application and weed control. The proportion of the input budget spent on fertilizer and weed control was considerably greater in Australia compared to Cambodia. This is also a key extension message arising from the project with regard to lifting rice productivity in Cambodia bearing in mind that the yield of rice crops in Australia is approximately three times that in Cambodia.

Cambodian farmers are generally 'risk-averse' (Nesbitt 2003) and are reluctant to spend on 'secondary' inputs such as fertilizer and herbicide until they are confident that the crop will produce yield. This tends to be when the paddy fills with water. Often by this time, a low physiological yield potential has already been set by the rice plant. Limited yield gains can therefore be made from late fertilizer and herbicide applications.

Although rice paddy yields in Cambodia have reached the 3 t/ha mark, the trend appears to have levelled off. Cropcheck is a participatory planning, action and review cycle that was developed in Australia to address stagnating and variable crop yields. Smith et al. (2011) found that application of Cropcheck principles in Lao PDR pin-pointed crop management factors that contributed to rice yield variability.

Is there a case for Cropcheck in Cambodia? Smith et al. (2011) reported on a project designed to adapt the Cropcheck extension model developed in Australia to rice production in Lao PDR. Cropcheck is a systematic process that enables benchmarking of high and low yielding crops against potential abiotic and biotic yield-limiting factors. The system requires local identification of the management factors affecting rice production.

once factors have been identified for inclusion in Cropcheck, measurements are taken at appropriate times in the farmers' fields.

A number of key checks have been identified in this project through farm surveys, farmer field schools, on-farm demonstrations and experiments. These include the need to:

- Improve direct seeding practices to reduce seeding rates and improve crop establishment uniformity by adoption of land levelling and mechanised seeders such as drum seeders or seed drills;
- Improved weed management, especially with regard to the timing in early stages;
- Improved fertilizer practice with regard to the amount and timing of applications.

Smith et al. (2011) found that implementation of Cropcheck in Lao PDR was constrained by the resources available to government extension agencies. This would also be the case in Cambodia. However, input suppliers such as UCA , Uni-Mart, Nokor Thom now provide technical advice and agronomy support to farmer clients. Cropcheck is an ideal tool for the private sector to improve their credibility with farmers as well as help them to adopt more profitable cropping practices.

Recommendations

Recommendation 2. Cropcheck could be adapted for Cambodia to help farmers better manage resource use efficiency in the rain fed rice system with the objective of optimising rather than maximising crop yields. Input suppliers who employ agronomists and technical specialists would be the ideal vehicle to roll out Cropcheck in Cambodia and would need to be engaged in the Cropcheck development process in collaboration with public sector R,D&E organisations.

Follow up farmer surveys

Trends of key indicators (2010-2013)

Data collected on key farm indicators in 2010 and 2013 allowed an analysis of trends in Tramkok District, Takeo Province, Chumkiri District, Kampot Province and Baray District, Kampong Thom Province.

There is a general lack of awareness and adoption of the best management practices for growing rice. There are wide variations in the use of seed, nitrogen and other inputs and variable crop yields that will have an adverse impact on estimated potential benefits, cost and economic viability of the on-farm adoption of new technologies such as the drum seeder (

Table 8.31, Table 8.32).

Farm size

The average number of farms less than one hectare declined from 88% to 52% between 2010 and 2013 and there was a corresponding increase in farm holdings greater than two hectares (Figure 8.10). This trend was greatest in Baray where farms less than one hectare declined from 91 to 10%. The change resulted in an average increase in fragmentation from 1.1 to 1.7 parcels of land. The median cropping intensity increased from 1.1 to 1.7 crops per year with a similar trend across all districts.

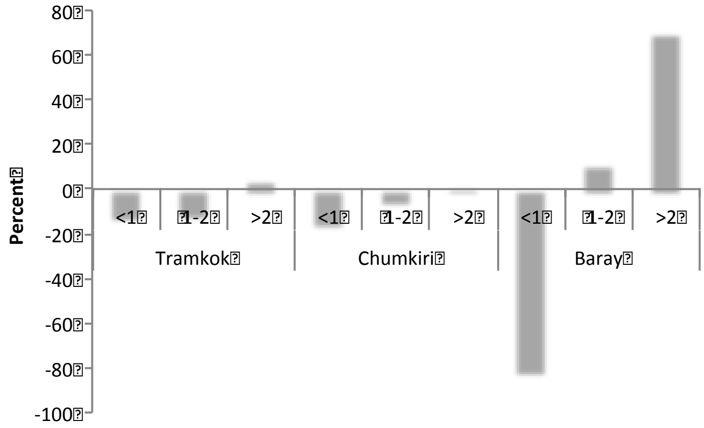


Figure 8.10: Trend in farm size between 2010 and 2013.

Machinery

On average, ownership of 2-wheel tractors increased from less than 1% to 21% between 2010 and 2013. Ownership of knapsack sprayers increased from 22 to 60% on average with the greatest level of ownership in Baray (91%). This corresponded with an average increase in the use of herbicides from 29% in 2010 to 67% in 2013.

The attitude towards the benefits of mechanization changed between 2010 and 2013. In 2013, 46% of farmers recognised the importance of mechanization for timeliness of operations compared to 10% in 2010. 33% of farmers recognised the importance for increased cropping intensity compared to 4% in 2010.

Seeding practices

Most farmers keep their own seed for sowing with 13% buying seed in the EWS, 5% in the MWS and none in the DS. It is doubtful if purchased seed can be classed as 'certified' because the certification statistics are printed on the bags rather than on individual tags stitched into the bags.

Between 2010 and 2013, there has been a significant reduction in the number of farmers transplanting rice. In the EWS, the biggest reduction was in Chumkiri district where transplanting was replaced largely by wet direct seeding (Figure 8.11). In the MWS, the biggest reduction in transplanting was in Baray district and it was replaced by dry direct seeding (Figure 8.12).

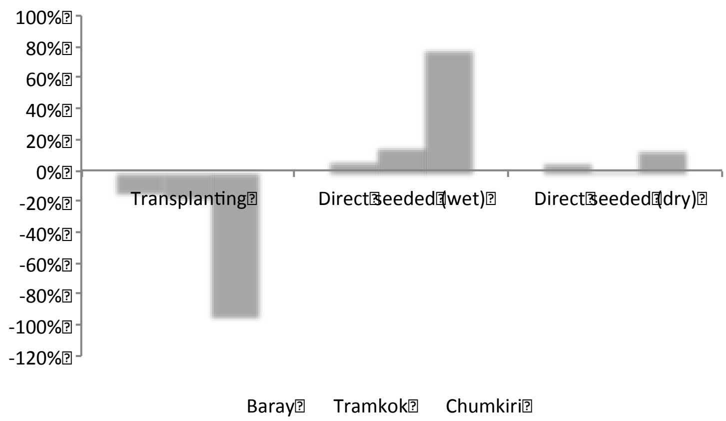


Figure 8.11. Trends in planting method for the EWS.

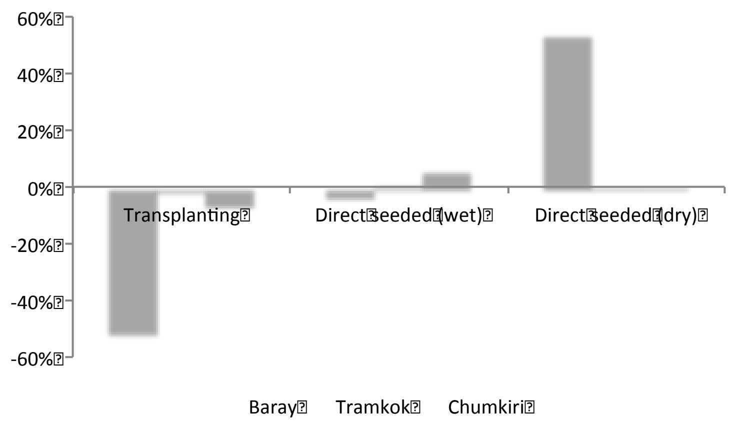


Figure 8.12. Trends in planting method for the MWS.

It is interesting to note that the transition from transplanting to direct seeding in the project target areas is up to 20 years behind some other parts of Cambodia. Chan and Nesbitt (1997) wrote “Broadcasting of rain fed rice is a common practice in Battambang and in some parts of Pursat and Banteay Meanchey. This is generally achieved by ploughing the soil once or twice, broadcasting dry seed, and possibly harrowing once after sowing. Labour for establishing and managing a nursery plus transplanting is thereby eliminated. Weeds are a problem using this technique and often farmers will plough the crop once 6-8 weeks after emergence to kill the weeds.” This remains the main practice for planting MWS rainfed rice in these Provinces.

Fertilizer application

There was no consistent trend in the amount of N applied in the EWS. However, there was a trend at all locations for increasing frequency of fertilizer application with a large decline in single applications and a transition to 2-3 applications (Figure 8.13).

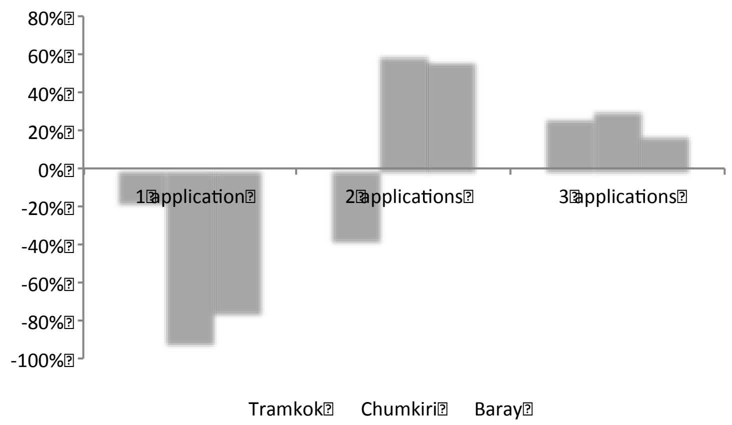


Figure 8.13. Trends in the number of fertilizer applications in the EWS.

Similar trends occurred in Tramkok and Chumkiri in the MWS (Figure 8.14).

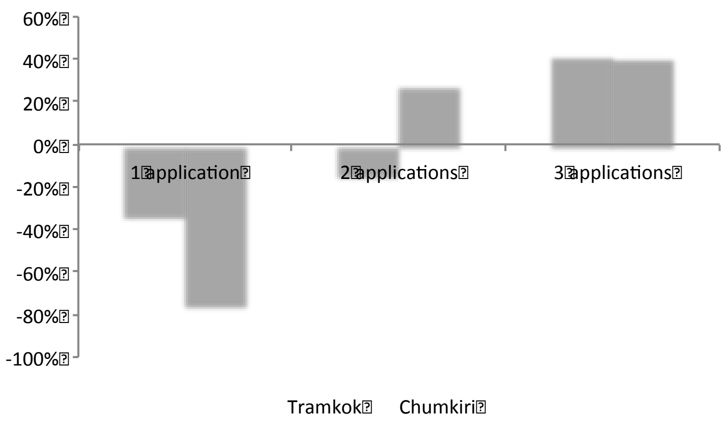


Figure 8.14. Trends in the number of fertilizer applications in the MWS.

Herbicide application

Herbicide application increased from 17% of farms in 2010 to 76% in 2013 (Table 8.4). There was a marginal increase in the MWS but the number declined in Chumkiri. In the DS, herbicide application increased from 36% to 68% on average with the strongest change in Baray where herbicide application increased from 0% to 90%.

Table 8.4: Trends in herbicide application.

Season	Tramkok		Chumkiri		Baray		Average	
	2010	2013	2010	2013	2010	2013	2010	2013
EWS	7%	78%	19%	68%	26%	82%	17%	76%
MWS	14%	40%	83%	39%	NA	89%	49%	56%
DS	0%	50%	50%	64%	59%	90%	36%	68%

Farmer Focus Group: Nitrogen Application

All farmers in the focus group used at least 20 kg N/ha in various combinations with P and K. The highest rates of N were applied in Takeo and the lowest rates in Kampong Thom (

Table 8.5). The highest rate of N applied was 120 kg N/ha.

Table 8.5: Rice yields and nitrogen application rates in a Farmer Focus Group study in Takeo, Kampot and Kampong Thom (2011-2013).

Province		N application (kg/ha)		
	Yield (kg/ha)	Minimum	Mean	Maximum
Kampot	3,980	30	43	75
Kg Thom	3,339	20	37	120
Takeo	4,006	66	93	120
Average	3,580	20	47	120

The rice paddy yield and N fertilizer data were arranged in order of N application rate and smoothed by taking a moving average for groups of 5 data points (Figure 8.15). Rice yield increased with N application up to around 70 kg N/ha (roughly equivalent to 150 kg/ha urea).

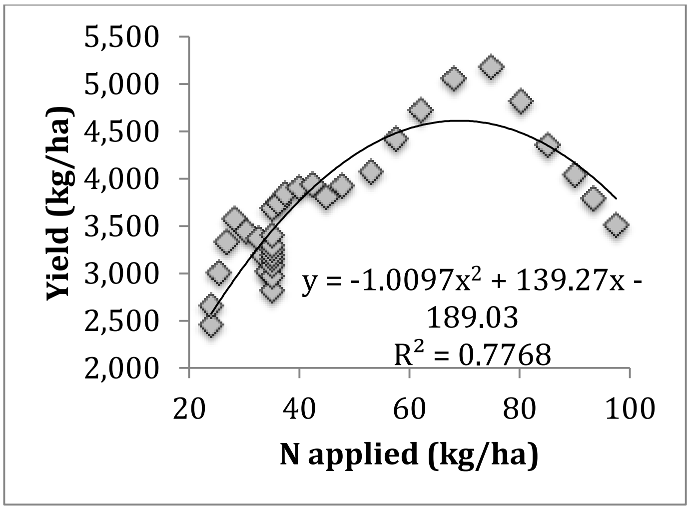


Figure 8.15: Relationship between yield and nitrogen (N) applied.

A partial budget for nitrogen application was calculated with the following assumptions:

- Price received for rice = $0.25/kg (non-aromatic);
- Cost of urea = $0.60/kg (fluctuates from year to year);
- Labour @ $5.00/person/day with 2.0 – 3.5 person/ha depending on urea rate.

Average rice yields increased from 2,480 to 4,613 kg/ha when urea applications were increased from 50 to 150 kg/ha. Further urea applications to 200 kg/ha resulted in a decline in yield. The economic analysis showed clearly that up to 150 kg/ha of urea could be applied with a MRR of 410% (Figure 8.16).

Table 8.6: Marginal rate of return for applying fertilizer N to rice.

N (kg/ha)	Urea equivalent (kg/ha)	Yield (kg/ha)	Urea ($)	Labour (person day/ha)	Labour ($/ha)	Urea variable costs ($/ha)	Income ($)	MRR (%)
23	50	2,480	30	2.0	10	40	620	
46	100	4,081	60	2.5	13	73	1,020	1231%
69	150	4,613	90	3.0	15	105	1,153	410%
92	200	4,078	120	3.5	18	138	1,019	-412%

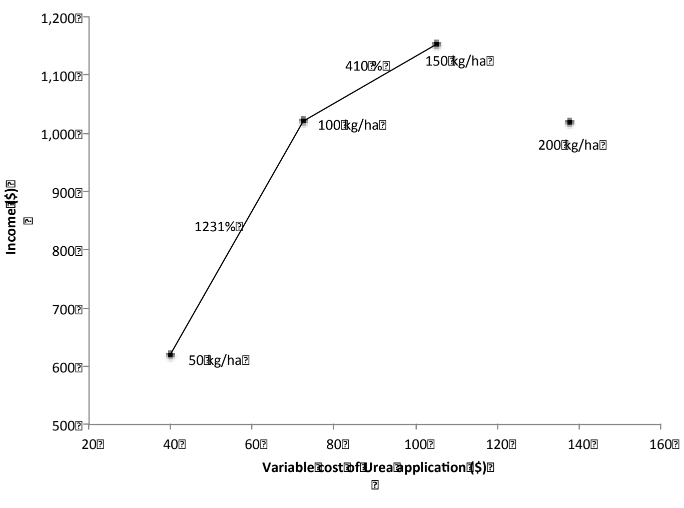


Figure 8.16: Net benefit of applying N to rice (costed as urea).

Key findings

1. The number of farms <1 ha is declining especially in Kampong Thom with a corresponding increase in the number of farms >2 ha.
2. Ownership of machinery increased significantly between 2010 and 2013: 2-wheel tractors (1 - 21%); knapsack sprayers (22 – 60%).
3. Use of herbicides increased from 17% in 2010 to 76% of farms in 2013.
4. Transplanting rice is being rapidly replaced by direct seeding in most districts.
5. Rice farmers applying 50 kg/ha or less of urea equivalent N are seriously limiting their profitability;
6. There was a trend for increased frequency of fertilizer application from 1 to 2-3 per crop.
7. On-farm economic responses to N application to rice can be expected with application of up to 150 kg/ha urea N equivalents;
8. Farmers who apply more that 150 kg/has urea equivalent N should review their practice as losses could be occurring due to lodging or other causes.

The trend for a reduction in the number of farms less than 1 ha in this study should be considered with respect to the analysis of de Silva et al. (2014) where a farm area of 0.5 ha is the estimated threshold for food self-sufficiency suggesting that almost half of rural households cannot produce adequate food to meet their dietary requirements, let alone produce a surplus to sell. Diepart (2010) found this figure to be 65% in Trapeang Russei, Kampong Thom Province. Farmers with 1 ha of land or more were able to increase their yields but farmers with less than 1 ha and limited savings to meet rising costs of production, had declining or stagnant wet- and dry-season rice yields (CDRI 2012). Rising prices of farm inputs meant that land productivity of small landholders with less than 1 ha declined. This constraint, combined with ineffective agricultural extension services, has limited the ability of small farmers to intensify and diversify their agricultural production (de Silva et al. 2014).

Large increases occurred between 2010 and 2013 in: machinery ownership; direct seeding; frequency of fertilizer application; and herbicide use. However, farmers have little or no knowledge about the optimum timing, methods or rates of application of fertilisers or pesticides. The project is in a position to correct these deficiencies by providing guidelines for best practice management of crop inputs. Public sector extension services reach little more than 1% of farmers in Cambodia (de Silva 2014), so there is a need to engage with input suppliers, who deal directly with 100% of farmers, to develop and deliver best practice advice on inputs for rice production.

Recommendations

Recommendation 3. Future extension strategies should take account of the exit of farms <1 ha and their integration into larger farms. This could range from advice on exit strategies for non-viable farms to support for expanding farms such as more advanced needs for technical support and advice on access to lower interest finance.

Recommendation 4. Future R&D projects should engage with input suppliers, who deal directly with 100% of farmers, to develop and deliver best practice advice on inputs for rice production. MAFF/PDA reach little more than 1% of farmers and should be encouraged to become the warehouse and deliverer of unbiased technical information to input retail sales outlets.

8.2. Objective 2: Develop the Cambodian Country Almanac (CCA).

Activity 2.1 Improve the existing CARDI soil science laboratory by provision of upgraded equipment and human capacity building.

Following supply of equipment and materials to the CARDI soils and water laboratory and training conducted for laboratory staff, a laboratory manual was developed and translated into Khmer. The laboratory is now capable of the following analyses: pH, EC, Org. C, NH_4^+, NO_3^-, N, P, K, Cation Exchange Capacity, and physical measures (bulk density, field capacity moisture content, and particle size analysis).

The number of samples processed by the laboratory increased by 260% during the life of the project (Table 8.7) and QC and QA processes have improved markedly as evidenced by production (in English and Khmer) and continued use of the lab manual (English version).

Table 8.7: Number of samples processed at the CARDI soils and water lab (2009-13)

Property analysed	**2009**	**2010**	**2011**	**2012**	**2013**	**Total**
Soil chemistry						
pH	285	297	325	451	356	1714
EC	47	42	54	44	227	414
Org. C	16	50	198	453	256	973
NO3-	x	98	318	161	240	817
NH4+	x	98	294	171	240	803
Total N	150	65	201	214	148	778
Olsen P	170	-	228	332	248	978
Exch. K	146	24	205	178	-	553
Ca2+	15	-	-	-	-	15
Exch. Al	x	x	10	8	-	18
Water quality						
TDS	-	-	-	8	59	67
Turbidity	x	x	x	8	59	67
Alkalinity	x	x	x	8	59	67
Fe	x	x	x	8	59	67
Soil physics						
Particle size analysis	-	28	31	23	21	103
Soil water content	-	202	294	168	181	845
Field capacity	15	30	56	-	30	131
Dry bulk density	15	30	56	-	30	131
Total	**859**	**964**	**2,270**	**2,235**	**2,213**	**8,541**

Activities 2.2 – 2.4 Cambodian Country Almanac

There are now over 500 registered users of CLEAR. Based on observations by the trainers, CLEAR was mostly used by university students and NGOs, and not much used by government institutes.

Recommendation 5. The current license for CLEAR expired at the end of February 2014 and there are currently no plans to prepare an updated version. If continued updating and addition of data is considered beneficial, then discussions will need to be opened to find potential donors/owners for the database.

8.3. Objective 3: Strategies and options to optimise rice establishment practices, and Objective 4: Identify agronomic practices to raise dry season irrigated rice system productivity by 25%.

Effect of establishment method, seeding rates and weed control method on weed biomass and rice grain yield

No-tillage dry direct-seeded rice

Rice yields in Farmer practice plots were "at par" with hand weeding twice (18 and 40 DAS), or cono weeder twice (18 and 40 DAS) or bispyribac sodium 8 DAS + 2,4-D 18 DAS.

Table 8.8. Effect of weed control method on weed biomass and rice yield under no-tillage at Kampot in 2013 (upper field in the topo sequence).

Treatment	Dry biomass (t/ha)		Yield (t/ha)
	18 DAS	40 DAS	
Control	0.32 a	0.36 a	0.88 b
Farmer's practice	0.26 b	0.32 b	2.64 a
Cono weeder and 40 DAS	0.17 c	0.15 c	2.75 a
Hand weeding 18 and 40 DAS	0.17 c	0.14 c	2.73 a
Bispyribac sodium 8 DAS + 2,4-D 18 DAS	0.09 d	0.08 d	2.72 a

Although weed control was significantly better for the herbicide treatment, this did not result in a higher yield compared to farmer practice in the upper field in the topo-sequence (Table 8.8).

Table 8.9. Effect of weed control method on weed biomass and rice yield under no-tillage at Kampot in 2013 (lower field in the topo sequence).

Treatment	Dry biomass (t/ha)		Yield (t/ha)
	18 DAS	40 DAS	
Control	0.36 a	0.37 a	0.92 c
Farmer's practice	0.27 b	0.27 b	2.55 b
Cono weeder 18 and 40 DAS	0.16 c	0.16 c	2.94 a
Hand weeding 18 and 40 DAS	0.17 c	0.17 c	2.92 a
Bispyribac sodium 8 DAS + 2,4-D 18 DAS	0.10 d	0.09 d	2.90 a

The herbicide treatment gave the best weed control but the yield was not significantly different to cono weeder or hand weeding in the lower topo-sequence field.

Crop establishment method

Experiments were carried out to compare: direct-seeding at different seeding rate; transplanting with two ages of seedlings and plant spacing; and with and without weed control (see section 5 for methods). The collection of graphs of direct seeding results by site and season are presented in Appendix 3.

Weed biomass in the unweeded plots did not significantly differ between planting methods. Weeded plots had no weeds. Rice plant density was reduced with presence of weeds. Broadcast seeding at a high seeding rate (>100 kg/ha) gave a higher rice plant density.

Wet seeding with a drum seeder at 80 kg/ha resulted in high rice plant density and similar to broadcasting 100-200 kg seed/ha in some locations (Prey Veng and Kampong Thom) with good control of water.

Yield of rice established by drum seeder at 80 kg/ha yielded similarly to broadcast seeding using up to 200 kg/ha seed rates.

Rice plant density experiments

Rice plant density was highest when rice was broadcast at 200 or more kg/ha. Lowest plant densities were in transplanted rice.

Weed biomass varied among rice establishment methods and locations. Generally, weed biomass was least in plots with high rice plant populations.

Rice yields were highest in transplanted rice regardless of seedling age and plant spacing when plots were weeded. When plots were not weeded the results were not consistent across sites. Looking at the relationship between seed rate and yield, the optimum biological seed rate is 100 kg/ha.

The optimum seeding rate for rice grain yield was higher in the presence of weeds compared to weed-free. However, when the cost of seed was taken into account, increasing seeding rate to suppress weeds was found to be uneconomic.

Herbicides used in direct-seeded rice

There is quite a range of herbicides used in direct-seeded rice in Cambodia (Table 8.10).

Table 8.10. Herbicides commonly used in direct-seeded rice in Cambodia

Herbicide active ingredient	Timing	MOA group*
2,4-D	Post-em	O
Bispyribac sodium	Post-em	**B**
Butachlor	Pre-em	K
Butachlor + propanil	Pre, Post-em	K, C
Cyhalofop-butyl	Post-em	**A**
Cyhalofop-butyl + ethoxysulfuron+quinclorac	Post-em	**A, B, O**
Cyhalofop-butyl + pyrazosulfuron	Post-em	**A, B**
Cyhalofop-butyl + pyrazosulfuron+ethoxysulfuron+quinclorac	Post-em	**A, B, O**
Fenoxaprop-ethyl	Post-em	**A**
Fenoxaprop-ethyl + pyrazosulfuron	Post-em	**A, B**
Metsulfuron methyl + chlorimuron-ethyl	Post-em	**B**
Pretilachlor+fenclorim	Pre-em	K
Pyribenzoxim (POE)	Post-em	**B**
Quinclorac + bensulfuron-methyl	Post-em	**O, B**
Quinclorac +pyrazosulfuron	Pre, Post-em	**O, B**

***HRAC (2014).**

Most options (bold letters) include herbicides from A or B mode of action (MOA) groups which are the highest risk with regard to herbicide resistance. Another constraint is that pre-emergence herbicides such as Butachlor cannot be used in broadcast or wet-seeded rice because there is no soil separation between the rice seed and the herbicide. Pre-emergence herbicides can be used in drill seeded rice or drill seeded rotation crops.

The current narrowly-based herbicide options in direct-deeded rice are at a very high risk for the development of herbicide resistance and an integrated weed management strategy is required that incorporates herbicide resistance management.

General principles of herbicide resistance management

The general principles of herbicide resistance management according to the weed Science society of America are as follows:

1. Apply integrated weed management practices. Use multiple herbicide modes of action with overlapping weed spectrums in rotation, sequences, or mixtures, and ensure correct and safe use of application technology.
2. Use the full recommended herbicide rate and proper application timing for the hardest to control weed species present in the field.

3. Scout fields after herbicide application to ensure control has been achieved. Control escapes with an alternative method. Avoid allowing weeds to reproduce by seed or to proliferate vegetatively.
4. Monitor site and clean equipment between sites.

It is important to develop a weed management plan that covers the full crop cycle and annual crop sequence in the field as follows:

- Keep the fallow field weed-free and control weeds early by using a non-selective herbicide (glyphosate, paraquat) or tillage in combination with a pre-emergence residual herbicide as appropriate;
- It is important to use an integrated weed management package involving cultivation, mechanical or manual weed control and crop rotation, where possible. This enables a wider range of herbicides to be included in the rotation.
- Use good agronomic principles that enhance crop competitiveness, such as maximising crop vigour (via fertilizer access), sufficient plant population (high crop establishment efficiency and uniformity) and high seedbed utilization (narrow spacing).

The Integrated Crop Establishment (ICE) experiment weed management options

ICE experiments were set up at Bati Research Station, Takeo, CARDI, Kampong Thom (KGT), Kampot (KPT) and RUA (see section 5 for experimental details). Two weed management options were included as sub-plot treatments in ICE:

1. Complete weeding, herbicide treatment + one hand weeding (CW);
2. One hand weeding at 30 days after seeding (HW).

Effect of establishment method on weed biomass

At Bati in TPL, weed biomass was less in CW compared with HW in 2011 and 2012. Weed biomass in TPL was substantially lower in all treatments in 2013 (Figure 12.8). In WSR at Bati, weed biomass was greater for HW in 2012. In DSR at Bati, weed biomass was lower for CW compared to HW and lower in 2012 compared to 2011.

At Kampot in TPL, weed biomass for CW tended to be greater than for HW in 2011 but this difference was reversed in 2012 (Figure 12.9). In all treatments, weed biomass was reduced in 2013. For WSR, weed biomass was similar for CW and HW in 2011. Weed biomass in WSR was lower in 2012 but HW was less effective than CW. In DSR, HW was less effective for ZT compared to FT in 2011 but this effect was not evident in 2012.

At Kampong Thom in TPL, weed biomass was similar in 2011 and 2012 (Figure 12.10). For WSR, weed biomass levels were similar for most treatments except for high levels in treatment 3 for CW. For DSR, weed biomass was relatively low in both years but even lower in 2013.

Rice grain yields were similar for treatments 1, 2, 5, and 6 at all locations and years except for Kampong Thom where yields were substantially lower in 2013 (Figure 12.11). For WSR, yields were highest at Kampong Thom and lowest at Kampot. For DSR, there were no consistent trends.

Weed species dynamics

Log-rank charts showing shifts in weed species composition between EWS 2012 and EWS 2013 for the five ICE sites are given in Appendix 5. At Bati, wet-seeded rice (WSR) was dominated by *Rotala indica*; dry-seeded rice (DSR) was dominated by *Rotala indica* and *Fimbristylis miliacea*; and transplanted rice (TPL) was dominated by *Monochoria vaginalis*.

In WSR at Kampot, weed species changed from *Paspalum distichum* in the first crop to *Hydrolia zeylanica* in fully tilled plots. While in zero-tilled plots weed composition shifted from *F. miliacea* in the first crop to *Lindernia ciliata* in the second crop. For DSR following a fallow period with full tillage and DSR following WSR, *M. vaginalis* dominated but in the zero-tilled plots *F. miliacea* was dominant. For TPL, *F. miliacea* was the dominant weed in the first crop but was replaced *by Marsilia minuta* in the following year.

At Kampong Thom, *F. miliacea* dominated WSR following a fallow period but in the second year the plots were dominated by *M. minuta*. In DSR full tillage, plots were dominated by *F. miliacea* while the zero-tilled plots were dominated by *M. minuta*. DSR sown after WSR under conventional tillage was dominated by *P. distichum* while under zero tillage *F. miliacea* and *Panicum repens* dominated the plots. In TPL, the plots were dominated by aquatic weeds such as *M. vaginalis*, *Utticularia aurea*, *Ottelia alismoides* and *M. minuta.*

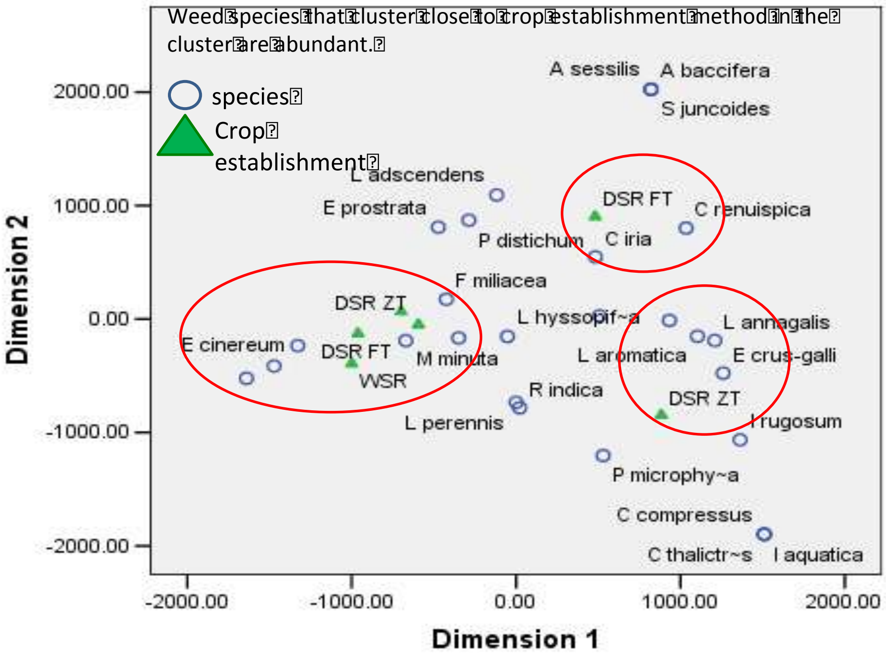


Figure 8.17. Cluster analysis of weed species shifts as affected by rice establishment method.

The cluster analysis weed species shifts (Figure 8.17) indicates that the change to direct seeding rice might result in a weed species shift. Significant shifts in weed species composition have occurred after the shift from transplanting to direct seeded rice in other Asian countries (Juraimi et al. 2013). In areas of Cambodia where direct-seeding has been carried out for some years, grasses such as *Echinochloa* spp. and *Leptochloa chinensis* have become more prevalent and are proving difficult to control in direct-seeded rice.

Key findings

- Herbicides gave the best weed control but the rice grain yield was not always higher than for cono weeder or hand weeding.
- Establishment of rice by dry-seeding under zero tillage using a seed drill is feasible.
- With wet direct-seeding using drum seeder, reduced seeding rates can save seed and achieve the same yield as higher seeding rates.

- Three crops of rice in a year is feasible where supplementary irrigation is available and can increase land productivity but uncertainty exists as to the sustainability of triple cropping and thought needs to be given to inclusion of rotation crops such as mungbean.
- Herbicide followed by hand weeding effectively controls weeds.
- Weed control with herbicides resulted in similar grain yields to hand weeding at some sites and seasons, but was not as good at other sites because of differences in dominant weed species.
- In most seasons and locations, weed management in direct seeded crops is essential for good crop growth.

Unresolved issues related to herbicide use in direct-seeded rice

- Guidelines for integrated weed management (IWM) need to be adapted to the various rice production agro-ecosystems in Cambodia;
- Currently there is a narrow range of herbicide formulations for direct-seeded rice in Cambodia which is heavily dependent on high-risk MOA groups A and B. Herbicides from different MOA groups need to be included in the rotation;
- There is over-reliance on post-emergence herbicide options in wet direct-seeded rice. There are good pre-emergence herbicide alternatives that can be used if drill seeded rice or rotation crops such as mungbean are included in the rotation.
- Farmers lack knowledge about the basics of herbicide application technology such as application rate, timing, selectivity, crop tolerance, and efficacy on target weeds, as well as safety aspects. There is a need for practical technical information to be provided to and delivered by herbicide sellers who are the 1st port of call for farmers.
- Off-target damage by careless herbicide application continues to be a problem in Cambodia. There is a need for operator training in the basics of weather conditions: wind speed, temperature, volatilisation risk, etc.
- Lack of use of Personal Protection Equipment (PPE) is a long-standing problem in Cambodia. More prominent and explicit signage is required in herbicide retail outlets, as well as a strong training focus on product handling safety.

Recommendations

Recommendation 2. Guidelines for integrated weed management (IWM), including a herbicide resistance management strategy, urgently need to be developed and adapted to the various rice production agro-ecosystems in Cambodia.

Recommendation 3. Cambodian farmers lack knowledge about the basics of pesticide application technology such as application rate, timing, selectivity, crop tolerance, and efficacy on target weeds. Farmers also ignore or are unaware of environmental and human health impacts of careless and inappropriate use of pesticides. There is a need for practical technical information on efficacious and safe use of pesticides to be provided to and delivered by all pesticide sellers.

Comparison of crop establishment methods (2010-2011)

This study was designed to compare drum seeding with traditional transplanting and farmer practice direct seeding broadcasting for rice establishment under weed-free and weedy conditions.

Although weed biomass was significantly greater (838 kg/ha) in the wet season compared to dry season (498 kg/ha) there was no significant yield difference between wet (3,118 kg/ha) and dry season (3,014 kg/ha). The net return for wet season ($736) was significantly greater than for dry season ($650) because of the higher price received for fragrant rice.

The seeding rate * weed control interaction was significant for weed biomass, rice grain yield and net return. Weed biomass in the farmer practice treatment (969 kg/ha) was significantly less than for the other treatments. Drum seeding at 60 kg/ha gave the highest weed biomass (1,678 kg/ha).

Differences in yield between treatments were greater under non-weedy conditions (Figure 8.18). The highest yielding treatment was transplanting single seedlings (treatment 4) and the lowest yielding treatment was drum seeding at 60 kg/ha. Transplanting 2-3 seedlings per hill was the highest yielding under weedy conditions and was significantly greater than drum seeding at 60 kg/ha. No treatment was significantly better or worse than farmer practice under weedy conditions.

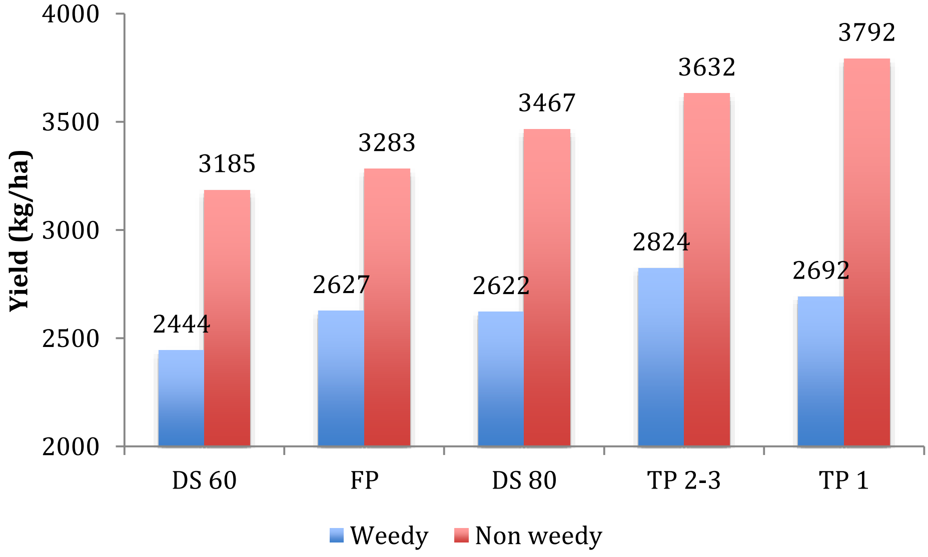


Figure 8.18: Effect of seeding method on rice grain yield.

Under non-weedy conditions, drum seeding at 60 kg/ha was the only treatment giving a higher net return compared to farmer practice and under weedy conditions, no treatments had a higher net return compared to farmer practice (Figure 8.19).

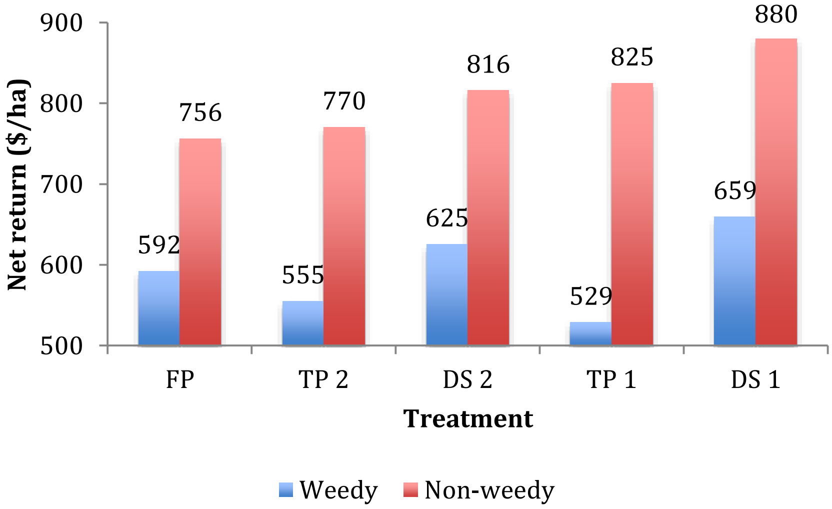


Figure 8.19. Effect of seeding method on net return.

The highest marginal rate of return was obtained from drum seeding at 60 and 80 kg/ha under both weedy and weed-free conditions (Table 8.11). All other treatments were dominated. Increasing seeding rate from 60 to 80 kg/ha with the drum seeder under weed-free conditions gave a MRR of 420% compared to 230% under weedy conditions.

Table 8.11: Marginal analysis of rice seeding methods (USD/ha).

Seeding method	Weedy		Weed-free		Marginal rate of return (MRR)	
	Cost	Net return	Cost	Net return		
DS 2	66	625	86	816	Weedy	Weed-free
DS 1	81	659	101	880	223%	420%
FP	152	592	172	756	D*	D
TP 1	233	529	253	825	D	D
TP 2	244	555	264	770	D	D

- **D = dominated.**

Key findings

1. Under non-weedy conditions, drum seeding at 60 kg/ha gave a higher net return compared to farmer practice broadcast seeding and traditional transplanting. But under weedy conditions, no treatments had a higher net return compared to farmer practice of broadcast seeding.
2. The highest marginal rate of return was obtained from drum seeding at 60 and 80 kg/ha under both weedy and weed-free conditions. All other treatments were dominated.
3. Increasing seeding rate from 60 to 80 kg/ha with the drum seeder under weed-free conditions gave a MRR of 420% compared to 230% under weedy conditions.
4. From an economic point of view, drum seeding at 80 kg/ha was the best option and was superior to traditional transplanting and farmer practice broadcast seeding.

Recommendations

Recommendation 4. Research showed that drum seeding at 60-80 kg/ha was more cost effective than traditional transplanting or broadcasting methods. This information needs to be incorporated into a basic agronomic extension package for rice production in Cambodia.

Table 8.12. Weed species present.

Species	Site				
	1	2	3	4	5
Brachiaria mutica					✔
Cyperus compactus					✔
Cyperus difformis	✔	✔		✔	
Cyperus iria	✔	✔			
Dactyloctenium aegyptium	✔	✔	✔	✔	
Echinochloa glabrescens	✔	✔		✔	
Eclipta alba		✔			
Eclipta prostrata	✔				
Eichhornia crassipes					✔
Fimbristylis miliacea	✔	✔			✔
Imperata cylindrica					✔
Ipomoea aquatica	✔	✔	✔	✔	✔
Leptochloa chinensis	✔	✔		✔	
Marsilea crenata		✔	✔	✔	✔
Marsilea minuta	✔				
Mimosa pudica					✔
Monochoria vaginalis	✔	✔	✔	✔	✔
Phaseolus lathroides					✔
Sphenoclea zeylanica	✔		✔	✔	

Effect of seeding rate of rice on weed suppression and yield (2010-2011)

The weed species mixture varied substantially between the five sites where 19 weed species were recorded. Nine species (shaded in Table 8.12) were present at three or more sites. However, weed species composition varied between agro-ecosystems and rice management practices. Climatic events also cause temporary shifts in weed composition with less common weeds becoming dominant during drought or periods of water shortage such as *Melochia concatenata* in 2014.

Effect of rice seeding rate on weed biomass and rice grain yield

Weed biomass and rice grain yield varied significantly between locations. The average weed biomass was 1,251 kg/ha and ranged from 246 to 2,323 kg/ha. The average rice grain yield under weedy conditions was 2,645 kg/ha and ranged from 1,786 to 3,631 kg/ha.

Weed biomass was significantly greater in the wet season (1,502 kg/ha) compared to the dry season (890 kg/ha) but there was no significant difference in rice grain yield between seasons.

Increasing the seeding rate of rice reduced the biomass of weeds and the relationship was best represented by a log function (Figure 8.20). Increasing seeding rate from 60 to 250 kg/ha reduced weed biomass by 726 kg (42%).

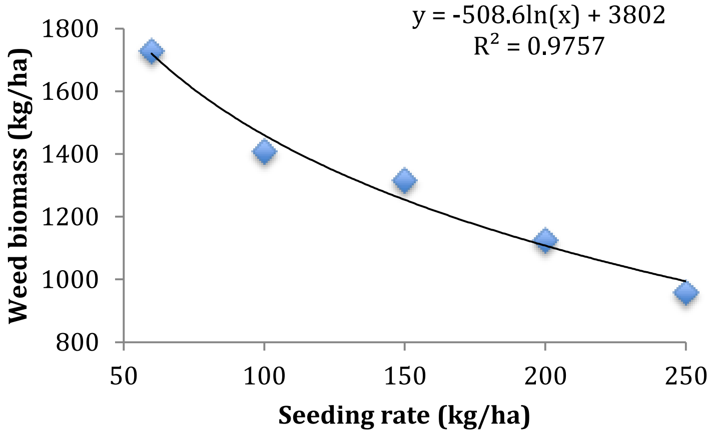


Figure 8.20. Effect of rice seeding rate on weed biomass.

Effect of weed competition on rice grain yield

On average across all sites and seasons, rice grain yield was reduced from 3.29 to 2.65 t/ha (24%) in the presence of un-controlled weeds. Therefore the average potential cost of weeds if left uncontrolled is more than $200/ha based on rice grain at $300/tonne. For every 100 kg/ha increase in weed biomass, there is a reduction of rice grain yield of 50 kg/ha. So assuming a harvest index of 50%, this means that weed biomass substitutes for rice biomass on a 1:1 basis (Figure 8.21).

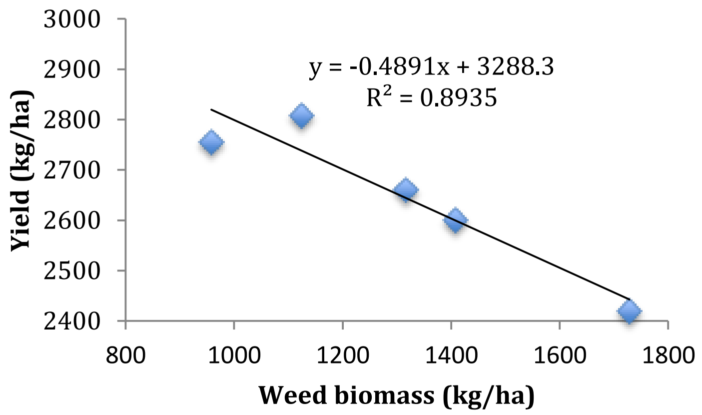


Figure 8.21. Effect of weed competition on rice grain yield.

Effect of seeding rate on rice yield with and without weeds

Rice yield increased with wet broadcast seeding rates up to 150 kg/ha under weed-free conditions. Under weedy conditions, rice yields increased with seeding rates up to 200 kg/ha. However, yields under weedy conditions did not reach those under weed-free conditions. Unfortunately data for established rice plant density and yield components were not available to explore the effect of weed competition on rice grain yield further.

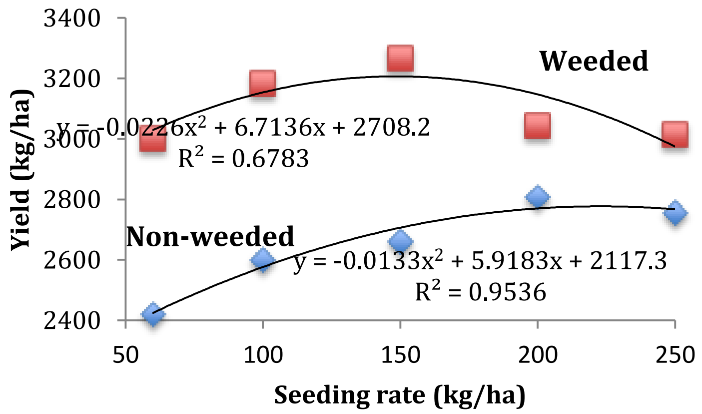


Figure 8.22. Effect of seeding and weed competition on rice paddy yield

Economic analysis of increasing seeding rate to control weeds

The minimum rate of return acceptable to farmers is generally assumed to be between 50 and 100% (CIMMYT 1988). The marginal rate of return (MRR) for increasing rice seeding rate from 60 to 100 kg/ha was 52% for weed-free and 24% for un-weeded rice (

Table 8.13). Further increases in seeding rate yielded resulted in mostly negative MRR. Therefore these results suggest that increasing seeding rate of rice to reduce the effect of weed competition on yield is not economically attractive. The results also suggest that the optimum seeding rate for weed-free broadcast wet-seeded rice is around 100 kg/ha.

Table 8.13. Marginal analysis of the effect of increasing seeding rate for reducing yield loss by weeds in rice.

Seeding rate (kg/ha)	Fitted rice grain yield (kg/ha)		Cost of seed @ $0.75 USD/kg	Income @ $0.30 USD/kg)		Marginal cost	Marginal return		Marginal rate of return	
	NW*	W		NW	W		NW	W	NW	W
60	2472	3030	$45.00	$727.36	$908.90					
100	2656	3154	$75.00	$772.84	$946.07	$30.00	$45.48	$37.17	52%	24%
150	2825	3207	$112.50	$811.74	$962.02	$37.50	$38.90	$15.95	4%	-57%
200	2928	3147	$150.00	$830.69	$944.08	$37.50	$18.95	$-17.95	-49%	-148%
250	2964	2974	$187.50	$829.69	$892.23	$37.50	$-1.00	$-51.85	-103%	-238%

*** NW = non-weeded; W = weeded.**

Key findings

1. Increasing the seeding rate of rice had a highly significant effect for reducing the biomass of weeds and increasing seeding rate from 60 to 250 kg/ha reduced weed biomass by 726 kg (42%).
2. Rice grain yield was reduced by 24% in the presence of un-controlled weeds and the average potential cost of weeds if left uncontrolled is more than $200/ha.
3. For every 100 kg/ha increase in weed biomass, there is an average reduction of rice grain yield of 50 kg/ha and assuming a harvest index of 50%, this means that weed biomass substitutes for rice biomass on a 1:1 basis.
4. Rice yield increased with seeding rates up to 150 kg/ha under weed-free conditions and under weedy conditions, yields increased with seeding rates up to 200 kg/ha.
5. Despite the clear biological response, the marginal rate of return (MRR) for increasing rice seeding rate even from 60 to 100 kg/ha was less than 100% for both weed-free and weedy rice.
6. The average weed-free yield across these experiments was around 3.3 t/ha which is less than 50% of an estimated potential of 6-7 t/ha. Other factors such as nutrition could have been limiting and it is possible that under higher yielding conditions, higher seeding rates could give economic returns for suppressing weeds.

Discussion

The finding regarding seeding rate for weed suppression agrees with that of Martin et al (1987) "Wheat grain yields were reduced by wild oats through the reduction in number of tillers, and this competitive effect could be reduced by increasing the density of wheat. Increasing wheat plant density beyond the weed-free optimum was found to be unsatisfactory for wild oat control." A similar economic analysis could be applied to studies on seeding rate for weed suppression on rice yield.

The average weed-free yield across these experiments was 3.29 t/ha which is well below a potential of 6-7 t/ha. Therefore other factors such as nutrition could have been limiting. It is possible that under higher yielding conditions, higher seeding rates could give economic returns for suppressing weeds.

Increasing seeding rates to suppress weed competition could be possible using kept seed or cheaper seed. However, this could be risky if the cheaper seed contains more weed seeds, new weed species or resistant biotypes. Therefore the decision to increase weed seeding rates to suppress weeds should be taken within the context of the farmer's integrated weed management strategy.

Integrated crop establishment (ICE) experiment

The ICE experiments were established to test options of crop establishment methods and likely sequence combinations suggested in the baseline experiments and socio-economic results.

Key findings

- Total rice grain yields, combined over locations for six seasons, ranged from 10.3 t ha with two crops per year (4 crops total) to 20.7 t ha with three crops per year (6 crops total).
- The lowest total rice grain yield occurred with crops sown under zero-tillage in both dry and early wet season (T4), especially influenced by the erratic crop establishment performance of zero-till drum seeding into un-puddled soil (simulating a potential technique for recession rice areas).
- The greatest total rice grain yield was obtained with both triple cropping options (T5 and T6, Fig. 5.2) regardless of whether drill seeding into cultivated seedbed or drum seeding into puddled soil was used in the EWS .
- In the dry season, drum seeding with pre-germinated seed after tillage (puddling) compared to drum seeding after zero-tillage resulted in approximately 30% more grain yield (3.68 v 2.81 t/ha) in 2012, and 70% more (3.40 v 1.99 t/ha) in 2013. This was strongly influenced by the highly variable crop establishment quality achieved without soil puddling.
- Drum seeded rice grown after a fallow period in the wet season (T3), compared to wet seeded rice after a transplanted crop in wet season (T5 and T6), gave 11% more grain in 2012, and 6% more grain in 2013.
- Dry seeded rice after tillage gave 0.99 t/ha more yield (2.68 v 3.67 t/ha) than after zero tillage in 2012 and 1.23 t ha more yield (2.87 v 4.10 t/ha) in 2013.
- Compared to broadcasting for wet direct-seeded rice (WSR), the drum seeder gave good establishment and enabled seed rates to be reduced by more than half.
- Drum seeding gave a row seeded crop and allowed for easier hand or inter-row weeding.
- Use of 200 kg seeds/ha broadcast on puddled soil gave the highest yield; farmers' rates were 250-400 kg seeds/ha.
- In water seeding for dry season rice, the appropriate water level was 5 cm deep. More than 5 cm and crop establishment was reduced, which can also reduce yield.
- Transplanting either 1 or 2-3, 20-day-old rice seedlings/hill gave a similar yield.
- The use of zero tillage combined with pre-germinated seed reduced costs and enabled early crop establishment in the DS in some cases.
- The hydro-tiller machine was able to cultivate wet soil faster and reduced land preparation time for sowing by drum seeder.

Table 8.14: Crop establishment options by season, hydrology and topography for Cambodian rice systems. IR = irrigated; RF = rainfed; ZT = zero till.

Topo-sequence	RF/IR	Early wet season	Main wet season	Dry Season
Low-lying,	RF		Deep flooding	Wet seeded rice or

prolonged deep flooding in monsoon				transplanted on receding flood.[1, 2]
			Rice; broadcast dry seed, deep water rice varieties [1]	Legume/ pulse crop on residual moisture. Row seeder options [1, 2]
Low – lying, shallow to temporary deep flooding in monsoon	IR	Dry seeding, broadcast or drill seeding. ZT an option: depends on soil type, residue management and land condition after machine harvest [1, 2]	Transplanted rice [1], mechanical transplanter.	Wet seeded rice after puddling or zero-tillage depending on residue / weeds. Drum seeder options. [1, 2]
	RF		Rice: transplanted or broadcast dry[1] Options for mechanical transplanter or row seeder.	Mungbean, sunflower on residual moisture. Options for drill seeding.
	IR	Dry seeding, broadcast or drill seeding. ZT an option - depends on residue management, land condition after mechanised harvest. [1, 2] Soil type may limit "window" for ZT options e.g. Prateah Lang [1, 2]	Transplanted [1] rice; mechanical transplanter.	Wet seeded rice after puddling or zero-tillage depending on residue/ vegetation. Drum seeder. [1, 2]
Upland	RF	Upland crops: maize, mungbean, peanut, soybean, sesame.	Rice; transplant or broadcast dry seed, options for mechanical transplanter or row seeder.	Mungbean, sunflower on residual moisture. No-till drill seeded.

Note: [1] establishment option relevant for Objective 3.1 and 3.2. [2] establishment option relevant for objective 4.1

Paddy yield trends in the ICE experiment

A detailed description of the statistical analysis of the ICE experiment is given in Appendix 6. The average of fitted paddy yield across sites and seasons was 3.07 t/ha (Table 8.15).

Table 8.15: Paddy yield trends – site * season.

Site	C1MWS11	C2DS12	C3EWS12	C4MWS12	C5DS13	C6EWS13	C7MWS13	Average
Bati	2.78	3.50	3.02	2.70	1.91	2.89	2.76	2.79
CARDI	5.03	2.54	3.02	3.12	3.43	3.10	3.17	3.34
Kampot	2.67	0.84	0.93	2.74	1.43	2.91	2.56	2.01
Kg Thom	3.95	4.78	3.06	3.95	3.46	3.38	1.49	3.44
RUA	2.04	3.81	5.75	2.77	4.00	5.45	*	3.97
Average	3.29	3.09	3.16	3.06	2.84	3.55	2.49	3.07

The highest yielding site was RUA and the lowest, Kampot. Yields at Kampot were low in the DS and EWS 2012 because of soil type-related water management problems at the site (Figure 8.23). EWS yields at RUA were not consistent with the other sites.

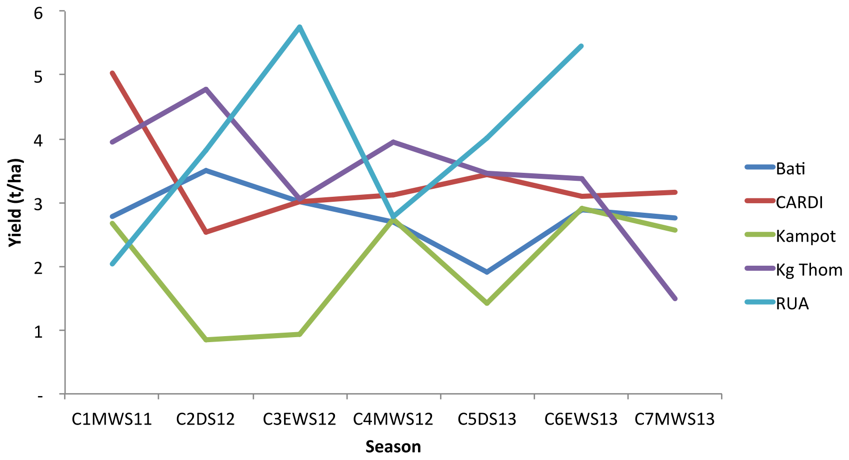


Figure 8.23: Site * season paddy yield trends in the ICE experiment.

Comparison of ICE systems across seasons

The highest yielding systems over the seven seasons were T5 and T6 which had three crops per year (Fig. 5.2 and Table 8.16). the lowest yielding system was the DS-ZT:Nil:WS system.

Table 8.16. Mean treatment yields across sites and seasons in the ICE experiment.

System	MWS11	DS12	EWS12	MWS12	DS13	EWS13	MWS13	Total
DS-FT:TP:Nil	3.29		3.55	3.03		4.18	2.54	16.59
DS-ZT:TP:Nil	3.29		2.61	2.94		2.78	2.51	14.13
DS-FT:Nil:WS		3.52	3.61		3.31	3.93		14.37
DS-ZT:Nil:WS		2.61	2.43		1.86	2.79		9.70
DS-FT:TP:WS	3.29	3.15	3.41	3.22	3.08	3.86	2.43	22.46
WS:TP:WS	3.29	3.15	3.34	3.04	3.12	3.72	2.50	22.16
Average	3.29	3.11	3.16	3.06	2.84	3.55	2.49	16.57

Economic analysis of ICE systems

Cost-price assumptions

Labour was included in the economic analysis at the rate of $5.00/day for: land preparation; transplanting; broadcasting; fertilizer application; hand weeding and irrigation.

Cost of seed for sowing was assumed to be $0.80/kg for fragrant varieties and $0.70/kg for non-fragrant varieties. The price received for paddy was assumed to be: $233/t (EWS); $327/t (MWS); and $214/t (DS).

Table 8.17: input cost assumptions for the ICE experiment.

Input	Unit	Riel/Unit	US$/Unit
Contract rates			
Plowing	ha	150,000	$37.50
Harrowing	ha	100,000	$25.00
Land leveling	ha	60,000	$15.00
Drum seeder	ha	60,000	$15.00
Rogro seeder	ha	120,000	$30.00
Cono weeder	ha	140,000	$35.00
Transport	t	26,667	$6.67
Combine Harvester	ha	400,000	$100.00
Herbicide, Pesticide & Fungicide application	ha	70,000	$17.50
Fertiliser			
Urea	kg	1,880	$0.47
DAP	kg	2,680	$0.67
KCL	kg	2,560	$0.64
20:20:15+TE	kg	2,480	$0.62
Philippine (16-16-8-13s)	kg	2,320	$0.58
Herbicide			
Pretilachlor	L	76,000	$19.00

Glyphosate	L	16,000	$4.00
Bispyribac Sodium	L	120,000	$30.00
2,4-D	L	18,000	$4.50

Sites

It was assumed that average variable costs ($713.77/ha) did not vary between sites. The average paddy yield across sites was 3.15 t/ha (Table 8.18). Gross margins ranged from -$158.90/ha at Kampot to $180.29/ha at CARDI. Kampong Thom was the most profitable regional site but still only achieved 93% of the CARDI gross margin.

Table 8.18: Average yield, income and gross margins for the ICE sites.

Site	Yield (t/ha)	Income ($/ha)	Gross margin ($/ha)
Kampot	2.01	$554.87	$(158.90)
Takeo (Bati)	2.80	$736.63	$22.86
Kampong Thom	3.40	$881.68	$167.91
RUA	4.20	$893.26	$179.49
CARDI	3.33	$894.06	$180.29
Average	3.15	$792.10	$78.33

Season

The MWS produced the highest average yield and gross margin (Table 8.19).

Table 8.19: Average seasonal yields, income, variable costs and gross margins for Bati, CARDI and Kampong Thom.

Season	Yield (t/ha)	Income ($/ha)	Variable costs ($/ha)	Gross margin ($/ha)
EWS (2012, 2013)	3.08	$716.85	$679.75	$37.10
MWS (2011, 2013)	3.59	$1,171.03	$730.74	$440.29
DS (2012, 2013)	3.27	$699.81	$739.34	$(39.53)

Marginal rate of return for ICE systems

It is conventionally assumed that a marginal rate of return (MRR) > 100% is required to interest farmers of changing practice (CIMMYT 1988). To carry out the marginal analysis, treatments were arranged according to increasing variable costs (Figure 8.24). The system with the lowest cost was 4 (DS-ZT:Nil:WS). The MRR for the change from this system to the next most costly one (3, DS-FT:Nil:WS) was 160%. The MRR between system 3 and system 2 (DS-ZT:TP:Nil) was 58%. The system with the highest MRR was 1 (DS-FT:TP:Nil) with a MRR of 190%. Systems 5 and 6 with three crops per year were “dominated” because these treatments had lower net benefits than treatments with lower costs.

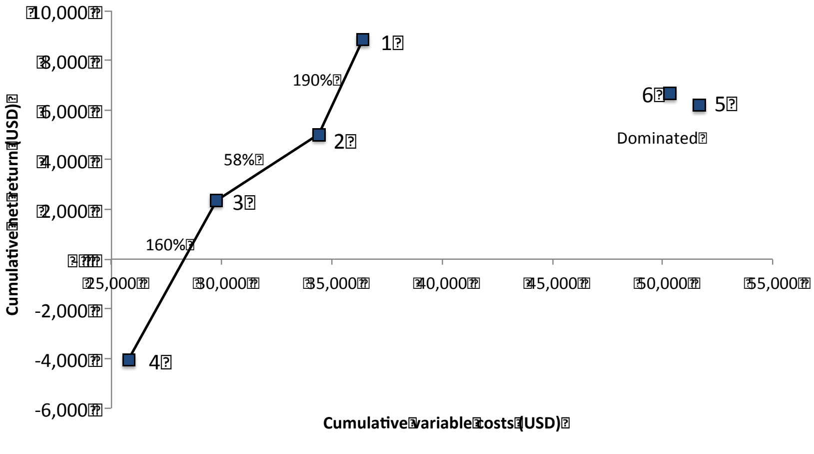


Figure 8.24: Marginal analysis of systems treatments in the ICE experiment.

The most profitable systems were 1 (DS-FT:TP:Nil) and 2 (DS-ZT:TP:Nil) which included an EWS and MWS crop. The DS crop appeared to be the least profitable and reduced the net returns for systems 3, 4, 5, and 6.

Weeding system

Main plots were split for weeding system: complete weeding (CW) which included herbicide followed by hand-weeding; and hand-weeding only (HW). Herbicide treatments applied in CW were as follows:

1. transplanting: pretilachlor + fenclorim @ 300 g a.i. ha, 2-3 days after transplanting;
2. wet and dry seeding: EWS - bispyribac sodium @ 25 g a.i. ha 8-10 days after sowing;

Hand-weeding was carried out using combination of push row/ cono weeder plus hand pulling at 30 days after seeding (DAS) or 30 days after transplanting (DAT).

There was no difference between weeding treatments for yield or income (Table 8.20). However because of the higher variable cost of hand-weeding the gross margin was less than for complete weeding.

Table 8.20: Economic comparison of weeding systems in the ICE experiment.

Trt	Yield t/ha	Income $/ha	Variable costs $/ha	Gross margin $/ha
CW	3.12	$792.80	$702.04	$90.76
HW	3.12	$791.40	$725.49	$65.90

Key findings

1. The most profitable systems were 1 (DS-FT:TP:Nil) and 2 (DS-ZT:TP:Nil) which included an EWS and MWS crop. The DS crop appeared to be the least profitable and reduced the net returns for systems 3, 4, 5, and 6.
2. There was no difference between weeding treatments for yield or income. However because of the higher variable cost of hand-weeding the gross margin was less than for complete weeding.

Recommendations

Recommendation 5. In general, the ICE experiment demonstrated the profitability of growing 2 rice crops (EWS and MWS). Further work is required to refine systems according to soil type and water availability. Further work is also justified to test rotation crops such as mungbean as alternatives to rice in the DS with flow-on benefits to the rice crops. This will require development of a soil suitability * agronomy package for DS rotation crop options.

Comparison of seeding and weed control methods for effect on weed biomass, rice yield and net return in the ICE experiment

This study was designed to compare:

1. Direct dry seeding with a Rogro seed drill under full tillage and no tillage conditions; and
2. Direct dry seeding with a Rogro seed drill and wet seeding with a drum seeder.

General assumptions for the economic analysis were: seed cost of Chul'sa variety rice was assumed to be 2,800 riel/kg; and the farm gate price of paddy rice was assumed to be $233/t. Input costs that varied between treatments are given in Table 8.21.

Table 8.21. Input costs that varied between treatments.

Input cost	Full vs zero-tillage				Dry seeding vs wet seeding			
	FT HW	FT CW	ZT HW	ZT CW	DS HW	DS CW	WS HW	WS CW
Land levelling	$15	$15						
1st ploughing	$38	$38						
2nd ploughing	$38	$38						
Harrowing	$25	$25						

Glyphosate			$8	$8				
Glyphosate application			$18	$18				
Herbicide			$8	$8		$8		$8
Herbicide application			$18	$18		$18		$18
Hand weeding	$150	$50	$150	$50	$150	$50	$75	$35
Total	**$266**	**$166**	**$202**	**$102**	**$150**	**$76**	**$75**	**$61**

Full tillage vs zero-tillage

Results of the analysis of variance:

1. Weed biomass: The effects of location, tillage and weed control method were significant but there were no significant interactions.
2. Grain yield: The effects of location, tillage and location*tillage were significant.
3. Gross margin: The effects of location, tillage, weed control method and location*tillage were significant.

Weed biomass (kg/ha) on the zero-till (ZT) treatment was significantly greater than for full tillage (FT) and the effect was greater at CARDI compared to the other sites (Table 8.22). Grain yield was significantly lower for ZT and the effect was greatest at CARDI (Figure 8.25). This effect carried through to gross margins which were negative for all sites for ZT and the greatest effect was at the CARDI site (Figure 8.26).

Table 8.22. Differences between locations for weed biomass, grain yield and gross margin.

Location	Tillage	Weed biomass (kg/ha)	Grain yield (t/ha)	Gross margin ($/ha)
BATI	FT	598	3.55	101
BATI	ZT	699	2.46	-51
CARDI	FT	531	4.23	260
CARDI	ZT	733	1.02	-386
KGT	FT	464	3.69	134
KGT	ZT	515	2.67	-2
SE		66	0.12	29
5%LSD		184	0.35	81

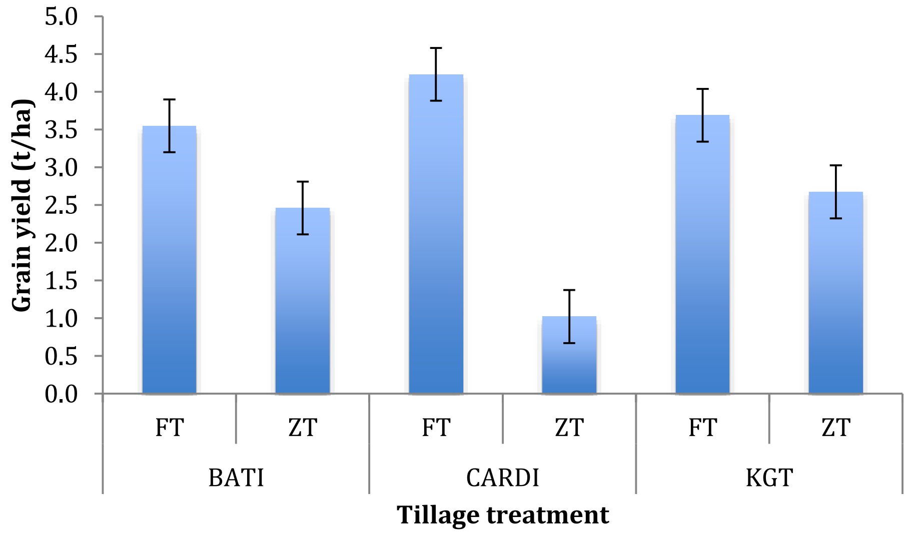


Figure 8.25. Effect of location and establishment method on grain yield.

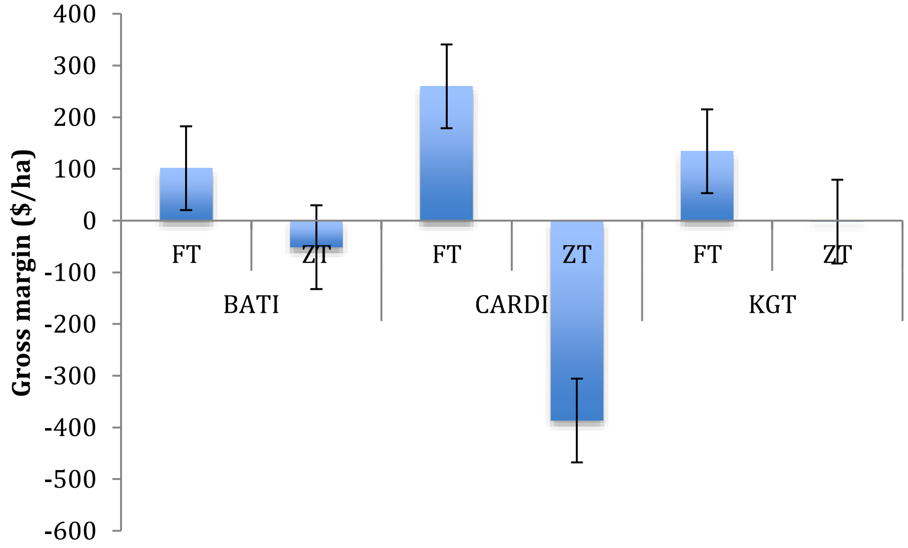


Figure 8.26. Effect of location and establishment method on gross margin.

Wet vs dry seeding

Grain yield was not significantly affected by seeding or weeding method but did vary between sites with CARDI (4.0 t/ha) being significantly higher than BATI (3.2 t/ha) and Kampong Thom (3.5 t/ha).

Weed control method did not have a significant effect on weed biomass or grain yield (Table 8.23) but the gross margin for hand weeding was significantly lower for the hand weeding treatment (-$44/ha) compared to complete weeding (+$63/ha) because of the high cost of hand weeding. The highest gross margin was for CW at CARDI (Figure 8.27).

Table 8.23. Effect of weeding treatment on weed biomass, grain yield and gross margin at three sites.

Location	Weeding	Weed biomass (kg/ha)	Grain yield (t/ha)	Gross margin ($/ha)
BATI	CW	316	3.32	107
	HW	509	3.09	3
CARDI	CW	461	4.13	295
	HW	479	3.90	191
KGT	CW	600	3.34	112
	HW	537	3.58	118
SE		84	0.18	41
5%LSD		236	0.50	116

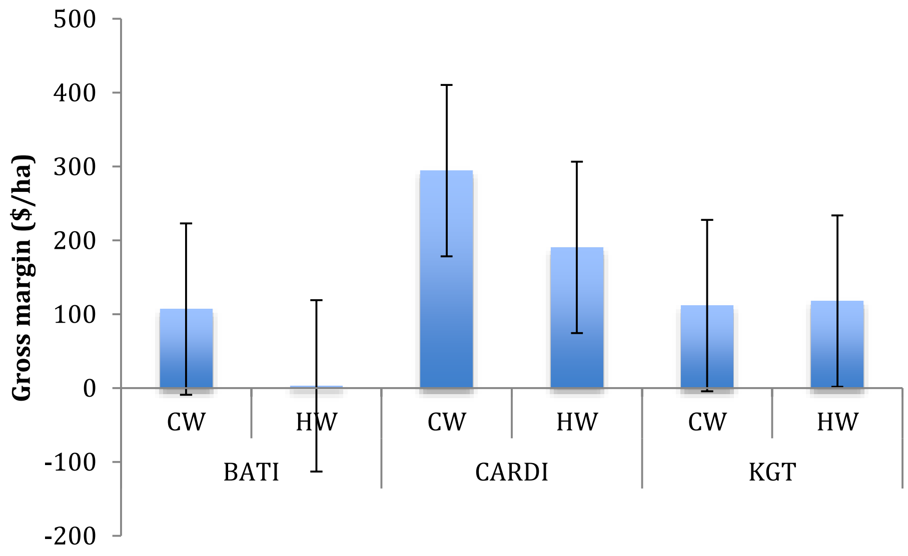


Figure 8.27. Effect of location and weeding treatment on gross margin.

Key findings

1. Weed control was less effective under zero tillage (ZT) compared to full tillage (FT) and this resulted in lower yields and negative gross margins for ZT.
2. The performance of ZT varied between locations and this appears to be associated with variations in suitability of soil type.
3. There was no significant difference between wet and dry seeding method for weed biomass, grain yield or gross margin.
4. There was no significant difference between weed control methods for weed biomass or grain yield but the gross margin for complete weeding (CW) was significantly greater than for hand weeding (HW).

Recommendations

Recommendation 6. The performance of zero-tillage for rice production varied according to soil type. Further research is justified to identify and resolve soil and crop residue management constraints to expand options for zero-tillage in rainfed rice systems.

Weed management

Weed dynamics

There were differences measured in the weed species composition in the rice depending on the crop establishment method. In dry seeded rice with zero-tillage for instance, the annual grass weeds: *Echinochloa colona* and *Leptochloa chinensis* occured while these were not present in wet seeded rice in the same season. Broadleaved weeds such as *Monochoria vaginalis* and *Rotala indica* and the annual sedge *Fimbristylis miliacea* were the main weeds in transplanted rice.

Weed management - replicated trial results (2011- 13)

- There were clear differences in total productivity of the different cropping systems.
- Effective weed control is essential to prevent serious crop losses in all direct seeded rice crops.
- Weed species composition was affected by crop establishment, and previous cropping history and practices.
- In most situations, hand weeding can achieve as good weed control as herbicides plus hand weeding.
- Herbicides can be effective in providing good weed control.

- Smallholder farmers commonly lack knowledge and equipment for timely, accurate and appropriate herbicide application.

Zero tillage

- On average, zero tillage increased weed biomass by 24%, and reduced crop establishment at 10 days by 13% and grain yield by 31%
- No relationship between increased weed biomass (R^2 = 0.52 ns) and reduced crop establishment at 10 days (R^2 = 0.25 ns) to the reduction of grain yield.

Direct seeding tool

- No significant different between drum seeder with wet seed (T6) and Rogro with dry seeding (T5) for grain yield in both early wet seasons.

Cropping systems

- Wet season + early wet season rice produced about 500 kg of paddy less than dry season + early wet season, but the former system would sell wet season product (6,465 kg) in 1.6 time higher price.
- Triple cropping produced about 6,000 kg higher than both double cropping systems, but the productivity per crop was about 300 and 400 kg/ha less.

Identification of best-bet weed management approaches that take into account weed species shifts

Experiments were conducted in Takeo, Kampot, CARDI and Kampong Thom to look at weed control options in transplanted and wet direct-seeded rice. Options tested included herbicides (pretilachlor, 2,4-D, metsulfuron+chlorimuron), and use of cono weeder (mechanical rotary weeder); these were compared with farmer weed control practice and results include:

- In transplanted rice the use of metsulfuron + chlorimuron 2 DAT followed by 2,4-D at 18 days after transplanting (DAT provided adequate control of weeds and a gave a yield advantaged of 0.3 – 0.9 t ha ha compared to the farmer's practice while the use of cono-weeder provided a yield advantage 0.9-1.0 t ha.
- In wet direct-seeded rice, where rice was sown in row using a drum seeder and weeds were controlled by cono weeder or herbicide + 2,4-D the yield advantage over the farmers practice is 0.5 and 0.7 t ha respectively. Broadcast WSR treated with pretilachlor + 2,4-D, gave the yield advantaged over farmer's practice is 0.95 t/ha.
- In transplanted and wet direct-seeded rice herbicides (pretilachlor, 2,4-D and metsulfuron + chlorimuron) provided adequate control of weeds and increased yield over that of the farmer. Similarly, the use of cono weeder in transplanted rice and row-seeded wet direct-seeded rice provided adequate weed control and increased rice yield over that of the farmer's practice.

Mechanisation research and development

Early findings

- The use of a drum seeder for sowing wet direct-seeded rice helped improve crop establishment and reduced seed rate by more than half, with seed rate as low as 60 kg/ha able to be used.
- In water seeding for dry season rice the appropriate water depth is 5 cm; more than this depth and crop establishment is reduced which can also reduce yield.
- Use of 200 kg seeds/ha broadcast on puddled soil gave highest yield; this rate is as low as 50% of what famers are using (250-400 kg seeds/ha).
- The use of zero tillage resulted in early crop establishment in recession rice.
- Introduction of hydro-tiller machine can cultivate the soil faster without ploughing and can provide quicker opportunities to sow seeds by drum seeder.

- The use of herbicide or cono weeder to manage weeds can reduce the cost of weed control and improve farmers' income.

Adaptive research to develop machinery recommendations and options

One of the major outcomes of the research and development on mechanisation has been the development of recommendations on the suitability of mechanised dry/wet direct seeding options according to soil type, topo-sequence and season (Appendix 8).

Overall, the practical constraints experienced with promoting drill sowing of rice have included:

- Significant investment expense;
- Technology can be heavy and cumbersome to use;
- Drill hitching can be awkward (2 people) and some drills need tractor adaptation;
- Drill settings in the field need specific tools
- Significant training is required for calibration, operation and maintenance;
- Suitability is often soil condition specific;
- Timing is critical for some soil types with limited sowing windows.

Best practice drum seeding developed by the project is summarised in Appendix 8a. Similarly, practical constraints were experienced with promoting mechanised drum seeding of rice, and included the following:

- Poor paddy levelling, poor drainage and non-uniform land preparation can lead to non-uniform soil consistency and poor crop establishment
- Labour cost is greater than with seed broadcasting (two operators at best)
- High care for correct seed preparation and timing of seeding
- Field operation difficult: high efforts required with drum seeder sinking in deep mud, seed wastage on headlands
- Prevalence of lodging and predation by birds/mice (especially in lighter soil types) – relative to transplanting
- Seed rate not so flexible

Adaptive research to develop dry sowing machinery suitable for Cambodia

Development of the Cambodian seeder following evaluation of imported machinery

In a process of adaptive research, various modifications and improvements were applied to some of the imported machinery to improve performance under Cambodian soil conditions and respond to farmer feedback received at field sites. Field issues encountered with the imported machinery included:

- Poor furrow closure;
- Seed damage by metering system;
- Seed delivery impaired by rhizomatous weeds.
- Poor contour following ability resulting in erratic seed placement under typical paddy land conditions
- Poor ergonomics affecting operator fatigue and paddy sowing quality
- Some drill technology not suitable for existing 2WT

The following preferred specifications for a drill for cultivated seedbeds were identified:

- 'trailer-like' pulled and self-contained seeder unit with a simple 'pin and go' hitching process suitable for any 2WT available on-farm
- Disc openers set at a maximum 22-23 cm row spacing, with adjustable furrow closers, with an option for six disc openers set at 15 cm row spacing for (dry season and early wet season rice).;
- Adjustable metering system with fluted roller (Unit imported from China was evaluated with a rice seed capacity = 8.1 g per revolution and an approximate

seed rate calibration constant obtained with the drill design = 8 kg/ha per mm flute setting);

- Two side depth-gauging wheels, placed near the row of openers and with spanner-less adjustment for seeding depth and work/transport change-over.
- Independent and contour following star wheel ground drive attached to the drill only, with on/off clutch positions activated manually from tractor handle bar;
- Seed-only hopper in full view of the operator and including shallow seed funneling partitions.
- Overall, a simple to operate drill, with a base model affordability target at US$500.

Development around these specifications resulted in a self-contained disc drill being locally manufactured – the RAEM drill (Figure 8.28). This new Cambodian drill has been evaluated at several locations and demonstrated in the Takeo, Kampot and Kampong thom provinces during 2014, generating positive feedback among farmers, who are keen to use this drill under a 'free try, on-loan' format, with technical support from PDA staff. Consequently, 3 units were placed in 2 Takeo and 1 Kampong Thom villages on-loan during the main wet season, generating sowing of several dozen ha overall. This has been a key result of the adaptive research, field evaluation and farmer feedback undertaken in this project.

Figure 8.28: Project developed, Cambodian RAEM disc drill

Adoption pathways for seed drills

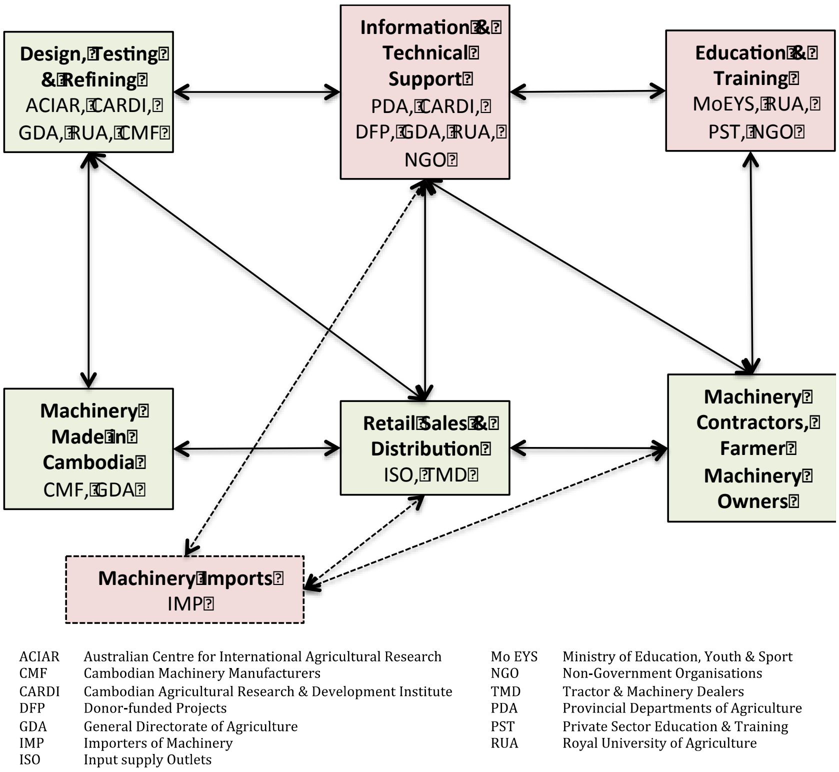


Figure 8.29. Suggested adoption pathway for adoption of machinery in Cambodia.

As indicated in the project Final Review, further training capacity building and vigorous testing of machinery based on the project recommended technologies is required to support an effective out-scaling of technology via PDA, NGOs and leading farmers. The project has identified adoption strategies that are most effective for the Cambodian conditions to share technology knowledge and to reach to the rural communities and private sector. A adoption pathway model for sustainable engagement of farmers via the private sector is put forward (Figure 8.29).

Figure 8.30. Agricultural input sales outlets are potential partners in promotion of project machinery innovations.

Discussion

The green boxes in Figure 8.29 suggest that the most likely and sustainable adoption pathway is via agricultural input and tractor-machinery dealers. United Cambodia Agri (UCA) is a new input sales and advice concept for Cambodia that employs agronomists to provide follow-up support to farmer clients. So far, UCA only operates in Battambang Province. The UCA model is based on the Australian model where companies like CRT or Elders provide agronomic advice to support sales of agricultural inputs as well as finance and insurance products. In Australia, these companies also work closely with government research and extension agencies who provide unbiased technical information and training to commercial agronomists. One-on-one advice to farmers is largely delivered by commercial agronomists in Australia and it appears that that there is currently a move in that direction in Cambodia.

UCA are also keen to promote new machinery technology (Figure 8.30). They are currently displaying drum seeders as well as the Cambo-drill at their stores. UCA and a major pesticide distributor, Nokor Thom, also provide technical advice on the safe and efficacious use of pesticides. These stores are also ideal places to make available leaflets and technical information. UCA agronomists conduct regular farmer training sessions, especially to promote adoption of improved practices and technologies. This is already underway in 2014 with the promotion of dry season cropping using principles of Conservation Agriculture by UCA.

Cambodian machinery fabricators can also be involved in direct retail as is the case for the project commercial partner, Larano. NGOs and other donors such as USAID and CAVAC can also be approached to support training and production of extension materials and leaflets. The role of importers is included as an alternative supply chain to the buyers via retail and linked to information and technical support from CARDI/GDA/PDA. However, it is expected that CARDI/GDA/PDA would need to evaluate imported machinery options with regard to local requirements.

Recommendations for mechanised direct seeding options

Recommendation 7. The most likely and sustainable adoption pathway for seeding machinery innovations is via agricultural input and tractor-machinery dealers who have virtually 100% one-on-one contact with farmers. The likely future role of government research and extension agencies is provision of unbiased technical information and training to commercial agronomists and machinery dealers. It is important for future research projects to engage directly with agricultural input and machinery dealers as well as with traditional partners.

Socio-economic study of mechanisation

Gross margin analysis

The benefits from using machinery, better seeding practices, land leveling, and irrigation of crops primarily derive from yield improvements brought about by better crop establishment and overcoming constraints imposed by weeds, insects, pests and nutrition. Potential for a reduction in input costs and more intensive use of land are also contributing factors. The effect of these on the gross margin of each crop/season and on the total annual crop sequence is shown in Table 8.24.

Table 8.24: Crop yield (t/ha), variable cost ($/ha) and gross margin ($/ha) of the seven cropping scenarios evaluated in the farm level benefit cost analysis

Scenario	Season - Crop	Yield	Variable costs	Gross margin	Total annual variable cost	Total annual Gross Margin
1	MWS	2.0	$140	$640	$140	$640
2	MWS	2.5	$280	$720	$280	$720

3	EWS	2.8	$230	$490	$370	$1,130
	MWS	2.0	$140	$640		
4	EWS	4.2	$500	$590	$780	$1,310
	MWS	2.5	$280	$721		
5	EWS	4.2	$500	$580	$920	$1,150
	DS - rice	3.8	$420	$570		
6	EWS	4.6	$700	$510	$1,160	$1,710
	MWS	4.7	$460	$1,200		
7	EWS	4.6	$700	$510	$1,580	$2,220
	MWS	4.7	$460	$1,200		
	DS - mung	0.8	$420	$510		

KEY: *MWS = main wet season, EWS = early wet season DS = dry season*

If farmers have access to irrigation water in the dry season and soils are suitable for growing a legume crop, then higher input Scenario 7 (3 crops, improved land preparation and varieties, CARDI fertiliser recommendations) has the highest annual gross margin. The annual gross margin from Scenario 7 was significantly higher than that from low input Scenarios 3 and 4 (2 crops using traditional varieties in early and main wet season, either with or without irrigation).

The dual crop Scenario 6, relying on improved land preparation, new varieties and CARDI fertiliser recommendations, represents a scenario where there is insufficient irrigation water to grow a crop in the dry season but enough to grow two crops in the early and main wet season, and achieves a 23% lower annual gross margin than Scenario 7. However the gross margin from Scenario 6 is still significantly higher than the conventional single crop sequence of non-irrigated and irrigated rice in the main wet season using low input and animal draught power (168% and 136% greater for Scenario 1 and 2 respectively). Scenario 6 – due to its higher input - also results in a 51% increase in the annual gross margin over the same dual crop rotation but under low input Scenario 3 - two rice crops in early wet and main wet season without irrigation) and a 30% increase if these two low input crops are grown with irrigation (Scenario 4). Scenario 3 can be seen as a low risk and effective way to increase the annual gross margin under rainfed systems, but the agronomic risks of EWS rainfed crop failure were not considered in the analysis. Scenario 5 (dual crop EWS + DS) assumes access to sufficient irrigation water in the DS and into the follow-up EWS, and has a 18% higher variable cost level mainly driven by the dry season irrigation inputs, and achieves a 12% lower gross margin realtove to the other low input irrigated dual crop sequence (Scenario 4). A logical progression from Scenario 5 is a triple cropping scenario such as Scenario 7, subject to affording the large step in high input + mechanisation variable costs.A farmer adopting Scenario 7 would need $1,580 pa to meet the high operating costs associated with growing this rotation. This is an 11 fold increase in operating costs compared to Scenario 1 (unirrigated, traditional rice crop in the main wet season) highlighting a high risk/cash outlay scenario. The availability of funds to meet the additional costs involved in growing crops in advanced rotations would likely be a problem, especially for those farmers operating at a subsistence level and not able to borrow funds, or not be inclined to risk borrowing at interest rates of over 30% per annum. Overall, the analysis shows that, under high operating cost scenarios per ha (driven in part by the use of motorised power to achieve improved land preparation), high gross margins can only be achieved with high inputs cropping scenarios, including nutrition/irrigation.

Benefit cost analysis

The estimated net present value (NPV) of mechanisation for Scenarios 6 and 7 was compared to estimates from the base case scenarios 1-4 separately.

The comparison of Scenarios 1- 4 with high input mechanised Scenario 6 (Table 7.25) shows the largest potential NPV of benefits arises when mechanisation occurs with a change from the single crop scenarios (1 or 2). The NPV of benefits and the benefit: cost ratio (BCR) is small when the change is made from an already double cropping scenario (3 and 4). The BCR for scenario 4 (1.2) shows that investing in higher input Scenario 6 including mechanisation is risky and would likely not be worthwhile for these farms. Mitigating options are to use machinery on a contract basis and to transition via higher fertiliser input as a pathway to increasing both the gross margins and the benefit-cost ratio.

Table 8.25: Net present value of benefits and the benefit:cost ratio (BCR) from comparing scenarios 1 to 4 with a shift to Scenario 6 (mechanised double cropping + irrigation + high fertiliser input) and with a shift to Scenario 7 (mechanised triple cropping + irrigation + high fertiliser input).

Farming system	**NPV of benefits ($/ha)**	**BCR**	**NPV of benefits ($/ha)**	**BCR**
Comparison with	*Scenario 6*		*Scenario 7*	
Scenario 1*	$8,600	3.1	$12,710	4.6
Scenario 2	$7,921	2.9	$12,032	4.3
Scenario 3	$4,616	1.7	$8,730	3.2
Scenario 4	$3,200	1.2	$7,334	2.7
Scenario 5				

*Note: NPV and BCR values relative to Scenario 1 are for comparison purpose only as Scenario 6 and 7 are unlikely to apply to Scenario 1 farmers, who have no access to irrigation. Should irrigation water become available in the future, the cost of investing into irrigation hardware needs then to be included in the analysis.

The BCR of shifting to mechanised-irrigated-high input double cropping (Scenario 6) is lower than a shift to mechanised-irrigated-high input triple cropping (Scenario 7), irrespective of which baseline scenario the change is made from (Table 8.25). The largest NPV of benefits and BCR arise again when mechanised intensification occurs with a change from traditional single monsoon crop scenarios (1 and 2). The BCR for a change from dual cropping Scenario 4 or 5 to Scenario 7 (high input mechanised triple cropping) shows the benefits remain great enough for it to be worthwhile for farmers to invest. Furthermore, farmers currently growing two irrigated crops of rice each year (Scenario 4) may be in a better financial position to invest (76-82% greater gross margins, Table 7.24) and adopt mechanisation compared to the other baseline scenarios.

Although the benefits and costs are measured using a very high discount rate (30%) using an accounting period of only 10 years, the NPV and BCR from the adoption of mechanisation (Scenarios 6 and 7) are encouraging and the anticipated investments are likely to be financially viable, but may only suit farmers who are not risk averse and able to safely invest into variable costs that are up to 4-6 times their current levels (ref. Scenario 2).

Sensitivity analysis

The discount rate of 30% used in the analysis represents the current market interest rate on agricultural loans in Cambodia. In Takeo, no farmers grow mechanised, drill seeded rice in the early wet season, so the yield of 4.6 t/ha is an estimate. To demonstrate the effect of more favourable assumptions, NPV and BCR were calculated at a discount rate of 10% (a 66% decrease) and at a higher early wet season yield of 5.5 t/ha (a 20% increase). The results of these sensitivity analyses are shown in Table 7.26, and highlight very significant benefits from the effects of lower discount rate and higher yield potential, the latter being tied to best practice management implying dedicated support from extension workers and agronomists.

Table 8.26: Net present value of benefit and BCR comparing scenarios 1-4 to scenario 6 and 7 with lower discount rate (10%)

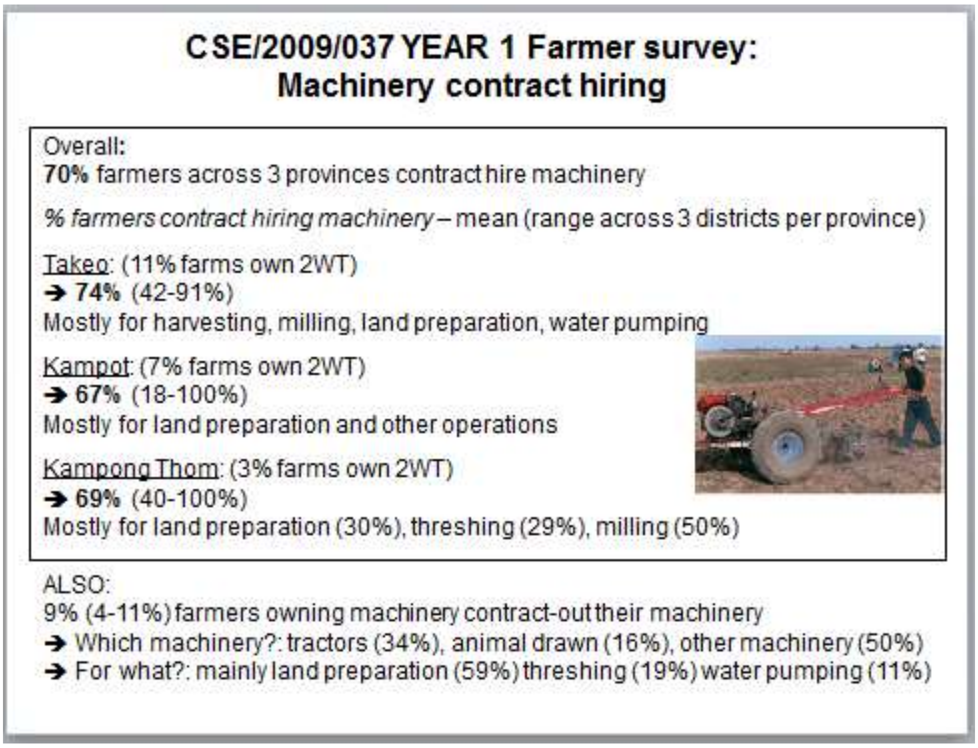
Farming system	Effect of lower discount rate (10% cv 30%		Effect of higher yield (5.5 t/ha cv 4.6 t/ha)	
	NPV of benefits ($/ha)	BCR	NPV of benefits ($/ha)	BCR
	Comparison with Scenario 6			
Scenario 1	$14,460	4.6	$17,400	5.5
Scenario 2	$13,320	4.2	$16,260	5.2
Scenario 3	$14,680	4.8	$10,710	3.4
Scenario 4	$9,420	2.7	$8,360	2.7
Scenario 5				
	Comparison with Scenario 7			
Scenario 1	$21,380	6.8	$24,320	7.7
Scenario 2	$20,240	6.4	$20,270	6.4
Scenario 3	$14,680	4.7	$20,270	5.1
Scenario 4	$12,680	3.9	$15,280	4.8
Scenario 5				

The total overhead and operating costs of using own machinery

The total cost of using owned machinery for 400 hours for different field operations to growing 2 crops a year on a 2 ha farm was $480 per ha. The cost per hectare was significantly lower on farms growing more crops annually or where the machinery was used on a larger area.

A farmer is able to use power machinery for 400 hours when growing two crops a year on a two ha farm and still have the capacity to use it for several hundred hours of contract work. However, because of narrow windows for competing operations, timely completion of different field operations is essential if double or triple cropping is to be successful.

Whilst a power tiller can cultivate 2 ha per day, farmers may be too tired to do additional work after walking behind a tiller for 5-6 hours under humid conditions. Farmers may not be able to do enough contract work on other rice farms to bring in sufficient income to help with machinery payments. There is evidence from the project survey that only a small proportion of machinery owner farmers contract machinery out for tillage operations.



Financial constraints to the adoption of mechanisation

Since most farmers in the project areas operate at a subsistence level, the adoption of mechanisation would require intensification (double/triple cropping, higher fertiliser input, , effective pest/weed control, and additional irrigation) to achieve improved gross margins. Capital costs could include:

- the cost of machinery for cultivation and direct drilling of rice (power tiller, disc, harrow, leveller, cage wheels, seed drill)
- axial flow pump
- pressure regulated knapsack sprayers
- a trailer.

Apart from the capital cost, the intensification and the growing of improved rice varieties would involve significant additional operating expenses associated with machinery operations for improved land preparation and crop establishment such as levelling, cultivation, and drill sowing; pumping for additional irrigation; purchase of better/accredited seed, additional fertiliser and chemicals for plant protection; as well as mechanical harvesting and transportation as likely additional expenses.

Economic assessment of on-farm adoption of drum seeding technology in lowland rice growing areas of Cambodia

Cambodia is witnessing a shift away from traditional transplanting to direct seeding of rice using manual broadcasting techniques, mainly broadcasting wet in the lowland rice growing areas (Table 8.27).

Table 8.27. Rice establishment practices in different rice ecosystems (2013 follow-up survey).

Seeding practices	TP*	DSW**	DSD***	Total (no)
	(Percent farmers)			
Dry Season fully irrigated	13	82	5	127
Dry Season recession rice	0	100	0	124
EWS rice	26	64	11	129
MWS rice	71	17	3	145

***TP = transplanted; **DWS = direct seeded broadcasted wet and ***DSD = direct seeded broadcasted dry.**

Using a drum seeder (Figure 7.44), a lightweight and low cost manually operated technology, can help address some of the limitations of broadcasting seeds and may also help improve the productivity of rice, as reported in the literature. The drum seeding technology was evaluated by the project for direct seeding rice in early wet season (EWS) and dry season (DS), but can also have a role in the main wet season, particularly in upper fields where risks of flooding may be controlled.

Figure 8.31. A 6 drum (12 row) 2.4 m wide drum seeder (www.knowledgebank.irri.org).

Potential benefits of planting rice using the drum seeder

Although a drum seeder, operated manually, is not as labour efficient as a drill seeder (a two-wheel tractor operated machine), this technology is expected to provide the following benefits over broadcast crops:

- Seed placement in defined rows;
- Lower seed rate;
- More uniform crop emergence;
- More efficient weed control on inter-row areas;
- Prospects of achieving higher yields under optimum management.
- Expected trade-offs in the adoption of drum seeding may include:
- Heavy rains during wet season planting can destroy the planting lines;
- water depth control during seeding operation is essential to maximising the benefits;
- labour required for drum seeding is greater than for broadcast seeding.

Where the drum seeder is used on farm, 34% of the total benefits are from saving of seed, whereas 66% of the total benefits are from labour savings (Table 8.28). Where a farmer hires a skilled operator to operate the drum seeder, the income from contract work will reduce at the rate of $4/ha paid to an operator, reducing the income from contract work and the net financial annual benefits.

Table 8.28. Comparative labour used for planting and manual weeding in wet-broadcast v/s drum seeded rice.

Operation	Planting method	
	Broadcasting	Drum seeding
Sowing operations(Days*/ha)		
- Seed preparation	0.75	0.5
- Planting	0.5	0.5
Gap filling	3-5	1-2
Weed control (Days/ha)		
Manual weeding after a chemical spray	12	8

***1 day equals 8 hour – note: the above is assumed for the 2 ha farm area only.**

Table 8.29. Value of potential annual benefits and costs of adoption of drum seeding on a 2 ha farm growing rice in the EWS + DS

Particulars	Value of annual benefits ($/farm/year)		
	Scenario 1	Scenario 2	Scenario 3
Total cost over Farmer Practice (FP)	$50	$66	$71
Potential benefits over FP			
Seed	$70	$70	$70
Labour (planting, weeding)	$138	$138	$138
Income from contract work (no hired labour)	0	$56	$112

The financial analysis without skilled labour hire (Table 7.30) indicate that, under the assumed scenario, the drum seeder technology is viable on a 2 ha farm where it is used to plant rice in both the EWS and DS, assuming no grain yield penalty. Using the drum seeder for additional contract work for planting 4-8 ha of rice (2-4 ha each in the EWS and the DS) makes it financially more attractive.

Table 8.30. Financial analysis of on-farm adoption of drum seeding (owner farmer operating himself the drum seeder for contract work)

Costs and benefits	Scenario 1	Scenario 2	Scenario 3
Total annual cost ($/annum)	$50	$66	$71
Total annual benefits ($/annum)	$208	$264	$320
Net annual benefits ($/annum)	$159	$198	$249

Sensitivity analysis

While the potential for using drum seeders is in the EWS and DS, farmers in some areas would be able to use the drum seeder for planting rice in the EWS. Further, the operational size of over 85% of the farms in the lowland rice growing areas is less than 2 ha, mostly subdivided into 2-6 small parcels of land with different topography and soil type. This means that a significant number of farmers may be able to grow less than the 4 ha annual area on their own farm considered in the financial analysis of drum seeding.

Drum seeding rice may initially achieve lower yields compared to broadcasting wet until farmers become proficient operators. In the longer term, improved farmers skills and more efficient and adapted use of inputs in row cropping may help achieve higher yields from drum seeded crops. It was therefore, considered worthwhile to undertake sensitivity analysis to demonstrate the effect of change in yield, potential annual use of the drum seeder and farm size, mainly to give an idea about the sensitivity of these variables on returns. The data from these sensitivity analyses are presented in Appendix 4.

The value of annual net financial benefits of drum seeding, was sensitive to both changes in yield and the operational size of holding (Table 11.12.9,

Table 11.12.10, Table 11.12.11). The drum seeder remains financially feasible where farmers are able to use their machine for contract work. If yield increases by 5% there are substantial benefits.

The findings of the economic analysis presented above suggest that the drum seeder technology is expected to be financially feasible, where farmers are able to use this technology for growing rice in both the EWS and DS and achieve the same or higher yield compared to rice broadcast wet. Best management practices able to generate yield increases would also likely require significant investment such as land laser levelling which will offset the profitability outlook.

Constraints to drum seeder adoption

The study has also identified some key socio-economic, technical and institutional constraints that may affect the adoption of drum seeding in the lowland rice growing regions in Cambodia. These include:

- Limited practicality of the drum seeder in fragmented small size of holdings;
- High cost of borrowing - poor borrowing capacity;
- Early risk of poor crop establishment – lack of knowledge and skills and extension support;
- Lack of farmers' capacity for accurate (laser) levelling of paddies, influencing crop establishment success;
- Potentially higher labour burden relative to broadcast seeding;
- Drum seeding yield benefits hinged on successful weed management;
- Inefficient contract arrangements;
- Lack of information on potential benefits and costs of using drum seeders;
- Lack of adoption of recommended best-management practice including quality high vigour seeds to sustain low seed rates.

The results of the economic analysis suggest that the annual net financial benefits from adoption of drum seeding were significantly higher than the related annual cost where the technology is used for planting 2 ha of rice in each of two seasons (EWS and DS). This conclusion is based on the conservative assumption that no grain yield increases would be expected with drum seeding. This is in contrast to the findings of some overseas studies citing yield increases of up to 10%, usually attached to best practice management successfully implemented by the farmer, which would also come at an extra cost.

It is important to note that of the total benefits from drum seeding on the 2 ha farm area alone, 34% are from saving seeds and 66% are from labour savings. In an underdeveloped country like Cambodia, especially in the least developed lowland rice growing belt, the labour saved (from family) may not be able to be used to generate any extra income from working as agricultural labour or off farm. In the project follow-up survey, 60-95% of the farming families in different survey districts earn no extra income from surplus labour available on farms (Table 8.33).

Further, sensitivity analysis indicates that the returns from drum seeding are more sensitive to yield than its total potential contract use or farm size. Even a small decline in crop yield would erode all the benefits, leading to financial losses where farmers are using the drum seeder on their own farm only. This underlines the importance of effective farmer training in implementing best practice drum seeding.

It is also important to note that a 5% increase in crop yield would not only lead to huge net annual benefits from adoption of drum seeding, even without taking into account any income from additional contract work, but forms the strongest basis for a quick and widespread adoption of drum seeder technology.

There is a general lack of awareness and adoption of the best management practices for growing rice. There are wide variations in the use of seed, nitrogen and other inputs and variable crop yields that will have an adverse impact on estimated potential benefits, cost and economic viability of the on-farm adoption of new technologies such as the drum seeder (

Table 8.31, Table 8.32).

Key findings

1. The use of high vigour quality seeds is central to the success of crop establishment under low seeding rates and the extent of benefits of seed savings may be reduced by the cost of higher quality seeds.

2. It is essential to more widely expose this technology to farmers and support its correct use in a variety of contexts, in order to better estimate its annual use, the real benefits observed and costs incurred before broadly recommending this technology for on-farm adoption.

Table 8.31. Seed rate, seeding practice and yield of rice grown in the Dry Season by province (2013 follow-up farmer survey).

	Transplanted		Direct seeded wet		Direct seeded dry	
	Seed (kg/ha)	Yield (t/ha)	Seed (kg/ha)	Yield (t/ha)	Seed (kg/ha)	Yield (t/ha)
			Takeo			
Median	63	5.5	190	4.3	63	4.4
Range	3 -170	3-6	20-600	2-8.	16-100	4-5
(N)	4	4	36	36	4	4
			Kampot			
Median	20	3.3	48	3.0	70	4.0
Range	7-60	1.2-1.5	5-200	1-5.	40-100	4-4
(N)	13	12	28	26	2	2
			Kampong Thom			
Median	-	-	258	4.3	-	-

Range	-	-	67-400	2.5-7	-	-
(N)	-	-	40	40	-	-

Table 8.32. Fertilisers used (kg/ha) in relation to farm size in eight districts (2013 follow-up farmer survey).

District	Farm size	N			P			K		
		Median	Range	n	Median	Range	n	Median	Range	n
Baray	≤1	80	64-90	2	25	20-30	2	-	-	0
	1-2	57	45-73	4	39	20-53	4	21	20-23	2
	>2	64	30-81	5	20	10-32	5	12	11-14	2
Steung Sen	≤1	38	38-38	1	38	38-38	1	38	38-38	1
	1-2	-	-	0	-	-	0	-	-	0
	>2	80	41-119	19	25	10-60	19	41	8-60	8
Chhouk	≤1	54	5-207	19	15	5-60	17	15	3-30	9
	1-2	51	33-142	10	15	10-107	7	45	15-60	3
	>2	42	18-99	3	42	20-43	3	42	42-42	1
Chomkiri	≤1	32	9-234	15	8	4-30	13	6	5-8	4
	1-2	64	29-110	6	6	4-20	5	4	4-4	1
	>2	44	32-55	2	10	10-10	2	-	-	0
Angkor Borey	≤1	88	81-110	3	19	18020	2	8	8-8	1
	1-2	70	60-89	3	13	10-22	3	8	8-8	1
	>2	98	16-183	7	25	10-45	7	15	5-45	6
Bati	≤1	78	40-112	4	15	10-60	3	12	10-15	2
	1-2	53	23-88	2	17	10-24	2	12	12-12	1
	>2	61	31-118	5	10	8-28	5	8	8-15	4
Kirivong	≤1	55	55-55	2	10	0-10	2	-	-	0
	1-2	92	92-99	1	23	23-23	1	23	23-23	1
	>2	62	32-93	9	18	8-70	9	10	8-23	6
Tramkok	≤1	44	16-64	8	8	2-20	6	-	-	0
	1-2	58	51-64	2	13	6-20	2	-	-	0
	>2	32	32-32	1	10	10-10	1	-	-	0

Table 8.33. Farming families earning no extra income from labour work – both from agricultural and off-farm (2013 follow-up farmer survey)

Total surveyed	Districts	Spouses	Other members
Agri labour		no of districts	
60%	1	2	1
75%	2	1	1
80%	3	1	1
95%	1	4	4
Off farm			
60%	1	2	1
75%	2		1
80%	3	2	1
95%	1	3	4

Economic evaluation of seeder technology

Benefits of the seeder (relative to seed broadcasting)

- Seed placement at optimum and uniform depth
- Prospect for using lower seed rates
- More efficient weed control

- More efficient use of fertiliser
- Reduced risk of losses due to lodging
- Prospect of establishing crops in stored soil moisture
- Prospect of achieving higher yields

Data and assumptions

Capital cost of drill seeder (RAEM 4D, 220)	$650
Potential economic life of seeder	7 years
Residual value of seeder (% capital cost)	20% if used on own farm only, 5% if used also under custom hiring
Interest rate on borrowing	24% per annum
Farm size	2 ha
Depreciation	Linear
Annual repair and maintenance (% capital cost of drill)	5% if used on own farm only, 7% if used also under custom hiring
Replacement of discs	$30 after every 50 ha of drill seeding

Potential use of seeder

Drilling rice on the owner's farm	2 ha in the EWS and 2 ha in DS
Contract work	5 ha in the EWS and 5 ha in DS
Potential capacity of drill seeder	2 ha/day
Time for drill seeding rice	3.5 hours /ha
Custom hiring rate	$30 /ha (tractor + drill + driver and helper)
Wage rate for skilled driver	$8/day ($5/day for unskilled)
Unskilled workers required for broadcasting	2 (1 skilled + 1 unskilled)
Workers required for drill seeding	2 (1 skilled + 1 unskilled)
Baseline work rate for seed broadcasting	2 ha/day

Labour rate $/day	Lower end	Upper end
Skilled	6.5	10
Unskilled	4	5.5

Operating costs (VC)

Fuel consumption	2.5 litre/hour
Fuel cost (diesel)	$1.25/litre
Cost of lubricants	1.5% of fuel cost

Input assumptions

Gap filling post-emergence to redress to poor establishment, predation and misses: Broadcast (worse with low seed rate): 3-5 labour days, seed drill: 1 labour day (subject to driver pass to pass accuracy, uneven soil can be worse).

Chemical fertilisers: Same as being used in FP

No. of irrigations: Same as are being used in FP

Plant protection: same as being used in the farmer practice i.e. herbicide for weed control (Farmer survey 2013) and 5 sprays of different chemicals for plant protection from insect, pest and disease control; same as being used in farmers practice (Sovandina Chea. Personal communication).

Seed rate: In the EWS, 135 kg of seed used for rice broadcasted wet v/s 80 kg in the rice drill seeded (same quality as is being used by farmers).

In dry season 175 kg/ha for rice broadcasted wet compared (farmer practice) to 100 kg/ha seed used for direct drilled rice.

Wet broadcast: add seed preparation (soaking/incubating/air drying): 0.75 day per ha overall (skilled labour)

Current crop yield (Broadcasting wet) on rice farms in Bati, Takeo (ref: 2013 survey):

- EWS: 3.5 t/ha   - DS 4.8 t/ha

Results

Scenario 1

Total annual income	$487 /ha
Total annual costs	$454 /ha
Net annual profit	$33 /ha

Breakeven: Contract work ~21 ha or ~$45/ha custom hiring rate or 4% increase in yield of rice grown in both the EWS and DS

Scenario 2:

Total annual income	$873 /ha
Total annual costs	$454 /ha
Net annual benefits	$419 /ha

This scenario achieves the highest net benefit due to the high income arising from contract servicing. This option may not be widespread for farmers, especially as mechanisation levels increase and competition interferes.

Scenario 3: (10% increase in crop yield with no contract work)

Total annual income	$573 /ha
Total annual costs	$307 /ha
Net annual benefits	$266 /ha

A 10% increase in crop yield would lead to significant adoption of rice seeder in the lowland rice eco systems. The seeder will be economically viable even without any additional contract work by farmers using own drill seeder. The scenario of achieving higher yield would rely on quality initial training and dedicated support from extension workers/agronomists able to ensure proper drill use and maximise the agronomic benefits the seed drill.

Contract rate for 4D-220 seeder and 2WT – to be charged by a part-time contractor

Assumptions

The contract rate for the drill seeder was determined on the basis that the farmer was working as part-time contractor and

1. Direct drilling rice on owner's own 2 ha farm i.e. (2 ha in the EWS and 2 ha in the DS)
2. Contract drilling rice over 5 ha each in EWS and DS (contracting out drill, 2WT and labour)
3. Uses 2WT for 850 hours per annum (including the use of 2WT for 14 ha of drilling seeding = 50 hours per year)
4. Total annualised overhead costs of tractor and seeder ($27.80 /ha)
5. Total annualised operating costs of tractor and seeder including fuel and lubricants, wages of skilled operator and helper ($17.60 /ha)
6. Capacity of the seeder at 2 ha/day.

Considering the assumptions, the total per ha cost of drill seeding is approximately $45/ha.

Considering a mark-up of 20% on the total cost, the minimum contract rate should be around $54/ha

This contract rate of ~$54.00 is based on a best case scenario where a part time contractor is able to find enough work that will help him to direct drill 2 ha /day. In Cambodia, particularly in the lowland areas, where farm size is very small and most farms are fragmented into 3-6 small parcels of land located at different locations, it is possible that a contractor may not be able to drill 2 ha per day that will further increase the labour cost/ha.

A mark-up of 30% may help to cover this risk and will encourage many farmers to buy machinery and work as part time contractors to provide machinery services to small and marginal farmers.

It is important to note that that the current market contract rate of $30.00 /ha if applied to drilling rice, helps a contractor earn $12/ha over the total variable costs, but is $15 (or 50%) less than the true cost of drill seeding per ha.

There may some minor differences from the estimates presented above, compared to the analysis that will be done using the current data, especially on some of the tractor costs.

Observation

The calculated contract rate for the drill seeder was $55/ha, almost double the rate received currently by contractors ($30/ha). In Cambodia there is strong competition between machinery contractors for ploughing, seeding and harvesting crops. The contract rate is lowered by this competition to a point where costs of maintenance and depreciation are not met.

Objective 5: Increase the capacity of CARDI, GDA and RUA to lead adaptive research and demonstrations of rice establishment practices and associated technologies (including machinery)

Results from capacity building activities are described under the following objectives:

1. Develop training packages on rice establishment (Activity 3.3.) and dry season rice technology (Activity 4.3)
2. Increase the capacity of farmers and their communities in three target provinces
3. Increase the capacity of private entrepreneurs
4. Increase the capacity of project partners and their organisations.

Develop training packages on rice establishment (Activity 3.3.) and dry season rice technology (Activity 4.3.)

A range of training and mentoring activities were conducted during the project (Table 8.34, Table 8.35). The following training packages/modules were also developed and delivered:

- weed management and the safe use of herbicides - produced during three weed control training sessions. Materials used in the training are able to be further developed for farmer training;
- a leaflet in Khmer on the use of the drum seeder for sowing wet direct-seeded;
- a poster dealing with pests, diseases, establishment techniques, and crop management - made and used as learning tools in IPM farmer field schools.
- The IRRI Rice Weed Identification Book was translated and produced in Khmer.

Table 8.34. Training and mentoring activities in Cambodia 2011-2014

Activity	Location and date	Participants	Trainer
1. CLEAR database training (see Table 7.13)	Various 2011/12	353	ARUNA

2. Machinery seed drill calibration, pre-testing & field establishment data	CARDI Feb 2012, Mar 2012	12 (CARDI, GDA, RUA)	Dr Jack Desbiolles (UniSA)
3. Weed management via safe and effective use of herbicides	CARDI, May 2011	25 (CARDI, GDA, RUA)	Dr. D E Johnson, Dr. Joel Janiya (IRRI)
4. Improved weed management for rice:	GDA, Dec 2011	28 (CARDI, GDA, RUA)	Dr. Joel Janiya, Dr. Ted Migo (IRRI)
5. Safe and effective operation of rotary till seed drill technology:	Various, Apr 2012	22 (CARDI, GDA, RUA, PDA, IDE, Private sector)	Mr Scott Justice
6. Weed Identification & herbicide application:	RUA, May 2012	31 (CARDI, GDA, RUA)	Dr. Joel Janiya, Dr. Ted Migo (IRRI)
7. Machinery field calibration and operation, trial design, setting up and implementation, data sampling (asoects repeated during 2013)	Jul-Aug 2012 – CARDI Stn, Takeo/Kampot July 2012 – GDA Tonle Bati station & Takeo Jul-Aug 2012 – RUA Campus & Takeo	6 - extended CARDI team 4 - extended GDA team 5 - RUA team and students	Dr Jack Desbiolles (UniSA)
8. Tine and disc drill improvements, Cambodian drill prototype development and demonstrations	Various 2013/14 CARDI, Russeykeo, Takeo field testing and demo sites, Kampong Thom and Kampot demo sites	CARDI Ag Eng team, GDA Ag Eng team, Russeykeo industry partner, RUA team, IDE Cambodia NGO	Dr Jack Desbiolles

Table 8.35. Field days conducted by partners (CARDI, RUA, GDA)

Trainer	Topic	Location	Attendees
RUA	Performance of Drum Seeder	Tram Kak, Takeo	20 farmers, 2 Policy makers, Rector of RUA and Director of Department of Agricultural Engineering
RUA	Performance of Rogro drill under zero-till conditions	Tram Kak, Takeo	30 farmers, policy maker (including Minister for Agriculture), RUA students
CARDI	Mechanised crop establishment techniques	6 field days Takeo, Kampot,	total 270 farmers (92 women), 2 Policy makers, Rector of RUA and Director of Department of Agricultural Engineering
GDA / CARDI	dry direct seeding machinery field demo.	Tram Kak, Takeo	total 30 farmers, 2 NGOs, 1 manufacturer, 10 CARDI/GDA staff
GDA	Farmer field days to demonstrate technology in Kampong Thom	9 villages in 7 districts	244 men 121 women
GDA DAEng	Mechanised seed drill demonstrations and field days (2014)	Takeo (x 3), Kampot (x 1), Kampong Thom (x 1)	> 200 attendees over 5 field days
CARDI	Cambodian seed drill demonstrations and sowing by farmers	Takeo	X 2 Villages with >40 ha in 2014 EWS and MWS

Increase farmer capacity to improve rice productivity in target provinces (GDA)

44 farmer field schools (FFS) delivered participatory training to 1,130 farmers (552 females) in Kampong Thom, Takeo and Kampot provinces from 2011 to 2013 (Appendix 9). Evaluation showed significant new knowledge was gained by the participants.

The full-time participants in the FFS were only farmers. Extension workers and technical staff from other partners, such governmental and non-governmental organisations, and from the private sector attended field days at the end of FFS. These numbers were not separately recorded during the field days.

Yield assessments from the 44 FFS in the three target provinces showed that the average yield from the Technical Plots was 3,967 kg/ha, whilst the average yield in the Farmer Practice Plot was 3,192 kg/ha, showing a potential yield increase of 775 kg/ha if the lessons learnt in the FFS are adopted by course participants.

Ballot box tests with multiple choice questions were used to measure the knowledge of the participating farmers before and after each FFS. Key questions focused on farming methods; land preparation; variety selection; rice growth stages; identification of beneficial, pest and neutral insects; and fertiliser and pesticide use. The results of this testing (Figure 8.32) show there was a 33% improvement in the test scores for the farmers who attended the FFS.

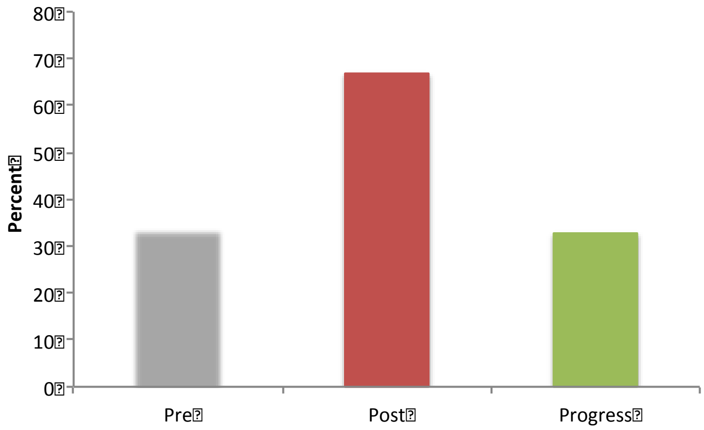


Figure 8.32. Pre and post-test scores for farmers participating in farmer field schools (source GDA)

FS graduates benefited from higher production and profits which they used for better nutrition, education or debt reduction. These benefits were achieved based on the following improvements in knowledge and understanding reported by FFS farmers:

- performance and characteristics of different rice varieties,
- advantages of good land preparation and its contribution to weed control, germination for direct seeding, water management, fertiliser distribution and pest management,
- rice growth stages and related management such as fertiliser application, water management, and pest occurrence, damage and control,
- performance of different seed rates for different planting methods - direct seeding using drum seeder and hand broadcasting; and transplanting,
- types of fertilizers (inorganic, organic and green manure) and rates and timing of applications based on soil type and fertility in order to get higher yields,
- types of weeds and weed management,
- insect pest control – agro ecosystem analysis and consideration of crop growth, pest infestation, and the interaction between natural enemies and pests allowed farmers to make informed decisions based on the field situation and take action in an ecologically sound and economically viable manner,
- types of diseases, symptoms of damage and disease management,
- post-harvest management and technology - determining harvest times, effective threshing, cleaning and storage of grain to reduce losses and improve grain quality,

- economic analysis of rice production - farmers recorded all expenses and calculated their profit. They then understood how their profit was generated and they learnt to think about what to spend on production to get the highest income.

FFS also empowered farmers to create a safer working environment for themselves and their families. By raising awareness of the negative health effects associated with pesticide application and teaching ways to reduce this risk, farmers (men and women) who attended were able to change practices to minimise the health and environmental risks associated with of pesticide use.

Increase the capacity of private entrepreneurs (Activity 4.2)

In a process of adaptive machinery research led by UniSA, a number of drill modifications were identified and developed following evaluation of the Thai and Rogro drills. Issues encountered included:

- low material and manufacturing quality (quick aging plastics, undersize parts failing, low strength steel),
- partial functionality (seed damage, poor furrow closure),
- poor ergonomics (cumbersome use).

A number of modifications were developed as a group exercise and implemented on all units by the CARDI and GDA DAEng workshop. The project enhanced the capacity of the CARDI Agricultural Engineering Office to develop ties with the private sector, now strengthened into a productive partnership with a local Russeykeo-based manufacturer (Russeykeo Agricultural Equipment Manufacturer - RAEM – Director Mr Ouchhoeun Larano) enabling the co-development a new simple seed drill prototype, following a fully inclusive collaborative process from concept design to prototype evaluation and early demonstrations. This process of engaging in co-design activities was facilitated by an existing linkage between this manufacturer and a key GDA staff (Mr Pen Nouv) at the GDA Department of Agricultural Engineering, also in charge of product development at the manufacturing workshop. This industry partnership with CARDI has strengthened over 2014 (with a total of 7 drills made for the project). Commercial interest from farmers is slowly emerging following the demonstrations and promotion activities, and has resulted in several small and larger drills (for 2WT and 4WT respectively) being commercially manufactured and promoted by both RAEM and GDA DAEng workshops.

Increase the capacity of CARDI, GDA and RUA to work together to develop agronomic recommendations and upscale demonstrations to extend advice to private sector (Activity 5.1), lead demonstrations of agricultural innovation, and use CLEAR (Activity 5.2)

The research mentoring activities and associated training programmes conducted over 2011-2014 have developed significant capacity at all 3 partner institutions for research, extension and education in the following areas:

1. Awareness of the technologies and selection criteria for a wide range of mechanised rice establishment and weed control technologies
2. Calibration, setting up and field operation of a wide range of 2WT drill machinery for both cultivated and zero-till applications
3. Calibration, setting up and field operation of row drum seeding for wet seedbeds
4. Use of hydro-tiller technologies for rapid wetland preparation in recession rice
5. Calibration, set up, field operation of knapsack technology for pesticide application
6. Operation of rotary mechanical weeders for row crops
7. Identifying key weeds present in Cambodian rice fields and select their recommended control methods

8. Delivering recommendations for the optimum use of these technologies under Cambodian soil/weed/paddy conditions.

Trials at RUA and CARDI (Appendix 10) were managed as project components by 45 undergraduate students. These students were exposed to innovative technologies, research and management practices and activities included direct involvement in:

- agronomy trial implementation, data collection and analysis, report writing
- machinery trial design, implementation, data sampling and analysis, report writing
- significant input from 10 RUA students in survey design, pre-testing and implementation, data basic analysis and reporting

The following courses in the BSc. curriculum at RUA Faculty of Agronomy related to rice production in Cambodia were updated as a direct outcome of learnings from the project:

1. Equipment & Ag Machinery - delivered by Chuong Sophal (RUA) now covers hydro-tiller, drum seeder, cono weeder and tine and disc seed drills technologies.
2. Plant protection - delivered by Dr Khay Sathya (CARDI) now incorporates aspects of safe use of herbicides, weed management options for rice with emphasis on Cambodian agriculture, assessment of weed control treatments.
3. Farm management - delivered by Som Bunna (CARDI) now incorporates a synopsis of rice establishment practices.

At CARDI, an increasing quantity of trials implemented by the project team now default to use of a mechanised drill for dry direct seeding or drum seeding for mechanised wet seeding, including trials with an agronomic focus (e.g. nutrition and weeds).

At GDA, the rice department collaborated closely with the Agricultural Engineering Department to implement machinery trials and are currently planning to continue the use of mechanised seeding practices as part of their future research and demonstration programmes.

Training on CLEAR was delivered by Aruna Technology Ltd. to 353 people from 16 institutions (Appendix 11). Attendees learnt how to capture geospatial data and present it on maps.

Objective 6: Australian component - investigate current and predicted future problems with rice seedling establishment including cultural practices and soil type interactions and issues related to the use of groundwater

Activity 6.1 Identification and review of literature and replicated glasshouse and field experiments

Years 1 and 2

Head House experiments

A head house (controlled temperature glass house) experiment conducted in year 1 with six seed treatments which included GA, IBA and water soaking, found there was no significant difference between any of the seed treatments for all of the measurements collected.

In the second year, three head house experiments were conducted to further examine if seed treatments increased speed of emergence, number of plants emerged and seedling vigour.

1) A small experiment was conducted that found when seeds were sown at 4 cm depth neither Zn seedcoat nor “Seed Boost” increased the speed of seedling emergence or the percentage of seedlings that established above the control treatment.

2) The second experiment with two seed sowing depths concluded that seed treated with GA at either of two rates was not quicker to emerge and did not significantly increase the number of seedlings to establish, than the non-treated control.

3) A third experiment was conducted in the head house with similar treatments to experiment two but with only the shallower sowing depth used. In this experiment the seedlings from the two GA treatments were both quicker to emerge and a significantly higher number of seedlings established than the non-treated control.

Slant board experiments

Two slant board experiments were conducted looking at the effect of different seed treatments on root and shoot growth in several varieties. In both experiments, treatments where GA was either applied to the seed directly, or the seed was soaked in a mixture containing GA, shoot length was significantly longer after 14 days than treatments not containing GA. There was no difference in root length between treatments.

Field experiments

In year 1 field experiments were conducted at three sites with aerial and drill sown experiments at each site. In all aerial sown experiments the seed treatments had no effect on establishment or plant growth and yield. In the drill sown experiments at both the LFS and YAI sites, DAP sown with the seed, increased establishment number over the control as did the Zn seedcoat at the LFS site. The only effect the seed treatments had on plant growth and yield in the drill sown experiments was the DAP increased dry matter at panicle initiation over the control. Grain yield was not increased by seed treatments in any of the field experiments in year 1.

Experiments conducted in year 2 on cut and non-cut areas of a rice field observed significant differences in PI DM where triple super+50N+Zn seedcoat and the Granulock Z +50 N treatments had greater PI DM than all other treatments. This significant positive effect of zinc was also observed for PI nitrogen uptake. Yields of those treatments including zinc in the cut experiment were comparable to yields achieved in the no cut experiment. Although there were no significant differences observed in PI DM and grain yield, the highest PI DM and grain yield were achieved by the two treatments with zinc additions in the cut experiment.

Year 3

Polyhouse experiments

In this experiment soil was collected at three depths to simulate different depths of topsoil removal. Plant growth and grain yield decreased significantly with increased depth of topsoil removal with the normal 0-10 cm soil always highest regardless of treatments applied. The only significant difference in growth and grain yield across all the treatments is the control which has a significantly lower dry matter and grain yield than all other treatments. All treatments except the control received P in the form of DAP with the seed.

Field experiments

In all of the district experiments, except one, there was no significant difference in plant growth or grain yield between the control and the Zn and P treatments. In one of the aerial sown experiments the Zn seedcoat significantly increased plant dry matter at panicle initiation but there was no significant difference in grain yield.

Discussion

The GA seed treatment was found to provide an increase in shoot growth in the slant board experiments. In one head house experiment GA reduced the time to emergence and increased the number of seedlings established compared to the control but in the other head house experiments it had no effect. The IBA had no effect in any of the experiments. Neither GA or IBA provided a useful response in the field experiments.

The response from zinc in cut soils is variable and very dependent on soil pH, phosphorus and soil carbonate levels. Zinc deficiency becomes a problem at the seedling stage and it is important that zinc is applied close to the seed or as a seed coating. When zinc was deficient seedling establishment was very good, but when permanent water was applied the seedlings died.

Activity 6.2 Replicated field and glass house experiments will quantify the impact of water quality on the growth and yield of current and potential rice varieties

Salinity at vegetative stage

With the proviso that glasshouse grown plants may behave differently to field grown plants, it appears that the main Australian lines (Sherpa and Reiziq) are as tolerant of salinity during the vegetative stage as the two tolerant Asian check lines (Amber 33 and IR45427). Illabong, Kyeema and Amaroo appear the most sensitive of the Australian lines at the vegetative stage, with biomass (Figure 8.33) and leaf area (Figure 8.34) reduced to the same degree, if not more, as in the salt sensitive check lines (IR58 and IR29). Shoot biomass and leaf area in Quest and Doongarah were the least affected by salinity, whilst Basmati was the most affected.

Salinity at reproductive stage

Grain yield: The lower salinity (4.5 dS/m) in Experiment 2 did not significantly affect grain yield in any variety. At the higher salinity levels (8 dS/m) in Experiment 1, there was a significant difference between the grain yield of the fresh and saline treatments in six varieties: Illabong, Sherpa, Opus, Langi, YRW 4 and IR 45427 (
Table 8.36).

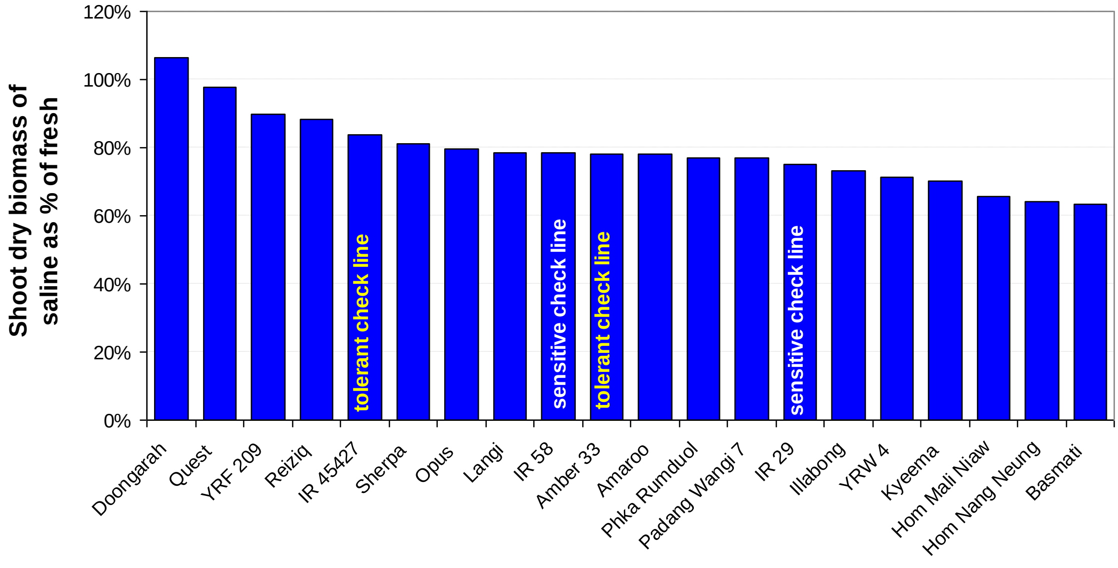


Figure 8.33. Shoot dry biomass (g/plant) of plants grown in soil solution of 8-9.5 dS/m during vegetative growth stage as a proportion of shoot biomass of plants grown in fresh water.

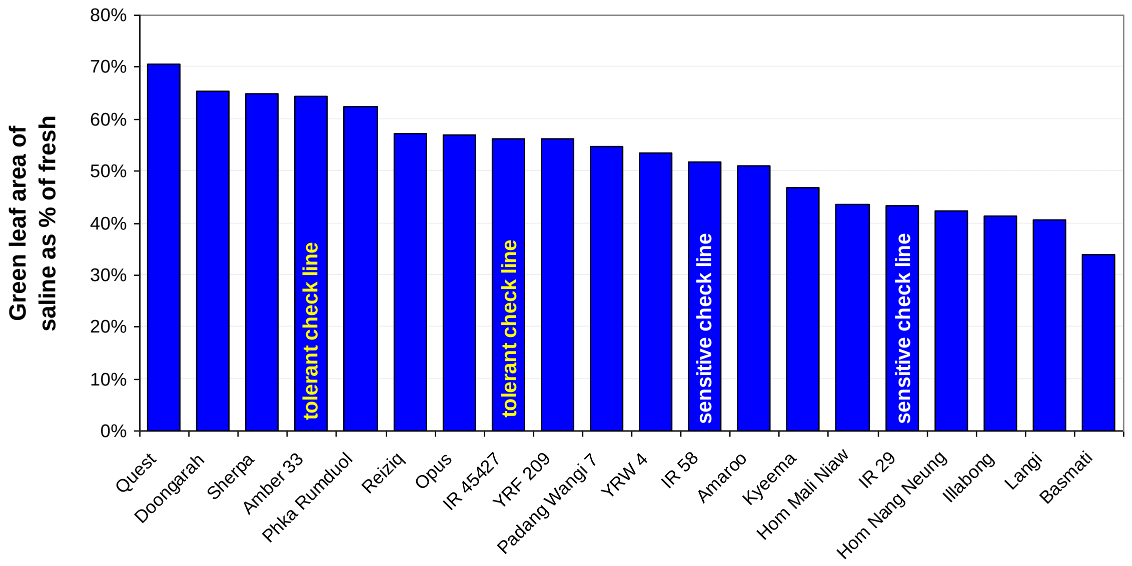


Figure 8.34. Green leaf area (cm2/plant) of plants grown in soil solution of 8-9.5 dS/m during vegetative growth stage as a proportion of shoot biomass of plants grown in fresh water.

Panicles per plant: Only YRW 4 in Experiment 1 showed a significant effect of salinity on the number of panicles per plant. An effect of salinity was indicated in Sen Pidao and IR 29 in Experiment 2, though this effect was not significant at the 5% level. There was also a significant difference in the number of panicles per plant (averaged across salinity levels) within each variety between the two experiments for all varieties except Amaroo, Illabong and Opus.

Table 8.36. Summary results of statistical analyses of grain yield (g/plant), panicles/plant, seeds/panicle and 1000 grain weight from Experiments 1 and 2. Significant differences at the 5% level between fresh and saline treatments within each experiment and variety for the three-way interaction (experiment × variety × salinity) are shown.

	Experiment 1				Experiment 2			
Variety	*yield/plant*	*pan/plant*	*seeds/pan*	*g/seed*	*yield/plant*	*pan/plant*	*seeds/pan*	*g/seed*
Amaroo				**sig**				**sig**
Doongarah				**sig**				
Illabong	**sig**		**sig**	**sig**				**sig**
Quest								
Reiziq			**sig**	**sig**			**sig**	
Sherpa	**sig**		**sig**	**sig**				**sig**
Opus	**sig**			**sig**				
Langi	**sig**		**sig**					
YRF 209			**sig**					
YRW 4	**sig**	**sig**	**sig**	**sig**				
IR 45427 (tolerant)	**sig**			**sig**				**sig**
IR 58 (sensitive)				**sig**				**sig**
IR 29 (sensitive)							**sig**	**sig**
Sen Pidao							**sig**	
IR 66								

Seeds per panicles: The number of fertile seeds per panicle was significantly different between the fresh and saline treatments for Reiziq in both Experiments, for Illabong, Langi, Sherpa, YRF 209 and YRW 4 in Experiment 1 and for IR 29 and Sen Pidao in Experiment 2.

Seed weight (g/1000 seeds): Seed weight was significantly lower in the saline treatments in both Experiments for Amaroo, Illabong, Sherpa, IR 45427 and IR 58. The higher salinity in Experiment 1 also had a significant effect on Doongarah, Opus, Reiziq and YRW 4. IR 29 was only grown in Experiment 2, but the salinity levels in that experiment significantly reduced its seed weight. Seed weight of Quest was not significantly affected by salinity in either experiment.

Quest was the only variety in which salinity had no significant effect on any yield component in either Experiment (
Table 8.36). In both experiments, salinity had a greater effect on all yield components in the “tolerant” check (IR45427) than it did on the “sensitive” check (IR 58).

Salinity from establishment to harvest

This trial was greatly affected by a mouse plague which started in early grain filling. Despite control measures (baiting), all plots were affected. Plots on the outer edges of the trial area where most affected, with nearly all grain lost to the mice in four Bays. In the end, little or no grain was harvested by the header from 29 of the 120 plots. The following steps were taken to derive useful information from the trial:

- Header grain yields were compared with (1) grain yield from 1 m^2 quadrats sampled from what appeared to be the least affected part of each plot; and (2) grain yield estimated from random grab samples of “full” (uneaten) panicles from each plot. A best estimate based on these three values was obtained.
- A strong linear relationship between panicle length and total spikelet number per panicle was obtained for each variety from the *2011-12 Salinity at reproductive stage* glasshouse trial (and confirmed by data from the University of Queensland: courtesy of Dr J Mitchell). This allowed an estimate of grain yield to be obtained from properties unaffected by mice: tiller number (quadrat cuts), tiller length (measured on grab sample) to get spikelet number per panicle, and 1000 grain weight (from header sample). Yields were then estimated from this data.

The trial was a blocked, split-plot design intended to be analysed using ANOVA. This was not possible because of the number of missing plots, so regression analysis was used to determine the relationship between grain yield estimated by the two methods described above and season average field water salinity Grain yield was over-estimated when calculated from yield component data. This is because tiller number was counted (not panicle number) and because the relationship with panicle length was with total grain number (sterile and fertile).

Despite this difference, the following is noted:

- A yield decrease is strongly indicated for Amaroo, Doongarah, Quest and Sherpa when season average field water salinity exceeds 2 dS/m
- Grain yield of Amaroo may be reduced by season average field water salinities of 1.5 dS/m, whereas grain yield of Quest may be unaffected at this salinity level.
- There is a close correlation in the slope of the relationships between the two estimates of grain yield and the season average field water salinity for Doongarah and Sherpa, but not for Illabong and Reiziq. This reduces confidence in any recommendation pertaining to Illabong and Reiziq from this field trial.
- If the relationship between calculated yield and season average field water salinity is accepted, then Quest, Doongarah and Reiziq appear the least sensitive and Amaroo, Sherpa and Illabong the most sensitive varieties to salinity.

Salinity by variety effects on transpiration

Salinity (5-6 dS/m) had a significant effect on leaf area, transpiration and biomass in the pot-in-bucket trial Glasshouse trial in 2013. The response in all varieties tested was similar; salinity caused a reduction in leaf area and transpiration and this resulted in lower shoot biomass. In the fresh control, water use (transpiration) was highest in Quest and Sherpa, and lowest in Reiziq and Doongarah. In the saline treatment, water use was similar across all six varieties (Figure 8.35).

Productivity in salt exposed plants was maintained by an increase in transpiration efficiency (TE = g shoot biomass/mm water transpired; Figure 8.36) and an increase in photosynthetic efficiency (inferred from an increase in leaf thickness). Under saline conditions, TE of Quest & Reiziq was significantly greater than TE of the other 4 varieties.

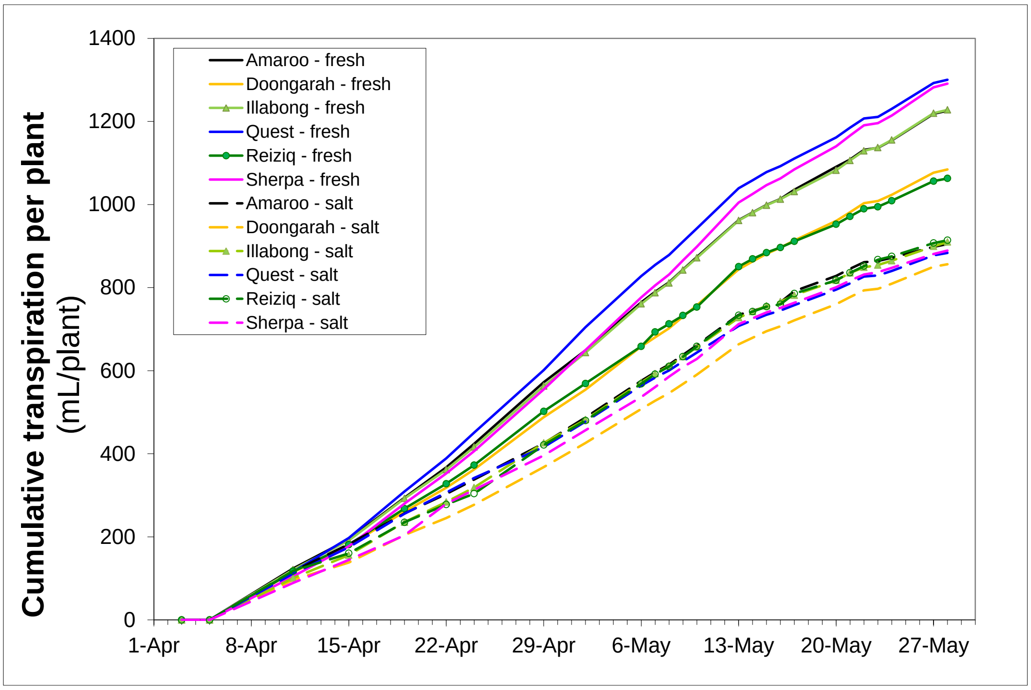


Figure 8.35. Cumlative transpiration of six Australian rice varieties exposed to fresh (0.2 dS/m) or saline (5-6 dS/m) water for seven weeks from the 4-5 leaf stage on.

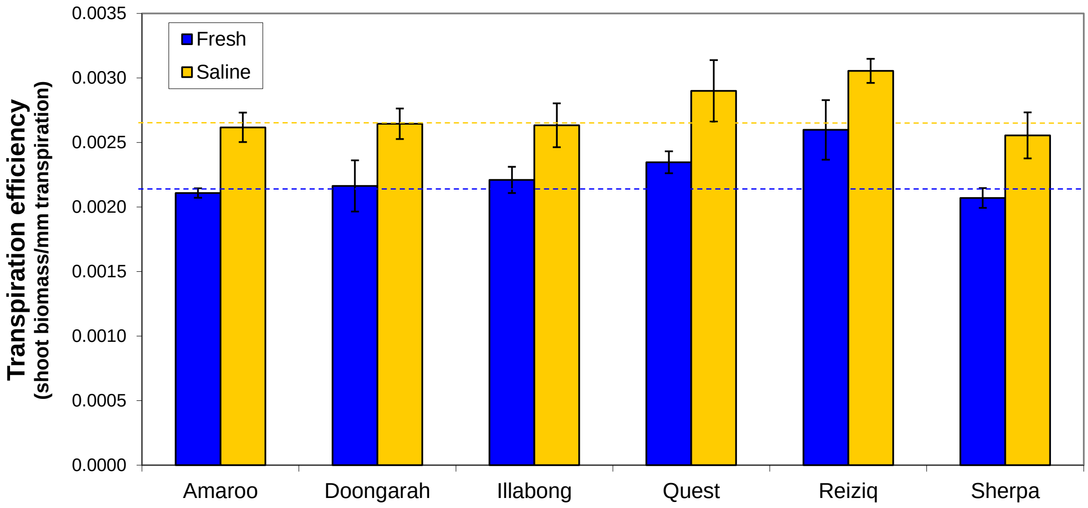


Figure 8.36. Transpiration efficiency (g dry shoot biomass per mm water used) of six Australian rice varieties exposed to fresh (0.2 dS/m) or saline (5-6 dS/m) water for seven weeks from the 4-5 leaf stage on.

A proposed model of response to salinity

Salt tolerance of halophytes is a multi-genetic trait and the same is true for non-halophytes. Breeding for yield has not delivered many salt-resistant varieties of the common crops (Flowers 2004; Whitcombe *et al* 2008) because of an evidently low probability of maximising yields under saline conditions by combining two complex traits (yield and salt tolerance). Yeo et al (1990) advocated understanding the physiology of tolerance and pooling a range of traits. The traits that need to be pooled (for wheat and barley and presumably rice) include Na^+ ‘exclusion’, K/Na discrimination, enhanced vigour, water use efficiency, the retention of ions in sheaths, tissue tolerance, ion partitioning into different leaves, osmotic adjustment, and early flowering (Colmer et al 2005 p 610 in (Flowers *et al.* 2010).

The pot-in-bucket transpiration trial showed there was a relationship between shoot chloride accumulation, leaf area and transpiration (Figure 8.37). Shoot chloride concentration has been proposed as a salinity stress index (Dalton *et al.* 2000) and Na:K ratio is regularly used to screen crops for salinity tolerance ((Gregorio, G. B., Senadhira, D., and Mendoza, R. D.1997)) Shoot chemistry data (Cl, Na, K) collected from plants in the Field trial (2010-11) and one of the glasshouse trials (2011-12) shows it may be possible to combine the two measures (Na:K ratio and shoot Cl concentration) to obtain a model of plant response which pools a number of traits: Na^+ ‘exclusion’, K/Na discrimination, enhanced vigour, water use efficiency (Figure 8.38).

Recommendations

Recommendation 8. Shoot chloride concentration has been proposed as a salinity stress index and Na:K ratio is regularly used to screen crops for salinity tolerance. Results in this study show it may be possible to combine the two measures (Na:K ratio and shoot Cl concentration) to obtain a model of plant response which pools a number of traits: Na+ ‘exclusion’, K/Na discrimination, enhanced vigour, water use efficiency. Further work on this model is needed before any conclusions or recommendations about its applicability can be made. However, if threshold values for chloride % and Na:K can be found, then this model may provide insight as to the differences in relative grain yield responses between field and glasshouse trials.

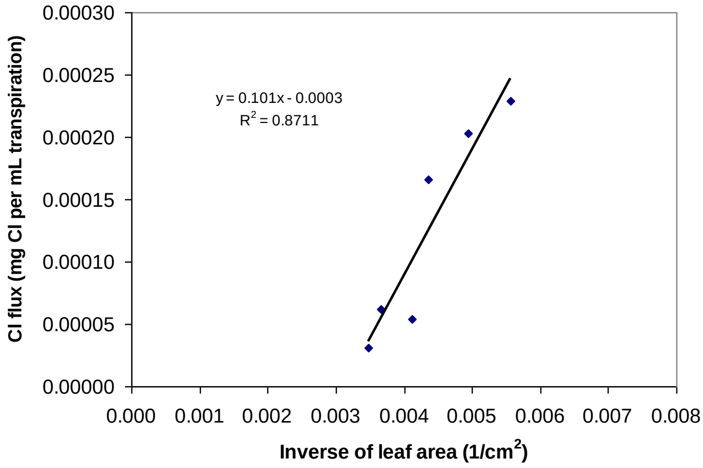


Figure 8.37. Relationship between chloride accumulation in above ground biomass per ML of water transpired and leaf area in Sherpa in the Pot-In-Bucket transpiration glasshouse trial.

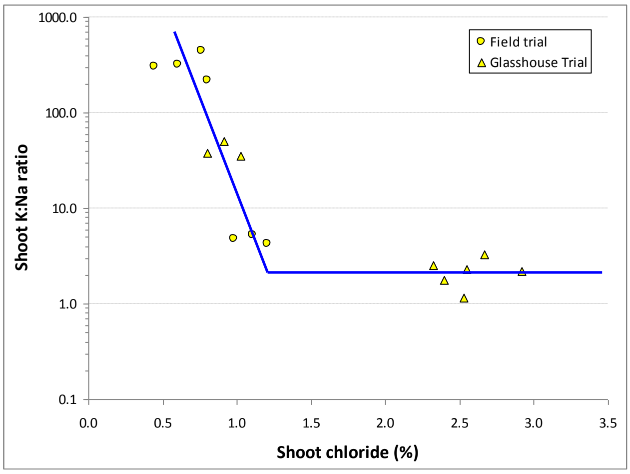


Figure 8.38. Relationship between Na:K ratio and chloride concentration of whole shoots of Amaroo .from field and glasshouse trials

9 Impacts

8.4. Scientific impacts – now and in 5 years

The full scientific impact of this project is not yet realised but significant impacts are expected during the next five years. The highly exploratory nature of the research conducted to increase knowledge of Cambodian rice agro-ecosystems from a comparatively low base will take time to be assimilated into the R,D&E framework. The trajectory of research, from baseline survey, to baseline trials and development of the ICE trials, and implementation of machinery performance optimisation trials, provides strong evidence of an increase in scientific capacity within the project team over the past four years leading to measurable practice change in the partner institutions.

The major increases in scientific understanding identified by the project team include:

1. Weed and pest management
    - Principal weed species and possible succession determined which have led to development of sustainable weed management practice recommendations.
    - Comparison of planting method and weed control measures completed at a variety of sites.
    - Partners now possess recommendations for weed control and herbicide options, particularly for the early wet season.
    - Ecological approaches to pest management (IPM) explored through field trials with preliminary finding that little or no yield penalty occurs with reduced pesticide applications.
    - Herbicide regimes have been identified and validated for wet, dry and transplanted situations.
2. Crop establishment
    - Mechanised options for wet and dry seeding were identified and evaluated in different soils, seasons and topographic sequences. Knowledge was developed on their preferred conditions of use and best practice aspects.
    - The project has optimised seed broadcasting and drum seeding techniques with clear evidence for a reduced seeding rate from 400+ kg/ha down to 80 kg/ha.
    - The interaction of seed broadcasting with water depth was explored and quantified during trials and demonstrations.
3. Comparisons of farmer practices with CARDI recommendations for fertilizer application showed that farmers are under-fertilising rice crops.
4. Mechanised wet and dry direct seeding options were also assessed under reduced and zero-tillage conditions, and some knowledge of their potential for Cambodian rice production was developed.

Evidence of this increase in scientific knowledge is found in the synthesis of project learning's incorporated into extension recommendations for rice establishment and mechanization options for Cambodia (Appendices 8, 8a).

Seed treatments in Australia

The GA and IBA seed treatments were found to be of no significant benefit in the field and there would be little value in continuing research into them in the future.

Salinity in Australia

A potential new model for application to screening of rice for salinity tolerance is being explored and may have significant impacts for assessing salinity tolerance in all field crops

It appears that the current main Australian rice varieties are as salt tolerant as the IRRI check lines (Amber 33; IR 45427). The impact of this on Australian breeding programs waits to be seen.

8.5. Capacity impacts – now and in 5 years

Bibliography

Currently located with Uni SA, this repository of knowledge has initially been a valuable resource for the project partners and has the potential to continue supporting capacity building both within Cambodia and internationally if a format for wider access can be organised and if it continues to be updated.

CARDI soils laboratory

The project was responsible for a significant increase in the capacity and scope of soil testing at CARDI, with a 260% increase in sample flow through the lab

Cambodian Country Almanac

CAVAC have used the CLEAR database developed in this project for other activities:

1. soil data in certain communes in the provinces Takeo, Kampot and Kampong Thom were exported into a data base file for the PDA call centres to provide information to farmers on fertilizer uses for specific soil types and,
2. soil data from CLEAR was used by the irrigation team to assist them in preparing feasibility studies for each soil type in the irrigation schemes.

For CLEAR to continue to create an Impact in Cambodia, an “owner” for the database will need to found.

Changes in knowledge and skills of project partners

Capacity building impacts have occurred across all Cambodian partners in:

- accessing scientific literature,
- designing, testing, conducting and analysing farmer surveys, and
- a multi-disciplinary understanding of many of the constraints to crop establishment in Cambodia, including direct seeding, irrigation regimes, weed management and agronomy,
- design and implementation of more complicated research trials, such as a systems trials on permanent sites
- set-up, repair/maintenance and operation of (new) agricultural machinery,
- design and implementation of mechanised seeder evaluation trials
- development of training and extension/advisory materials

A systems approach to field experimental design and conduct at permanent sites has developed among partners over the life of the project. All Cambodian partners have led field experiments in the provinces and all project partners have produced reports and made presentations (see Section 10.2).

The greatest indicators of success in respect to capacity building for the Cambodian project partners are:

1. Cambodian Agricultural Research and Development Institute
    - In research, demonstration and education activities, an increasing quantity of trials implemented by the project team now defaults to using a mechanised drill for dry direct seeding or drum seeding for mechanised wet seeding, including trials with an agronomic focus (e.g. seed multiplication, nutrition and weeds).
    - The ICE trial was voluntarily continued beyond the life of this project because of the value of the information being produced, particularly around an increase in productivity when shifting from double to triple cropping and the need for research to modify/update CARDI fertiliser recommendations.
2. GDA
    - The rice crop department has collaborated closely with the Ag Engineering Department to implement machinery trials and they are currently planning to continue the use of mechanised seeding practices as part of their future research and demonstration programmes.
    - Provincial Departments and District Offices of Agriculture staff have been exposed to the project and actively involved in implementing the project trials and have a significant capacity to support mechanisation adoption among farmers
    - GDA DAEng is planning to actively promote the mechanisation outcomes of this project in other mechanisation projects
3. Royal University of Agriculture
    - This project has helped to improve the curriculum in 1) farm socio-economics, 2) agricultural machinery, particularly direct drills, 3) crop production, particularly weed and pest management, and 4) rice production agro-ecosystems.
    - Students from RUA have contributed continuously and directly to the project's small holder farmer surveys and data analysis and can be significant promoters of the project innovative outcomes.

Changes in knowledge and skills of farmers in target provinces

More than 1,130 farmers attended the 44 Farmer Field Schools, including 552 women.

2,200 farmers attended project field days.

Farmers learnt to calibrate and operate Row-Grow tillers.

Cambodian partners have observed changes in rice management methods based on farmers' interaction with project activities in the three target provinces:

- Shift to direct seeding preferred in dry and early wet season combined with transplanting in wet seasons,
- New machinery is more attractive to farmers because of savings in labour, time, and seed cost and ease of weed control,
- Clear understanding and better use of herbicides in the farm system

Changes in knowledge and skills of private sector

The loss of CAVAC from the project in early 2012 severely reduced the capacity of this project to deliver significant Impacts in the private sector. CAVAC were the project partner with primary responsibility, skills and capacity for achieving this.

Despite the considerable hole in the project team created by the CAVAC exit from the project, there has been progress made in building capacity within the private machinery manufacturing sector. This is evidenced in the partnership that has developed between CARDI Agricultural Engineering staff and a local manufacturer (Russey Keo Agricultural Equipment Manufacturer - RAEM – Director Mr Ouchhoeun Larano) to trial, develop and build the Cambodian seed drill. This process of engaging in co-design activities was facilitated by an existing linkage between this manufacturer and a key GDA staff (Mr Pen Nouv) at the GDA Department of Agricultural Engineering, also in charge of product development at the manufacturing workshop. The partnership with CARDI has strengthened over 2014 and has generated a momentum of trust and positive interaction with CARDI researchers as well as with leading farmers interested in the seed drill technology. The industry partner has also shown an improved ability to adapt the technologies with developing large scale versions of the drill to meet a perceived more immediate market demand. To date, Both the RAEM and GDA Department of Agricultural Engineering workshops are producing commercial versions of the Cambodian seed drill and are tailoring the drill size and specifications to the market demand.

8.6. Community impacts – now and in 5 years

The two greatest community impacts are:

1. The increase in farmer knowledge and capacity in the target provinces which has occurred through the Farmer Field Schools. This is evidenced by
    a. the results of the pre and post School testing which showed a 34% improvement in the test scores of farmers who attended the schools.
    b. the 775 kg/ha yield increase observed in the "Technical Plots" compared to the "Farmer Practice Plots" which were run at each School.
2. The comments of Dr Ouk Makara made to the Final Review meeting at CARDI, Phnom Penh, in February 2014 that his minister had seen the results of the ICE trials and the findings were to be incorporated into Cambodian government policy.

Additional community impacts lie in the emerging momentum of interest in mechanised seed drill technologies judged by the high farmer attendance to machinery field days during 2014 and the keen interest by a number of farmers in testing this technology. It is anticipated that continued promotion and extension support would enable this momentum to strengthen and become self-sustaining within a few years.

Economic impacts

Cambodia

Analysis of the baseline (2010) and exit (2013) surveys has shown the number of farmers owning two wheel drive tractors increased from 3-11% in the target provinces to 42% in Takeo (a more mechanised province), with 83% of farmers now using 2WT. Whilst this change cannot be attributed to the project, it is clear evidence supporting the findings of the socio-economics team regarding the significant financial benefits to be achieved through mechanisation and intensification.

The work done within the ICE trials showing the potential impact of the adoption of triple cropping on productivity (15 t/ha to 20 t/ha) is significant. Furthermore, the work of the socio-economics team in providing insight into impediments to adoption should allow an informed approach to policy formulation around extension/adoption activities and any required legislation by the Royal Cambodian Government.

If the information regarding potential benefits and costs associated with mechanisation and intensification can be developed into training materials/packages and more widely disseminated, then it can be expected that it will have a significant impact in helping farmers make informed decisions regarding capital investment in farm power and machinery, and chemical inputs (herbicides, insecticides and fertiliser).

Other significant economic impacts include:

- Introduction of the drum seeder to Cambodia – 26 drum seeders were imported from Vietnam early in the project for project evaluation and local demonstrations in the three target provinces. During 2011-12, a large USAID funded *Cambodia Harvest* project (managed by Fintrac Inc.) across six provinces promoted drum seeders. There are also leaflets on the web that the project team developed in Khmer and gave soft copies to CARDI and iDE (P. Charlesworth) early in 2010 (http://asia.ifad.org/web/cambodia/). The ACIAR project's impact on drum seeder adoption is not easily quantified, yet it had a significant role in the early promotion of this technology among farmers via PDA staff in each province and genuine adoption among the partner institutions.
- Observed increases in wet season rice yield and income
- Increases in dry season rice yields
- Reduction in crop establishment costs – e.g. direct seeding rates have been shown to be able to be reduced from 400 kg/ha to as low as 80 kg/ha without yield penalty
- Yield improvements with correct herbicide usage – identification of the role of beneficial insects in controlling rice pest insects in Cambodia also has the potential to significantly reduce pesticide costs for Cambodian rice growers

Australia

- Zinc is essential to ensure seedling survival under flooded conditions and was shown to be limiting in some soils. Zinc can be provided through numerous fertilisers and it is important that it is placed with/nearby the seed to ensure access by the growing rice plant.
- Variation in zinc occurs across fields, particularly after land-forming and with different soil types. Seedling establishment can be greatly reduced when zinc is unavailable which leads to reduced grain yield and profitability.
- Recommendations around variety selection (Quest and Reiziq) and threshold field water salinity (< 2 dS/m) will be incorporated into Australian Rice Industry advisory packages.

Social impacts

There is evidence of better coordination among government extension agencies, NGOs and service providers for the judicious use of scarce research and extension resources in the development of rice industry.

Wider adoption and use of mechanisation has been observed during the life of the project, with increases in off-farm labour opportunities for farmers and the potential to improve family income.

Extension services using the farmer field school (FFS) approach are now using participatory, discovery-based and experiential methods, following the new education paradigm of learning by doing.

More effective crop establishment has been demonstrated to boosts efficiencies and yields, thus supporting farming families. The related adoption has been slower and this impact more limited because of the removal of CAVAC extension capacity from the project mid-term in 2012.

The Cambodian drill is anticipated to provide farming families with a gender mainstreamed solution to establishing rice crops with a low labour burden, reducing drudgery components on rice establishment.

Environmental impacts

Cambodia

Based on knowledge gained from the project, exposed farmers have altered their decision-making on insect pest control to observe and analyse field situations carefully before applying insecticides. Consequently, the applications of insecticides are decreasing and some components of production costs are reduced.

Project results contribute to agricultural policy on the development, regulation and management of highly toxic agro-chemicals taking into account an environmentally friendly crop protection approach.

> "*FFS training has led to more sustainable and cost-effective production; reduced ecological disruption and environmental contamination, a lowering of public health risks from toxic residues in food; and improved livelihoods, biodiversity and marketability of produce. This has made a huge contribution to food security and safety, poverty alleviation, and ultimately to the national economic growth which are the priorities of the Royal Government policy and strategy"* (Ngnin Chhay, GDA, Cambodia).

In the context of a rapidly developing and poorly controlled pesticide usage in Cambodia, the promotion of safe and effective use of herbicides by the project as part of integrated weed management with mechanical/manual weeding of in-line crops, and use of quality seeds has reinforced the capacity among partners to continue to convey this message within the farming community. The importance of effective weed control on productivity and profitability was demonstrated by the project and is a key part of reducing the spread of threatening weeds in rice crops.

Australia

The use of saline-sodic groundwater to grow rice has severe deleterious effects on soil structure and long term productivity (results not reported) and can NOT be recommended.

8.7. Communication and dissemination activities

The full range of publications produced within the project are listed in Section 10.2.

The project has produced the following rice farming resources in Cambodia:

- 33,553 copies of manual on rice ecosystem rice variety and soil type
- 10,220 copies of manual on improved rice technology package
- 4,720 copies of rice soil poster
- 1,000 copies of weed identification manual translated and published in Khmer
- 10,000 General Directorate of Agriculture books on Integrated Technology of Rice Intensification
- 10,000 leaflets on rice production distributed to extension workers and farmers
- 10,000 posters on rice production distributed to extension workers.
- 30 sets of standing exhibition posters for Field Days.

The project conducted Farmer Field Days about:

- Assessment of performance of different rice establishment methods
- Farm machinery field days.

Australian component activities

Date	Audience	Location
Jan 2011	Dr Gurjeet Gill (Adelaide University) and visiting Indian scientists: Dr Ashok Kumar, Dr Dharam Bir (CCS Haryana Agricultural University), Dr Sohan Walla (Punjab Agricultural University) and Dr Raj K. Jat (CIMMYT)	Deniliquin, NSW
Mar 2011	Australian Rice Industry Field Day	Yanco, NSW
Mar 2011	Australian Society of Soil Scientists, Riverina branch	Deniliquin, NSW
Aug 2011	NSW DPI rice research & extension staff	Yanco, NSW
Nov 2011	Rural Industries Research & Development Corporation (RIRDC) Rice committee annual review	Yanco, NSW
Mar 2012	ACIAR project CSE 2009-037 mid-term review	Phnom Penh, Cambodia
Jul 2012	NSW DPI rice research & extension staff	Yanco, NSW
Oct 2012	ACIAR Lao and Cambodian visitors, plus Dr Neil Dalgleish (CSIRO)	Deniliquin, NSW
Nov 2012	RIRDC Rice annual review	Wagga Wagga, NSW
Feb 2013	Australian Society of Soil Scientists, Riverina branch	Jerilderie, NSW
Mar 2103	Australian Rice Industry Field Day	Conargo, NSW
Sept 2013	Victorian Government agency staff (CMA and Goulburn-Murray Water)	Deniliquin, NSW
Nov 2013	RIRDC Rice annual review	Yanco, NSW
Aug 2014	Mr Men Pagnchak Roat (CARDI), Mr Chea Sovandina (GDA) and Ms Toch Sokunthea (RUA), supported by Dr Bob Martin, toured NSW rice growing districts and workshopped socio economic data analysis with NSW DPI economists, improving the recommendations and conclusions of the project and building capacity within the Cambodian partners.	NSW

10 Conclusions and recommendations

8.8. Conclusions

Cambodia

The following findings of the socio-economics team are instructive:

- There is significant increase in the use of 2 wheel tractors for both seed bed preparation and irrigation, with draught animals being replaced by power tillers;
- A significantly high proportion (?%) of farmers use knapsack pumps;
- 2 ploughings for seed bed preparation are a common practice with mechanised systems (no adoption of zero till to date may reflect lower yields in some scenarios;
- A significantly high proportion of farmers (??%) in all the surveyed districts grow 2 crops a year on the whole farm;
- Wet seed hand broadcasting is the main method used for direct seeding rice. Few farmers use drum seeders in the surveyed areas, although many farmers know about this technology. This is despite the programs promoting drum seeders in areas of each province;
- None of the farmers use 4 wheel tractors or tractor driven seed drills. NB, 4 wheel tractors are widely used in other provinces for land preparation and seeding. These are generally contractors;
- Due to poor financial capacity, lack of credit support (30% interest rates) and reliable extension advice, most farmers use poor quality chemical inputs relying on unqualified sources of advice i.e. Chemical retailers and fellow farmers.

Key constraints and impediments to adoption of mechanisation and intensification (which appear to need to occur together to generate sufficient returns to pay for the capital investment) were identified:

- Labour/time constraints with a shift to double and triple cropping and limited windows of opportunity to maximise opportunity for contract work;
- Lack of access to irrigation water, availability and affordability of quality seeds, quality chemical inputs, knowledge of BMP, extension advice and inefficient marketing infrastructure;
- The high cost of borrowing with the primary source of borrowings (micro finance, money lenders, input providers) charging 30-36% on short to medium term loans. NB. The monthly interest rates for un-secured loans are around 5% and for secured loans, 2%. Farmers without land title or other collateral cannot get secured loans.

These findings are somewhat at odds with the key results from the experimental work which show:

- a 25% lift in rice productivity per annum is possible with a shift from double to triple cropping, with some short duration varieties identified as having great potential for triple cropping;
- Input cost reductions from a reduction in seeding rates from 3-400 kg/ha down to 80 kg/ha with a shift from hand broadcasting to drum seeding (Note: this is mitigated by a best practice need to use quality seeds, at a cost premium);

- the suitability and success of some of the machinery sowing technologies for wet/dry direct seeding in many parts of Cambodia (Both seed drills and drum seeder); These positives are mitigated by acknowledged limitations such as poor ergonomics and higher labour than current practice, respectively.
- The potential to lift farmer rice yields by 775 kg/ha/crop if best practice technical advice is adopted (farmer field school comparisons);
- The potential for alternative varieties with good disease tolerance (Sen Pidau, Chul'sa) to yield as well as the most popular variety (IR 504), leading to potential reductions in fungicide and insecticide applications.
- The significant impact of effective weed control on crop productivity (??t/ha) and profitability (??$/ha).

Seeding rates

Although increasing rice seeding rate reduces weed biomass, the combined results from 17 separate experiments suggest that the practice is not economically feasible when the cost of seed is taken into account. The results also suggest that the optimum seeding rate for weed-free broadcast wet-seeded rice is around 100 kg/ha.

Increasing rice seeding rates to suppress weed competition needs to be balanced against the risk of introduction of more weed seeds, new weed species or resistant biotypes should be taken within the context of an integrated weed management strategy as per Recommendation 2.

During the six month extension the project team had two opportunities to sit together to present results and work out how they fit together. This made a great contribution to the project being able to realise its true worth and produce outcomes that accurately reflect the depth of thought and effort that has gone into it over the past four years.

The other conclusion centres around the strong need for good extension/advisory networks with clear and appropriate recommendations for farmers built into strong training packages. The GDA Farmer Field Schools have showed considerable a success in increasing farmer capacity, despite the loss of CAVAC as a key partner in this role from 2012. These efforts should continue to be supported and would provide a clear path to adoption of project-derived recommendations. Private sector one-stop-shop input sales outlets are developing rapidly in Cambodia and need to be considered as a serious option for the delivery of extension information and advice.

Australia

The GA and IBA seed treatments were found to be of no significant benefit in the field and there would be little value in continuing research into them in the future.

8.9. Recommendations

Cambodia

There is a need to develop a more robust methodology for socio-economic research (farmer surveys) and basic economic analysis of agronomic data that will facilitate analysis and deliver outputs more efficiently.

Extension materials are needed for:

- Raising productivity of dry season rice cropping;
- Herbicide choice rate and timing guide for wet seeding, dry seeding and transplanting. There is an urgent need to promote integrated weed management

guidelines that include a strategy to manage herbicide resistance and chemical application safety;

- Rice nutrient management based on cropping intensity, season and soil type is required. Cambodian farmers are under-fertilising and extension material needs to address this issue. More on-farm demonstration might help redress this limitation, including the use of regenerating dry-season legume break-crops;
- Promoting refined seeding rate recommendations in relation to crop establishment method;
- Insect pest management guide in rice (based on GDA's IPM studies and elsewhere). NB, CAVAC has developed a disease and insect management decision support system which is being evaluated by pesticide distributor Nokor Thom. Any future work in this area should be done with reference to the CAVAC tool.
- Promoting the optimum use of mechanised wet and dry direct seeding, including equipment maintenance and operation. This includes i) developing the current drum seeding brochure to reflect Cambodian learning and cropping conditions, and ii) developing a similar brochure for mechanised drill seeding of rice. These technical 'how to' brochures would be aimed at farmers via private sector retailers and extension advisors

Researcher and extension guides for:

- Weed management options by establishment method, levels of weed infestation and problem species. NB, once again, this needs to be done within the context of integrated weed management, herbicide resistance management and application safety;
- An improved adaptive machinery research methodology (on-farm evaluation and performance improvement, agronomic responses) aimed at improving machinery productivity (work and labour efficiency, crop establishment efficacy). NB, the first step is to continue facilitating farmer evaluation and then identify priorities for follow-on research and development. However, the project is at a critical stage where there is a need to support the industry partner with technology fine-tuning and accurately gauging farmer feedback to ensure these efforts are not wasted on the back of technical limitations.

Guidelines for rice establishment methods:

- Refine the rice establishment method guide across seasons, topo-sequence position and soil type (and develop into a researcher/extension guide). NB, It is suggested that an adaptation of the Cropcheck model is the next step to provide on-farm information to validate guidelines;
- Develop a extension/farmer-focussed machinery choice and operation guide for a given rice establishment option, soil type, topo-sequence position, season and economics. These mechanisation adoption guides would be complementary to the 'how to' technical brochures specified above.

The Cambodian drill has generated strong interest and is ready for some targeted farmer evaluation. This should include a structured feedback process to guide and assist further development in collaboration with the manufacturers. NB, United Cambodia Agri. (UCA) is marketing drum and drill seeders. They provide agronomic and technical advice to farmers and can help with this process.

More efforts (policy and research) are required to promote early maturing rice varieties in Cambodia in terms of their suitability for triple cropping, pest resistance, water and nutrient use, and availability and access of seed by farmers.

Australia

Rice growers and advisors need to consider the potential need and benefit of applying additional phosphorus and zinc to cut locations within rice fields. Cut and fill effects are apparent over long time scales.

Determining the requirement for zinc and phosphorus should be based on comprehensive soil tests with sampling based on cut/fill maps, yield or NDVI maps of previous crops.

Zinc needs to be placed close to the seed to ensure access to zinc by growing rice plants. Seedcoats and compound fertilisers sown with the seed when direct drilling are effective.

Quest was the most tolerant of the Australian lines across all trials. The current main Australian lines (Reiziq, Sherpa) appear to be as salt tolerant as the IRRI tolerant check lines (IR45427 and Amber 33).

There is no evidence to support raising the 2 dS/m field water threshold (season average) some evidence that it should be lowered to 1.5 dS/m for some lines.

Future project management

It is hoped that this report is an accurate reflection of the success of this project in generating significant new knowledge and research and extension capacity within Cambodia. However, this has not occurred without problems and there are lessons to be learnt by all parties.

The project was an experiment for ACIAR in that it included multiple Cambodian partners/agencies and required them to work together where there was little or no history of that occurring before-hand and despite differences in charter and function. The role of the ACIAR in country research manager under the CAVAC umbrella was critical with regards to more effectively co-ordinating, liaising, organising, mentoring and holding people/organisations on task and to timelines in this multi-partner and multi-national project (NSW DPI, Uni SA, IRRI, CARDI, GDA, RUA). The loss of the CAVAC link in early 2012, without a corresponding revision of project outputs - had a big foreseeable impact in the project's ability to deliver timely industry and adoption impacts. Additionally, the stepping down of the project Leader in early 2014 had a significant impact on the project completion (seen in the team's difficulties to meet some final milestones and synthesise all project results on-time).

It is recommended that future multi-partner projects such as this have on-going positions for an in-county Project Manager with cross-cultural capability (to manage people and liaise across agencies) as well as having a Project Leader at a project hosting institution (to lead scientific endeavour). Also, dedicated face to face mentoring during key project activities (such as survey development, field trials with machinery, seeder prototype development with industry) was a fruitful format of engagement for international project partners achieving more effective team and capacity building outcomes and should be more widely applied in future projects.

The project was granted a no-cost extension (April-Sept 2014) in order to undertake the following activities:

1. Complete the analysis of the socio-economic data/surveys and integrate findings into mechanisation and intensification recommendations arising from the trial work;
2. Collate all trial data, determine which trials can be combined for analysis, conduct statistical analyses to determine significance of treatment effects, and derive recommendations;
3. Conduct a facilitated workshop involving all participants to bring the combined dataset together and agree on the findings and how recommendations can be used to inform advisory/extension activity and/or policy.

Whilst this project has resulted in happy and productive partnerships between Cambodian and international partners, the Australian research activities and Cambodian activities could have been more strongly linked and coordinated (e.g. rice salinity research). In recognising this, it is hoped the over-sight can be corrected in future projects.

It is recommended that greater integration of Australian and Cambodian objectives be considered in future projects. More regular in-country activities operating side by side under a mentoring format would also help to maintain momentum and progress, and more effectively benefit research outcome applicability to both Cambodia and Australia.

Other project management suggestions include:

- The project aimed to bring together 3 very different Cambodian institutions, each with their own specific strength and focus, namely research (CARDI), extension (GDA) and education (RUA). Future project management should implement collaboration formats that are better able to draw on the strength of each one and promote knowledge and experience sharing on overlapping activities such as research, training, field demonstrations and promotions. Agreements on collaboration formats with clear roles and responsibilities, any IP implications should initially be aimed at to enable the process.
- There is a greater need in multi-partner projects such as this for clearer definition of tasks, outputs and deadlines for all individuals and teams within contracts, and for all partners to be led through the contract so they understand what constitutes their contribution.
- Potential for individual sub-contracts. There were a number of instances where project work was delayed because of the lack of immediate cash funds to buy spare parts or other sundries. In effect, a major output was held up until one of the international partners arrived to approve expenditure of $20 cash for a broken part.
- While a process of trial design, implementation and result presentation was closely adhered to for every cropping season, a lack of on-going full detailed reporting has made the task of developing the final report a major activity generating significant delays. Future project management need to apply regular milestones of full reporting with a supporting process of mentoring aiming at capacity development. The use of reporting templates would facilitate this activity.

8.10. Recommendations arising after the six-month extension

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Desbiolles J, Chea S, Som B, Pao S, Singh R, Chan S, Justice S and Meisner C. (2012) Two wheel tractor mechanisation in Cambodia- context, experience and opportunities with mechanised dry direct seeding of rice. Presentation at CIMMYT workshop- Research design for mechanisation entrepreneurship to leverage sustainable intensification in rainfed areas of eastern and southern Africa. Addis Ababa, 10-14 April 2012.

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Singh, R., 'Socio-economic Assessment of Baseline Farmers Survey of the Rainfed Lowland Rice Eco Systems in Kampot province in Cambodia', presentation at the Provincial Directorate of Extension, Kampot, 28 October 2011

Project related presentations: National, international conferences and workshops

Chauhan BS, Johnson DE. 2010. Opportunities to improve cultural approaches to manage weeds in direct-seeded rice. Paper presented at the 17th Australasian weeds conference, 26-30 September 2010, Christchurch, New Zealand.

Chuong S., S. Ro and K. Khun (2014) "Rice Status in Cambodia". Rice in Asia and Africa: Innovations in Production and Emerging Trends in Supply and Demand, 21-23 January 2014 TOKYO University, Tokyo, Japan

Ouk Makara attended the Annual Review and planning meeting of the Consortium for the Unfavorable Rice Environments in April 2013 in Indonesia, April 2012 in Thailand, April 2011 in Nepal and May 2010 in Cambodia

Vang (2011). *Role for Farming Systems and CA for Food Security in Cambodia*. Presentation at the Workshop on "Reduced labour for lower Mekong farming". 5th World Congress on Conservation Agriculture and 3rd Farming System Development Conference, Sept 25-29 2011, Brisbane Convention Centre, Brisbane, Australia. Viewed on 30 October 2011 at http://www.slideshare.net/johick68/role-for-farming-systems-and-ca-for-food-security-in-cambodia-vang

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Beecher G (2011) Improving rice establishment and productivity in Cambodia and Australia presentation on ACIAR CSE 2009 037 to ASSSI Riverina Branch Yanco Agricultural Institute 9 December 2011

North S. (2011) Rice salinity Tolerance NSW DPI Rice Research & Extension meeting, Yanco Agricultural Institute 5 August 2011

North S. (2011)-Salinity tolerance of Australian rice cultivars. RIRDC Rice R&D meeting, Yanco Agricultural Institute Yanco) 2 Nov 2011

Project visits in Australia

Mr Chea Sovandina I(GDA DAEng), Mr Men Panchat Roat (CARDI), Ms Toch Sokunthea (RUA) visited the Economic groups at Armidale and Wagga Wagga in Australia between 9-21 August 2014, for data analysis capacity building and final report survey analysis.

Mr Ngin Chhay and Mr Lim Vanndy participated in a training visit to rice growing areas of southern NSW in October 2012 (Crawford Fund training). Mr Ngin Chhay and Mr Lim Vanndy make presentations to Yanco Agricultural Institute staff on rice growing in Cambodia and on rice nutrition in Cambodia respectively. As part of their visit, Mr Chhay and Mr Vanndy were exposed to the full gamut of technology used in the Australian rice industry – sowing, harvesting, growing and managing, and the pure seed scheme.

Visit by Touch Veasna (CARDI) to Uni. of New England, Armidale NSW to attend the 16th Agronomy Conference, 14-18th October 2012. Veasna also went to Uni of Queensland on another ACIAR project activity.

Visit to Yanco Agricultural Station by scientists from Adelaide University (Dr Gurjeet Gill), CCS Haryana Agricultural University (Dr Ashok Kumar & Dr Dharam Bir), Punjab Agricultural University (Dr Sohan S. Walia) and CIMMYT (Dr Raj K. Jat)

Other project related communications: newsletters, brochures, factsheets, posters

Jack Desbiolles (2013). “Tractor powered drum seeding: A Cambodian development ”. CA two wheel tractors E-newsletter, April 2013, ed. R. Jeff Esdaile

CARDI (2011) Using a drum seeder to sow pre-germinated seeds – IRRI brochure [in Khmer].

CARDI (2011) ROGRO operator’s manual by Jeff Esdaile – in Khmer

Desbiolles J and J Esdaile (2011) Rogro drill trouble-shooting reference. 3p. – (CARDI in Khmer 2014)

Desbiolles J (2011) Procedure to calibrate a 2WT seed drill. 4p. – CARDI Khmer translation (2011)

CARDI (2013) Rogro seed and fertiliser drill technology and field operation. A0 Poster [in Khmer]

CARDI (2012) Manual for rice ecosystems, main rice growing soils, main characteristics of 10 rice varieties, and seed purification method for farmers in Cambodia

CARDI (2011) Manual for improved rice production technology in Cambodia

CARDI (2012) Profiles of rice soils and recommended rates of NPK fertilizers use for rice

IRRI (2011) A guide for identification of weeds in paddy rice in Asia (in Khmer 2012)

CARDI publications (In Khmer) for the project

Title publication	Printed	Distributed	Year
Manual for rice ecosystems, main rice growing soils, main characteristics of 10 rice varieties, and seed purification method for farmers in Cambodia	38,000	33,553	2011
Manual for improved rice production technology in Cambodia	2,000	10,220	2011
Poster on profile of rice soils and recommended rates of NPK fertilizers use for rice (SW)	5,550	4,929	2011
Farmer notes	9,160	3,476	2011
A guide for identification of weeds in paddy rice in Asia (PP)	1,500	n/a	2012
Poster (Ag Engineering)	1	n/a	2013

ACIAR mid-term review presentations: CARDI, Phnom Penh, 1 March 2012.

Singh, R., El, S., Chuong, S., Chea, S., Thaung, P., and Coombes, N., 'Socio-Economic Assessment of Baseline Survey of the Rainfed Lowland Rice Eco Systems in Cambodia – Province Level Analysis', presentation (by El Sotheary)

Chea S, Som B, Pao S, Desbiolles J and Justice S (2012). "Mechanisation component: Cambodia context, Activities to date, Project strategies. presentation by J. Desbiolles.

North, S (2012) Objective 6: problems with rice seedling establishment in Australia.

Singh R., El, S., Chuong, S., Chea, S. and Thaung, P.(2011), 'Socio-economic Assessment of Baseline Farmers Survey of the Rainfed Lowland Rice Eco Systems in Kampong Thom province in Cambodia, presentation to the ACIAR project (ACIAR CSE/2009/37) Annual Review Meeting, Royal University of Agriculture, Phnom Penh, 25-26 Oct 2011

Singh R., El, S., Chuong, S., Chea, S. and Thaung, P., (2011)'Socio-economic Assessment of Baseline Farmers Survey of the Rainfed Lowland Rice Eco Systems in Takeo province in Cambodia, presentation to the ACIAR project (ACIAR CSE/2009/37) Annual Review Meeting, Royal University of Agriculture, Phnom Penh, 25-26 Oct 2011

Singh R., El, S., Chuong, S., Chea, S. and Thaung, P.,(2011) 'Socio-economic Assessment of Baseline Farmers Survey of the Rainfed Lowland Rice Eco Systems in Kampot province in Cambodia, presentation to the ACIAR project (ACIAR CSE/2009/37) Annual Review Meeting, Royal University of Agriculture, Phnom Penh, 25-26 Oct 2011

12 Appendices

Appendix 1. Exit survey – summary of methods used.

Activities	Farmer Focus Groups (FFGs)	Farmer Survey
Methodology	2 districts per site * 5 sites = 10 districts Steung Sen, Baray, Angkor Borei, Kiri Vong, Tram Kok, Bati, Chum Kiri Chuk, Chhuok, Chum Kiri 2 communes/districts = 20 communes - 1 village/commune = 20 villages Within or nearby the project experimental zones	
	1 FFG/village = 20 groups	10 farmers/village = 200 farmers
	6-11 farmers/group (8-9 average)	Simple random sampling
	20-30% female/group	
	Stratified by farm size: small, medium and large (1.0ha; 1-2ha; >2ha)	
Data collection	In August 2013	In August 2013
	By CARDI (Kampot & Takeo) and GDA (Kampong Thom)	By RUA (Kampot & Takeo) and GDA (Kampong Thom)
	Collaborated with PDA or Agricultural dept. at district level.	
	Key info. collected from PDA or district level	
	Selection of villages with suggestion from PDA/district level agents	
Data entry	MS Excel format Prepared by CARDI	SPSS format Coded by CARDI, entered by RUA and GDA
	Checking errors and fix up by socio economic team.	
	Converting data from local unit (yield, size, cost, etc.)	
Data Analysis and reporting	NSW DPI	

Appendix 2. Synopsis of district practice rice establishment techniques used across lowland rice eco-systems by toposequence

	Seasons			
	Early wet season (SI)	**Main wet season**	**Recession rice (dry season)**	**irrigated rice (dry season)**
Rice varieties	short duration, non-photosensitive IR66/IR504 (non rice crops in upper fields mostly)	both photosensitive/non-photosensitive, early to late maturity subject to toposequence	short duration, non-photosensitive (IR66, IR504, Chul'sa, Sen Pidao)	short duration, non-photosensitive (IR66, IR504, Chul'sa, Sen Pidao), opportunities for non-rice crops
Low lying fields	i) transplanting ii) wet seed broadcasting iii) dry seed broadcasting	i) (earlier) transplanting with late maturing cv. - Note: less and less: deep water rice varieties	Later: i) wet seed broadcasting , ii) parachute transplanting* and iii) transplanting	i) wet seed broadcasting , ii) transplanting
Middle	i) transplanting ii) wet seed broadcasting iii) dry seed broadcasting	i) Transplanting (medium duration cv.)	i) wet seed broadcasting , ii) parachute transplanting* and iii) transplanting	i) wet seed broadcasting , ii) transplanting
Upper fields	i) wet seed broadcasting ii) dry seed broadcasting iii) transplanting	i) (later) transplanting (e.g.medium and short duration cv.) ii) dry/wet seed broadcasting (e.g. IR504/IR66)	Earlier: i) wet seed broadcasting , ii) parachute transplanting* and iii) transplanting	i) wet seed broadcasting , ii) transplanting

Sources: benchmarking survey + FFDG + CARDI/GDA/RUA experiences

* in limited areas only

Appendix 3. Crop establishment method graphs (related to discussion on crop establishment methods)

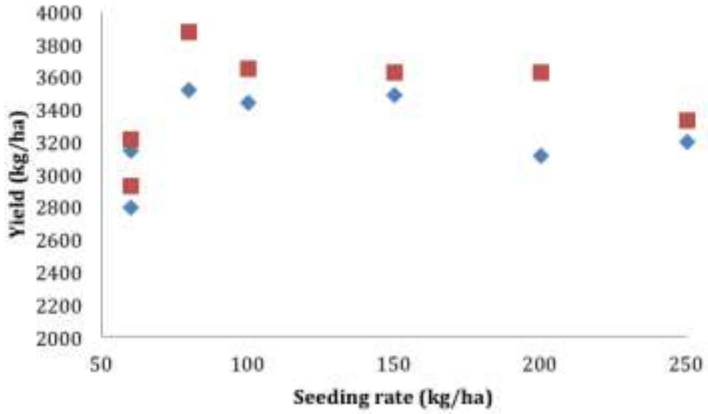

Figure 12.1. Effect of seeding rate on paddy yield in the 2010 dry season at Kampong Speu (red squares hand weeded, blue diamonds non-weeded).

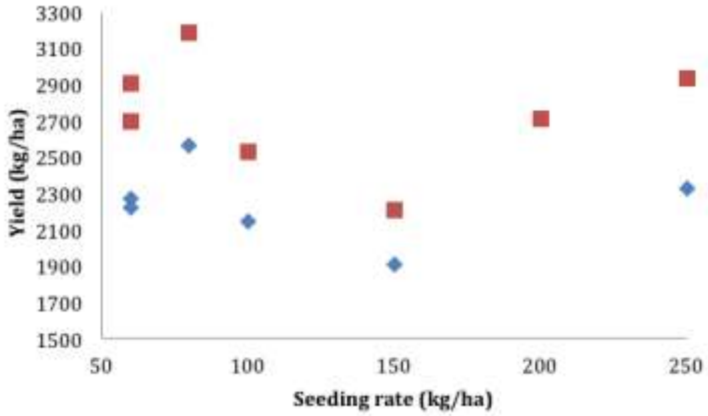

Figure 12.2. Effect of seeding rate on paddy yield in the 2010 wet season at Kampong Speu (red squares hand weeded, blue diamonds non-weeded).

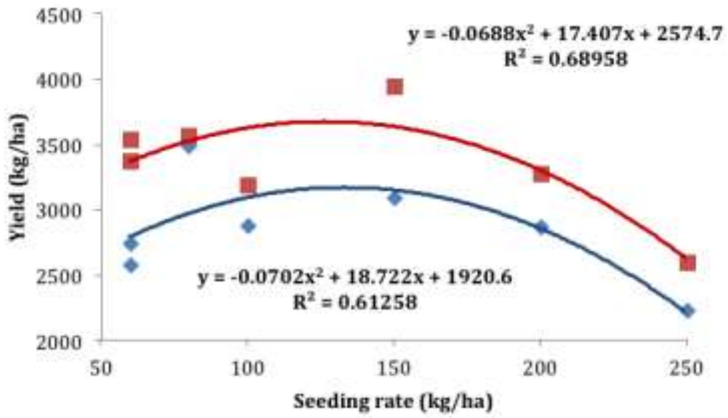

Figure 12.3. Effect of seeding rate on paddy yield in the 2010 dry season at Kampong Thom (red squares hand weeded, blue diamonds non-weeded).

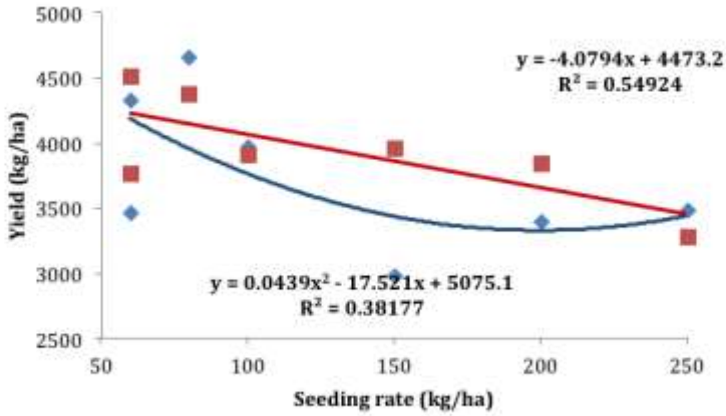

Figure 12.4. Effect of seeding rate on paddy yield in the 2010 wet season at Kampong Thom (red squares hand weeded, blue diamonds non-weeded).

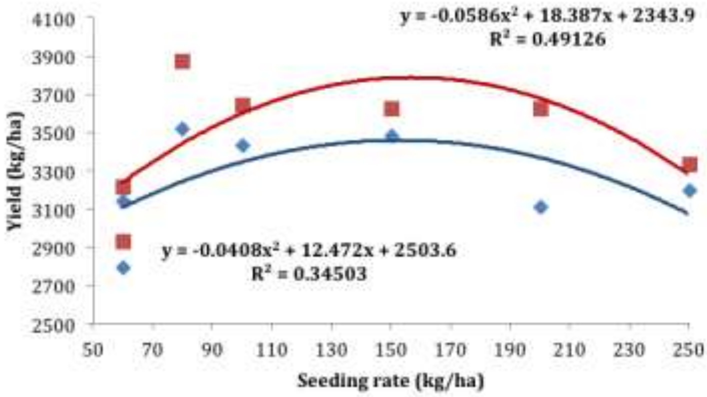

Figure 12.5. Effect of seeding rate on paddy yield in the 2010 dry season at Prey Veng (red squares hand weeded, blue diamonds non-weeded).

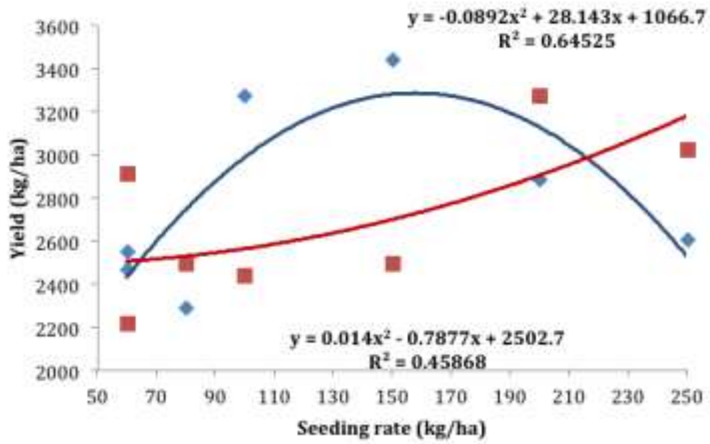

Figure 12.6. Effect of seeding rate on paddy yield in the 2010 wet season at Prey Veng (red squares hand weeded, blue diamonds non-weeded).

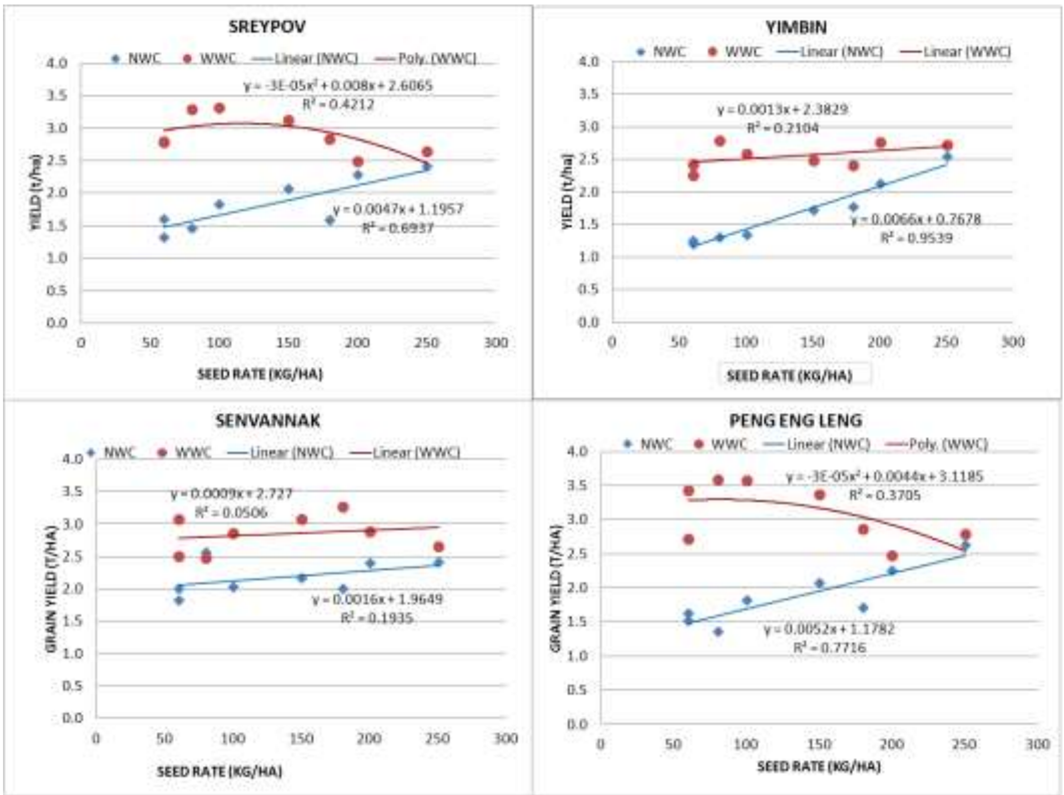

Figure 12.7. Effect of seeding rate on paddy yield at four locations (red circles hand weeded, blue diamonds non-weeded).

Appendix 4. Effect of establishment method on weed biomass and species dynamics.

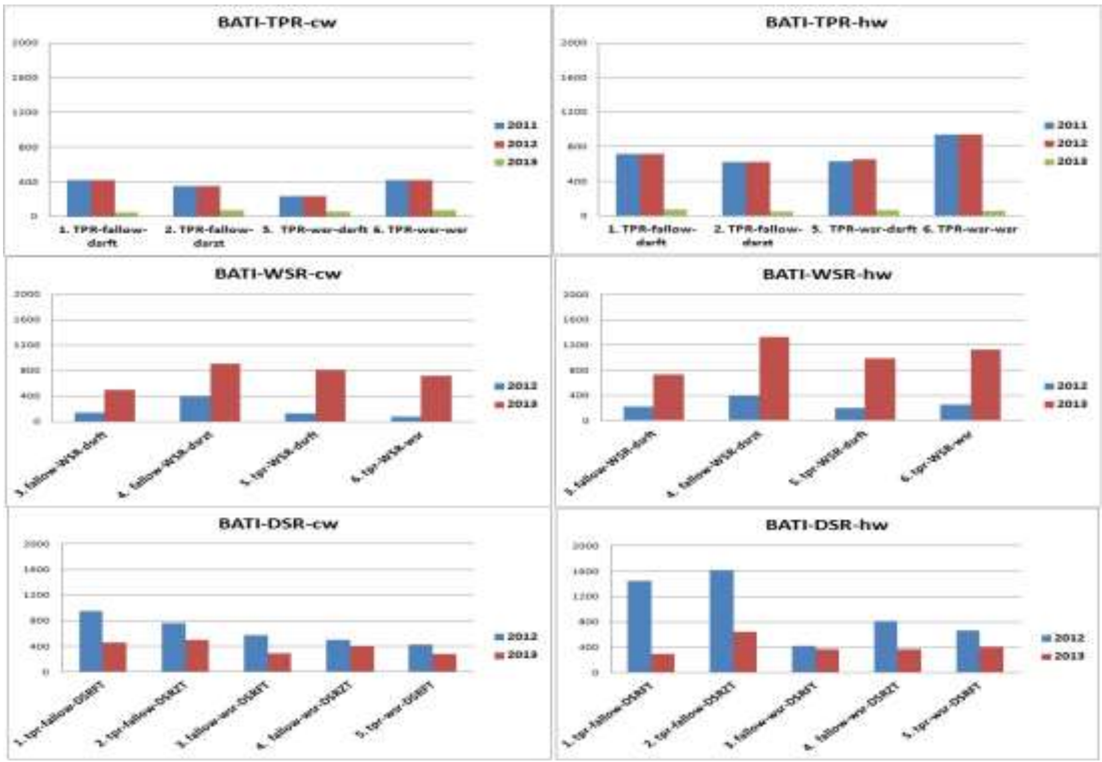

Figure 12.8. ICE experiment: Effect of different establishment methods on weed biomass at Bati Station in Takeo (kg/ha).

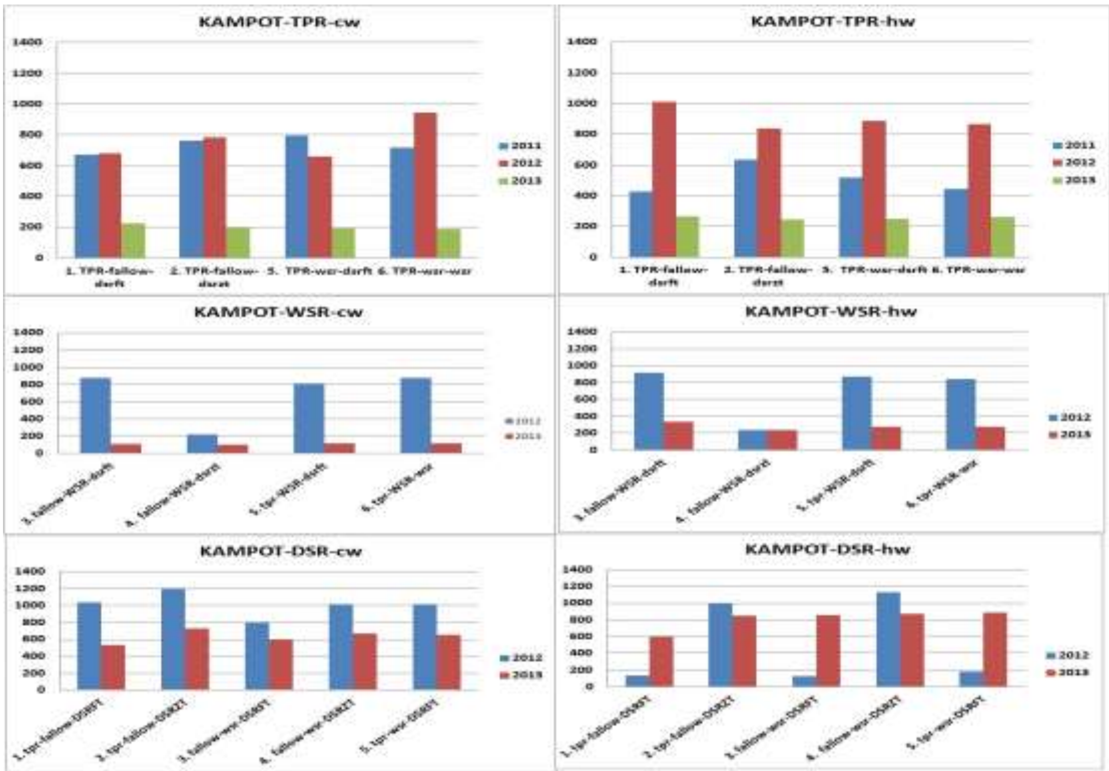

Figure 12.9. ICE experiment: Effect of different establishment methods on weed biomass in Kampot (kg/ha).

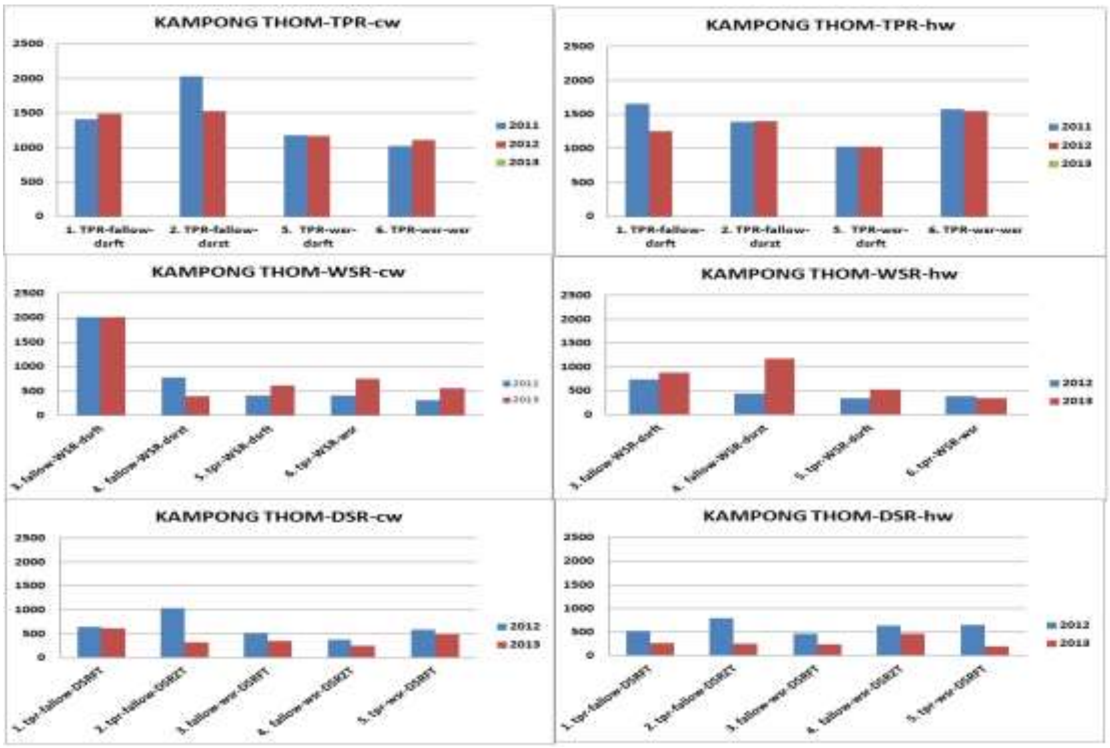

Figure 12.10. ICE experiment: Effect of different establishment methods on weed biomass in Kampong Thom (kg/ha).

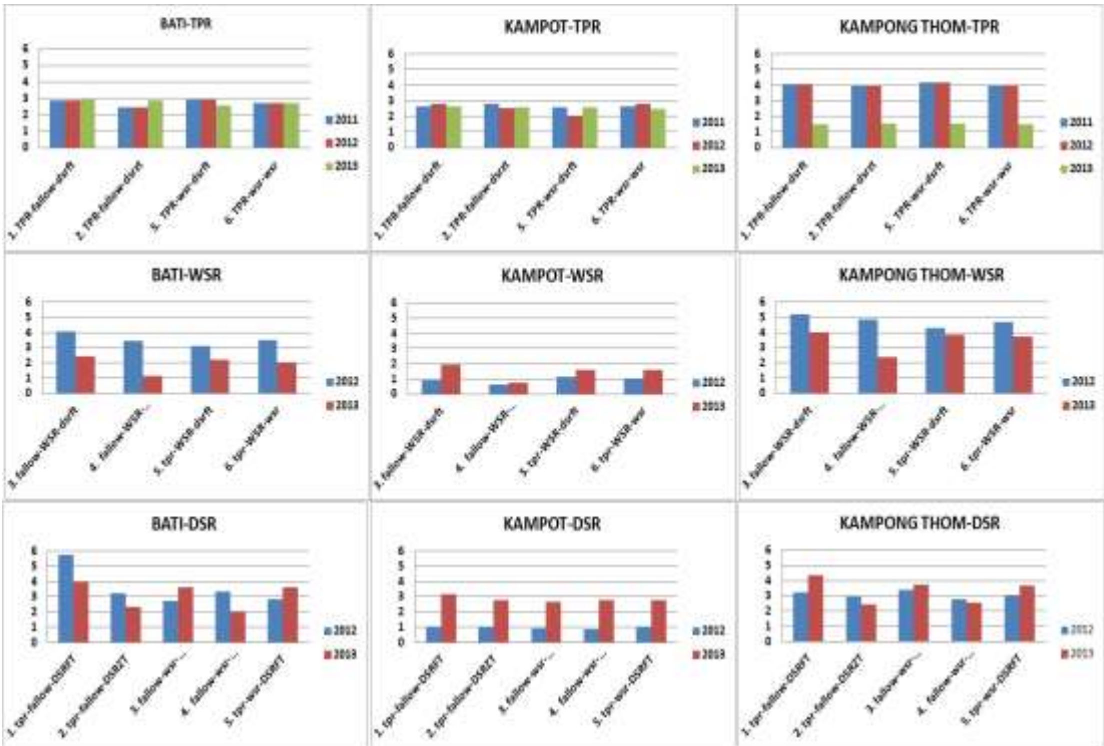

Figure 12.11. ICE experiment: Synopsis of different establishment methods on grain yield of rice (t/ha).

Appendix 5. Changes in weed species composition between 2012 and 2013.

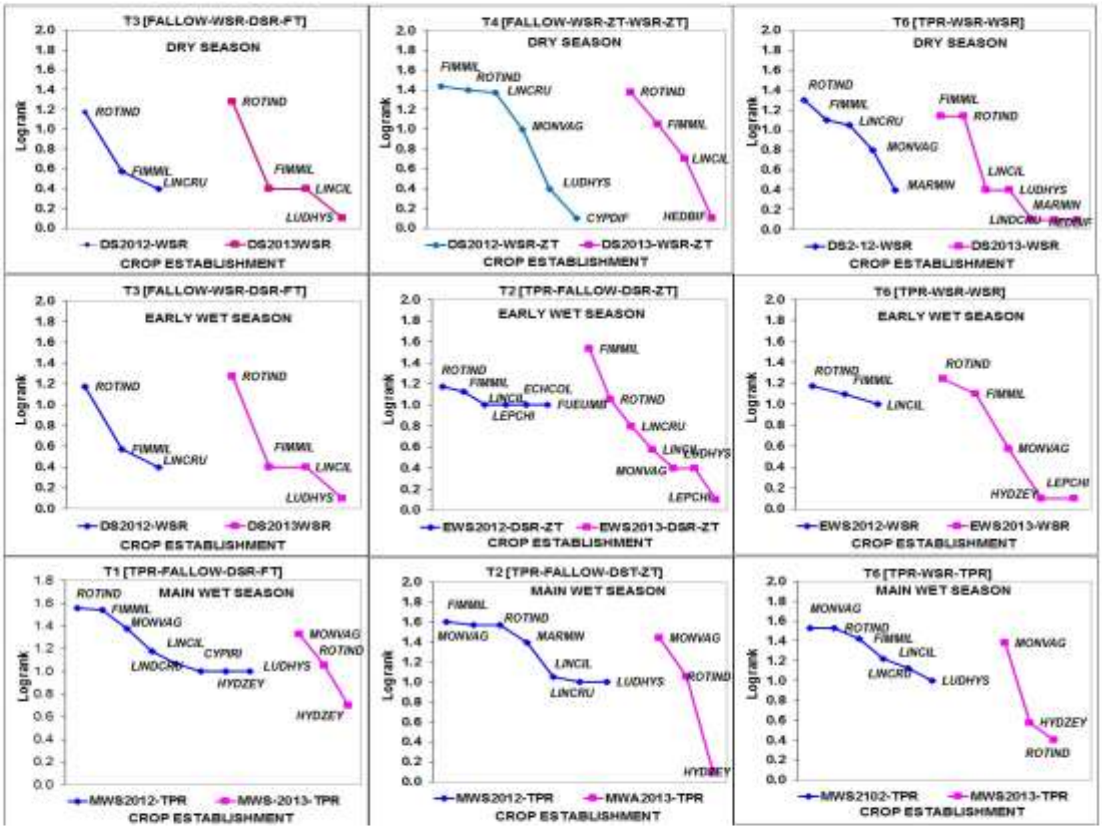

Figure 12.12. ICE experiment: Effect of different establishment methods on weed species composition at Bati Station site in Takeo.

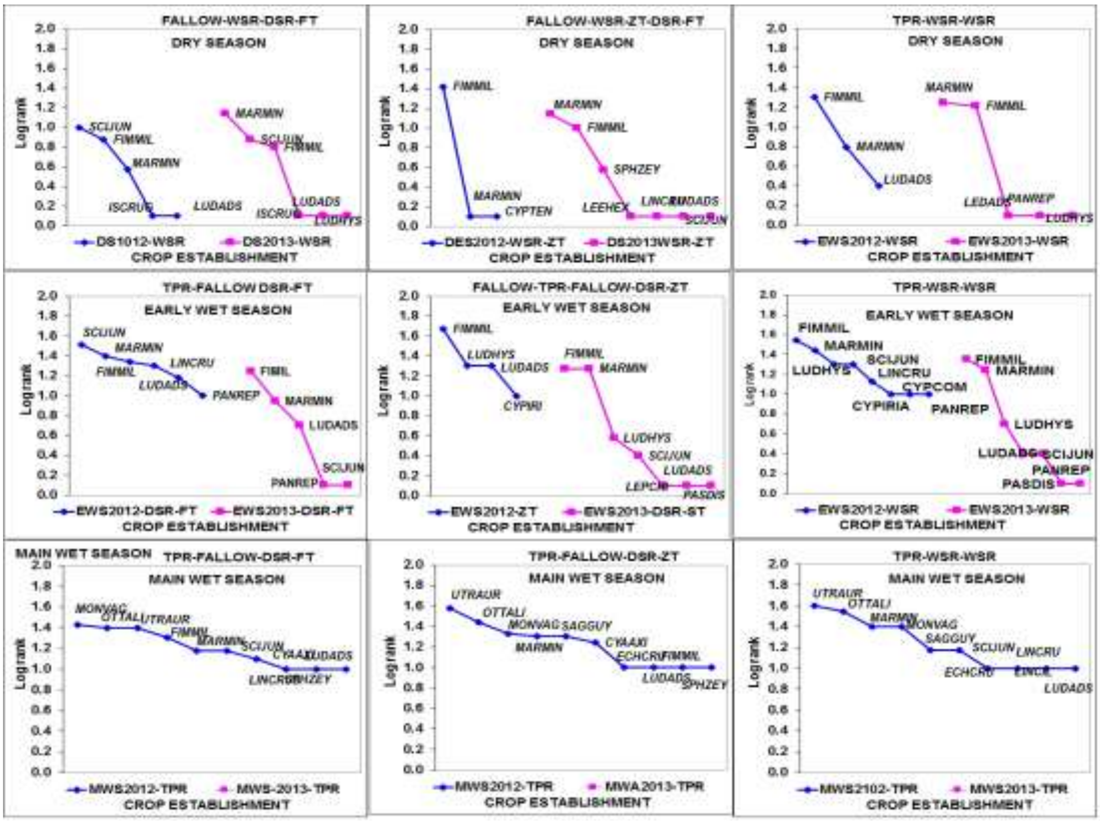

Figure 12.13. ICE experiment: Effect of different establishment methods on weed species composition at the Kampong Thom site.

Appendix 6. ICE grain yield analysis.

Neil Coombes, Biometrician, NSW DPI

The ICE experiments were set up at Bati Research Station, Takeo (BATI), CARDI, Kampong Thom (KGT), Kampot (KPT) and RUA. Each experiment examined 6 cropping systems over three rice growing seasons per year and two cycles of the sequence. Seven crops were grown in the sequence and labelled as follows:

1. C1MWS11 main wet season in 2011;
2. C2DS12 dry season in 2012;
3. C3EWS12 early wet season in 2012;
4. C4MWS12 main wet season in 2012;
5. C5DS13 dry season in 2013;
6. C6EWS13 early wet season in 2013;
7. C7MWS13 main wet season in 2013.

Table 12.1. Crop sequences for the six rotations.

Rotation	C1MWS11	C2DS12	C3EWS12	C4MWS12	C5DS13	C6EWS13	C7MWS13
1	TRP*	Fallow	DSR-FT	TRP	Fallow	DSR-FT	TRP
2	TRP	Fallow	DSR-ZT	TRP	Fallow	DSR-ZT	TRP
3	Fallow	WS	DSR-FT	Fallow	WS	DSR-FT	Fallow
4	Fallow	WS-ZT	DSR-ZT	Fallow	WS-ZT	DSR-ZT	Fallow
5	TRP	WS	DSR-FT	TRP	WS	DSR-FT	TRP
6	TRP	WS	WS	TRP	WS	WS	TRP

* Codes: FT=full tillage, ZT=zero tillage. Seeding methods: TRP=transplanting, DSR=dry seeding, WS=wet seeding.

There were no differences in the way that the MWS crops were managed. So effectively for C1MWS11 rotation treatments 1, 2, 5 and 6 had the same treatment in 2011, so the costs and yields associated with those treatments, apart from the additional weed treatment, should be the same within each site. Similarly treatments 5 and 6 had the same management for the next crop C2DS12 and so the costs and yields associated with those treatments, apart from weed treatment, should be the same within each site. The TRT codes were adjusted in seasons C1MWS11 and C2DS12 to reflect this in a factor called TRUTRT. From season C3EWS12 the coding for TRT and TRUTRT were identical.

Linear mixed models were used to analyse the grain yield, GY, from the five sites. The structure of the each experiment was a split-plot with four replicates at each site. The main plot was the rotation treatment which specified a tillage and seeding combination as in Table 12.1. Main plots were split for weeding treatments:

- CW, complete weeding - herbicide treatment plus one hand weeding;
- HW, one hand weeding at 30 days after seeding/transplanting.

A linear mixed model was fitted to grain yield in the R statistical package using asreml-R. The fixed treatments in the full model were the combinations up to the 4-way interaction of LOC*TRUTRT*WC*SEASON. The random model allowed for differing variability at each location, while _fitting effects for replicates, main plots and weed control sub-plots.

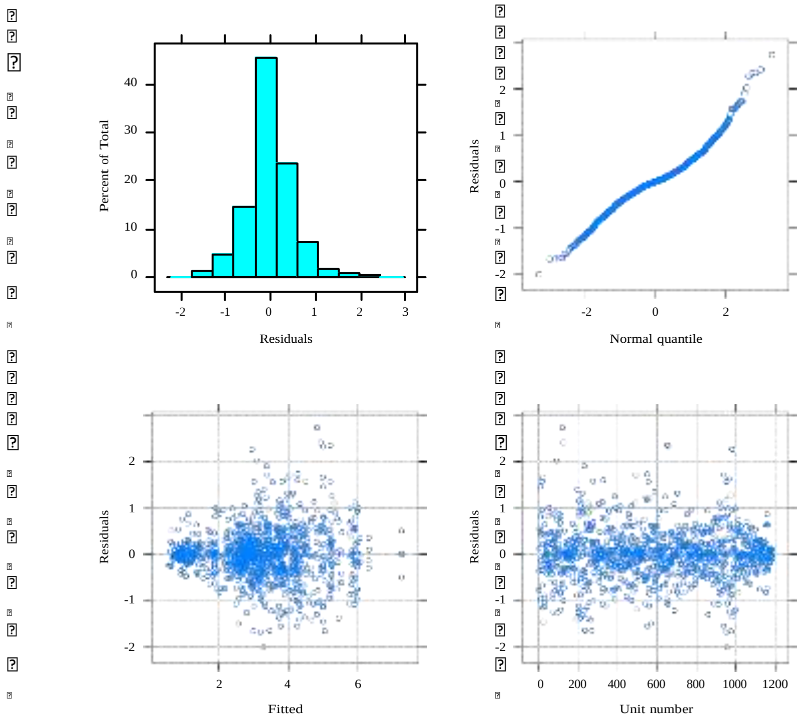

Figure 12.14: Residual plot of the analysis of GY, untransformed.

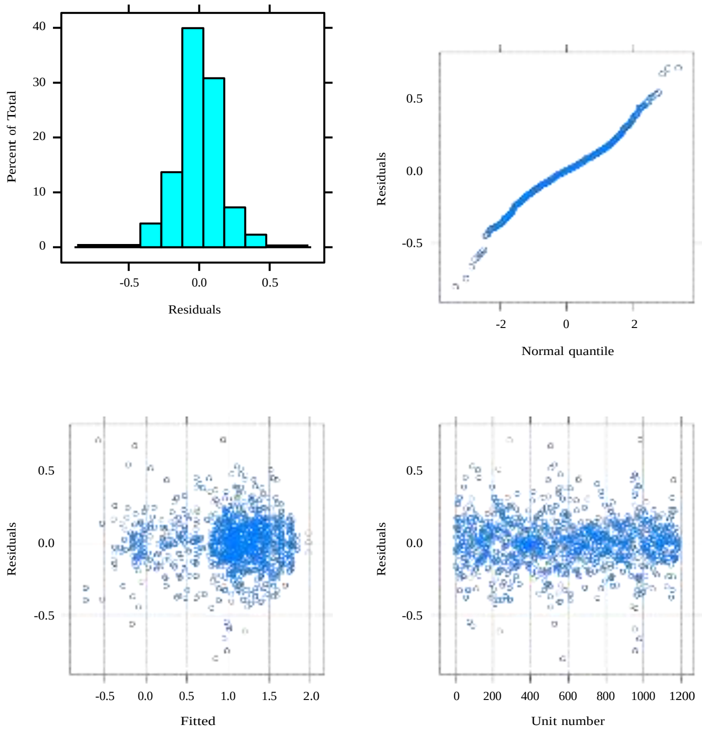

Figure 12.15: Residual plot of the analysis of `lnGY`.

Figure 12.15 shows that there is a clear mean-variance relationship in the residuals so that a transformation of GY is necessary. A square root transformation of GY was not sufficient to remove the mean-variance relationship so natural logs were taken, lnGY = loge(GY). The model was re-fitted to analyse lnGY.

Table 12.2: Wald statistics for fixed effects from the analysis of lnGY shows the final two terms, LOC:TRUTRT:WC:SEASON and TRUTRT:WC:SEASON are not significant and can be dropped from the model.

Table 12.2: Wald statistics for fixed effects from the analysis of lnGY

	Df	Sum of Sq	Wald statistic	Pr (Chisq)
(Intercept)	1	714.80	19216.09	0.00
LOC	4	22.73	611.07	0.00
TRUTRT	5	29.39	789.99	0.00
WC	1	0.05	1.31	0.25
SEASON	6	9.37	252.02	0.00
LOC:TRUTRT	20	55.31	1486.80	0.00
LOC:WC	4	0.68	18.41	0.00
TRUTRT:WC	5	0.10	2.61	0.76
LOC:SEASON	23	85.08	2287.32	0.00
TRUTRT:SEASON	16	6.09	163.61	0.00
WC:SEASON	6	1.22	32.76	0.00
LOC:TRUTRT:WC	20	1.12	30.22	0.07
LOC:TRUTRT:SEASON	61	13.26	356.41	0.00
LOC:WC:SEASON	23	1.69	45.49	0.00
TRUTRT:WC:SEASON	16	0.43	11.57	0.77
LOC:TRUTRT:WC:SEASON	61	1.95	52.45	0.77
Residual (MS)		0.04		

Predictions were made from this final model to get estimates of lnGY for each treatment combination.

Table 12.3: Wald statistics for fixed effects from the final model in the analysis of lnGY

	Df	denDF	F.inc	Pr
(Intercept)	1.00	19.90	19360.00	0.00
LOC	4.00	4.80	111.30	0.00
TRUTRT	5.00	348.70	159.80	0.00
WC	1.00	308.10	1.54	0.22
SEASON	6.00	935.30	42.55	0.00
LOC:TRUTRT	20.00	150.40	73.20	0.00
LOC:WC	4.00	168.00	4.80	0.00
TRUTRT:WC	5.00	467.40	0.54	0.74
LOC:SEASON	23.00	898.70	100.60	0.00
TRUTRT:SEASON	16.00	917.40	10.36	0.00
WC:SEASON	6.00	924.60	5.54	0.00
LOC:TRUTRT:WC	20.00	396.80	1.53	0.07
LOC:TRUTRT:SEASON	61.00	916.30	5.92	0.00
LOC:WC:SEASON	23.00	917.30	2.00	0.00

Table 12.4: Bati predicted grain yield (t/ha).

	C1MWS11	C2DS12	C3EWS12	C4MWS12	C5DS13	C6EWS13	C7MWS13
TRT1:CW	2.91		2.99	2.89		3.97	2.71
TRT1:HW	2.65		3.45	2.75		3.73	3.12
TRT2:CW			2.75	2.70		2.64	3.00
TRT2:HW			2.58	2.08		2.00	2.80
TRT3:CW		4.07	3.17		2.85	3.43	
TRT3:HW		3.82	3.42		1.81	3.01	
TRT4:CW		3.52	2.74		1.44	1.96	
TRT4:HW		3.18	2.84		0.87	1.66	
TRT5:CW		3.29	2.94	3.06	2.67	3.71	2.46
TRT5:HW		3.12	3.21	2.75	1.71	3.29	2.69
TRT6:CW			3.02	2.89	2.43	2.88	2.60
TRT6:HW			3.12	2.46	1.47	2.42	2.69

Table 12.5: CARDI predicted grain yield (t/ha).

	C1MWS11	C2DS12	C3EWS12	C4MWS12	C5DS13	C6EWS13	C7MWS13
TRT1:CW	5.14		3.72	2.93		3.85	3.06
TRT1:HW	4.92		3.73	2.88		3.83	3.27
TRT2:CW			0.88	3.25		1.35	3.02
TRT2:HW			0.85	3.06		1.29	3.08
TRT3:CW		3.05	4.55		4.20	4.96	
TRT3:HW		3.75	4.23		4.44	4.57	
TRT4:CW		0.74	0.89		1.24	1.05	
TRT4:HW		0.93	0.84		1.33	0.98	
TRT5:CW		3.14	4.77	3.73	4.03	4.18	3.17
TRT5:HW		3.60	4.14	3.17	3.98	3.60	2.93
TRT6:CW			3.78	2.95	3.79	3.75	3.25
TRT6:HW			3.89	2.97	4.42	3.82	3.55

Table 12.6: Kampong Thom predicted grain yield (t/ha).

	C1MWS11	C2DS12	C3EWS12	C4MWS12	C5DS13	C6EWS13	C7MWS13
TRT1:CW	3.70		3.00	3.61		4.23	1.41
TRT1:HW	4.19		3.40	4.45		4.37	1.52
TRT2:CW			2.95	3.84		2.60	1.60
TRT2:HW			2.80	3.95		2.25	1.45
TRT3:CW		5.27	3.45		4.48	3.99	
TRT3:HW		4.94	3.25		3.56	3.41	
TRT4:CW		4.75	2.67		2.49	2.60	
TRT4:HW		4.88	2.76		2.16	2.44	
TRT5:CW		4.33	2.90	3.77	4.07	3.71	1.53
TRT5:HW		4.49	3.02	4.25	3.57	3.51	1.51
TRT6:CW			3.17	3.58	3.86	3.82	1.45
TRT6:HW			3.36	4.12	3.45	3.68	1.47

Table 12.7: Kampot predicted grain yield (t/ha).

	C1MWS11	C2DS12	C3EWS12	C4MWS12	C5DS13	C6EWS13	C7MWS13
TRT1:CW	2.62		0.98	2.76		3.08	2.52
TRT1:HW	2.71		1.10	2.80		3.25	2.67
TRT2:CW			0.83	2.42		2.58	2.43
TRT2:HW			0.98	2.58		2.87	2.71
TRT3:CW		0.87	0.91		2.01	2.72	
TRT3:HW		0.94	0.94		1.80	2.62	
TRT4:CW		0.55	0.87		0.78	2.87	
TRT4:HW		0.56	0.84		0.66	2.60	
TRT5:CW		0.99	0.95	2.93	1.56	2.75	2.57
TRT5:HW		1.13	1.02	2.86	1.47	2.79	2.61
TRT6:CW			0.86	2.87	1.63	3.39	2.50
TRT6:HW			0.91	2.73	1.50	3.35	2.48

Table 12.8: RUA predicted grain yield (t/ha).

	C1MWS11	C2DS12	C3EWS12	C4MWS12	C5DS13	C6EWS13	C7MWS13
TRT1:CW	2.23		6.24	2.70		5.92	
TRT1:HW	1.84		6.89	2.52		5.60	
TRT2:CW			5.32	2.78		5.16	
TRT2:HW			6.13	2.71		5.09	
TRT3:CW		4.25	5.68		4.07	5.39	
TRT3:HW		4.23	6.44		3.89	5.23	
TRT4:CW		3.27	4.33		3.68	5.59	
TRT4:HW		3.69	5.57		3.99	6.15	
TRT5:CW		3.53	4.95	2.75	3.78	5.33	
TRT5:HW		3.91	6.24	2.92	4.01	5.76	
TRT6:CW			5.24	2.95	4.38	5.11	
TRT6:HW			6.02	2.85	4.23	5.02	

Appendix 7. Sensitivity analyses for adoption of mechanization options (from 7.3.7)

Adoption of drum seeder technology

While the potential for using drum seeders is in the EWS and DS, farmers in some areas would be able to use the drum seeder for planting rice in the EWS. Further, the operational size of over 85% of the farms in the lowland rice growing areas is less than 2 ha, mostly subdivided into 2-6 small parcels of land with different topography and soil type. This means that a significant number of farmers may be able to grow less than the 4 ha annual area on their own farm considered in the financial analysis of drum seeding.

Drum seeding rice may initially achieve lower yields compared to broadcasting wet until farmers become proficient operators. In the longer term, improved farmers skills and more efficient and adapted use of inputs in row cropping may help achieve higher yields from drum seeded crops. It was therefore, considered worthwhile to undertake sensitivity analysis to demonstrate the effect of change in yield, potential annual use of the drum seeder and farm size, mainly to give an idea about the sensitivity of these variables on returns. The following scenarios were considered for the sensitivity analysis for the drum seeder:

1. Scenario 1: Planting 2 ha of rice on own farm in the EWS and DS with either 5% yield penalty, no change in yield or 5% yield increase (in both EWS and DS), both with and without contract work for planting rice.
2. Scenario 2: Planting 1 ha of rice on own farm in the EWS and DS with either 5% yield penalty, no change in yield or 5% yield increase (in both EWS and DS), both with and without contract work for planting rice.
3. Scenario 3: Planting 2 ha of rice on own farm only in the EWS, with either 5% yield penalty, no change in yield or 5% yield increase (in both EWS and DS), both with and without contract work for planting rice only in the EWS.

The value of annual net financial benefits of drum seeding, was sensitive to both changes in yield and the operational size of holding (Table 11.12.9,

Table 11.12.10, Table 11.12.11). For example, even a 5% decline in yield of rice planted in the EWS and DS eroded all the financial benefits, leading to net annual financial losses where farmers are using the drum seeder on their own farm only. The drum seeder remains financially feasible where farmers are able to use this machine for contract work. If yield increases by 5% there are substantial benefits under all three scenarios.

This underlines the importance of thorough farmer training and support in implementing best practice management practices with drum seeding rice.

Table 11.12.9. Net annual benefits ($/year) with different crop yield responses to drum seeding on a 2 ha farm (EWS and DS)

Details	Scenario 1	Scenario 2	Scenario 3
Net benefits with 5% yield decline	-$-26	$14	$65
Net benefits with 0% yield increase	$159	$198	$250
Net benefits with 5% yield increase	$343	$382	$434

Table 11.12.10. Net annual benefits ($/year) with different crop yield responses to drum seeding on a 1 ha farm (EWS and DS)

Details	Scenario 1	Scenario 2	Scenario 3
Net benefits with 5% yield decline	-$38	$2	$53
Net benefits with 0% yield increase	$55	$94	$146
Net benefits with 5% yield increase	$147	$186	$238

Table 11.12.11. Net annual benefits ($/year) with different crop yield responses to drum seeding on a 2 ha farm (EWS)

Details	Scenario 1	Scenario 2	Scenario 3
Net benefits with 5% yield decline	$8	$20	$43
Net benefits with 0% yield increase	$90	$14	$42
Net benefits with 5% yield increase	$171	$182	$206

The findings of the economic analysis presented above suggest that the drum seeder technology is expected to be financially feasible, where farmers are able to use this technology for growing rice in both the EWS and DS and achieve the same or higher yield compared to rice broadcast wet. Best management practices able to generate yield increases would also likely require significant investment such as land laser levelling which will offset the profitability outlook.

Sensitivity analysis for mechanised seed drill adoption

The results of the sensitivity analysis on Scenario 1 (Section 7.15) for estimating the impact of change in crop yield of drill seeded rice grown in both the EWS and DS and different contract rates for hiring a drill seeder on the total income on a 2 ha farm are shown here.

Contract rate ($/ha)	Grain yield			
	10% less	Reference	10% more	20% more
$30 (District practice)	-$508	$33	$228	$596
$45	-$358		$378	$746
$60	-$208		$528	$896

*Reference grain yield: EWS = 3.5t/ha, and DS = 4.8t/ha

The results show clearly the importance of a minimum contract hiring rate (50% greater than district practice) and/or greater grain yield which are achievable under best management practice. The data also call for providing quality operator training to ensure the best drill seeding results are achieved in practice and enable the necessary productivity improvements.

Appendix 8. Recommendations on the suitability of mechanised dry/wet direct seeding options according to soil type, topo-sequence and season

SOIL TYPE: **Deep sandy soil (e.g. PREY KHMER)** and fine and coarse sands - 10-12% rice areas*. Soft structureless soils that are quick drying. LOCATIONS: Takeo, Kampot					
Topo-sequence	Mechanised seeding options	Season			
		Early wet season	Main wet season	Recession dry season	Full irrigation dry season
Rice paddy fields at seeding…		...are dry, moist or wet depending on rain & supplementary irrig'n	… are very wet, moist or dry depending on topography and timing	...are wettest on all soil type and topography	...are dry unless irrigated
Upper field reference	Disc seed drill (Thai, Cambodian): well suited to sowing in dry/moist conditions of this soil type, irrigation or rain required for seed germination, possibility of zero-till seeding as soil is soft enough, possible issues of excessive drill sinkage, least sensitive to uneven surface soil levelling	Yes	Yes		Yes
	Tine/press wheel seed drill (Rogro, ARC Gongli): well suited to sowing in dry/moist conditions - can establish rice in stored moisture - suitable for cultivated or zero-till seeding with low quantity and short residue - in-furrow seed delivery can be impaired by rhizome weeds, possible issues of excessive drill sinkage, variable seed placement in poorly levelled fields	Yes	Yes		Yes
	Rotary till drill (full or strip till 2BFG-100): Technology has best potential in unploughed soil conditions, full till set up increases seedbed moisture loss, strip till set-up likely most suitable as minimising tillage intensity, unlikely to operate well in heavy residue due to soft soil (testing required)	To be confirmed	To be confirmed		To be confirmed
	Drum seeder: n/a in this soil type	n/a	n/a		n/a
Low lying field specificity - risks of early & prolonged flooding	None	none, same applies	2WT drills likely too heavy for wet paddies (light weight disc drill may be used)	none, same applies	none, same applies

* Source: White PF, Oberthür T, Sovuthy P, eds. 1997. The soils used for rice production in Cambodia. A manual for their identification and management. International Rice Research Institute: Manila, Philippines.

SOIL TYPE: **Sandy loam soil (e.g. PRATEAH LANG)** - 25-30% rice areas*. Soils hardset on drying, and recompact easily with tillage operations in wet conditions, cloddy seedbed in dry conditions

LOCATIONS: Takeo, Kampot, Kampong Thom

Topo-sequence	Mechanised seeding options	Season			
		Early wet season	Main wet season	Recession dry season	Full irrigation dry season
Rice paddy fields at seeding…		...are dry, moist or wet depending on rain and supplementary irrigation	… are very wet, moist or dry depending on topography and timing, with issues specific to soil types	...are wettest on all soil type and topography	...are dry unless irrigated
Upper field reference	Disc seed drill (Thai, Cambodian): suitable in soft cultivated, non-cloddy, dry and moist conditions only, not suitable in zero-till conditions as not soft enough, irrigation or rain required for seed germination, least sensitive to uneven surface soil levelling	If soft conditions and with limited sowing window	If soft conditions and with limited sowing window - avoid very wet conditions (sinkage and blockage issues)	No 2WT drills too heavy for wet paddies (sinkage, blockage), technologies may work after sufficient drainage/drying has occurred, subject to evenness of drainage (testing required), delayed seeding as a result	If soft conditions & with limited sowing window
	Tine/press wheel seed drill (Rogro, ARC Gongli): can operate in any condition including hardset (timing to avoid too wet) - can establish rice in stored moisture - suitable for cultivated moist or dry - including hardset conditions or zero-till seeding with low quantity and short residue, in-furrow seed delivery can be impaired by rhizome weeds, variable seed placement in poorly levelled fields	Yes	Yes but must avoid very wet conditions (sinkage and blockage issues)		Yes
	Rotary till drill (full or strip till 2BFG-100): technology best for ZT seeding in non-compact & moist soil conditions. Full disturbance tillage exacerbates soil structure damage and promotes seedbed moisture loss, strip till concept with straight blades better suited, likely to operate well in moderate quantity of dry residue (testing required)	To be confirmed	To be confirmed but must avoid very wet conditions (sinkage and blockage issues)		To be confirmed
	Drum seeder: suitable with good even puddling on levelled paddy with drainage control (refer IRRI leaflet), and timing critical in this soil type and especially for zero-till drum seeding	Yes	Yes	Yes	Yes
Low lying field specificity - risks of early & prolonged flooding		none, same applies	2WT drills likely too heavy for wet paddies (light weight disc drill may be used)	none, same applies	none, same applies

<table>
<tr><td colspan="6">SOIL TYPE: Clay-loam (e.g. BAKAN) occur in 10-15% rice areas* and cracking clay soils (e.g. KBAL PO and TOUL SAMRONG in 13%and 7-10% rice areas, respectively* . Soils are soft and sticky when wet, harden upon drying, and produce a cloddy seedbed if tilled in dry conditions
LOCATIONS: Takeo, Kampong Thom</td></tr>
<tr><td rowspan="2">Topo-sequence</td><td rowspan="2">Mechanised seeding options</td><td colspan="4">Season</td></tr>
<tr><td>Early wet season</td><td>Main wet season</td><td>Recession /dry season</td><td>Full irrigation/ dry season</td></tr>
<tr><td colspan="2">Rice paddy fields at seeding…</td><td>...are dry, moist or wet depending on rain and supplementary irrigation</td><td>… are very wet or moist depending on topog’hy & timing, with issues specific to soil types</td><td>...are wettest on all soil type and topography</td><td>...are moist, drying unless irrigated</td></tr>
<tr><td rowspan="4">Upper field reference</td><td>Disc seed drill (Thai, Cambodian): suitable in soft cultivated, non-cloddy, dry and moist conditions only - not wet and sticky - not suitable in zero-till conditions as not soft enough, irrigation or rain likely required for seed germination, least sensitive to uneven surface soil levelling, soil stickiness is a problem (testing required)</td><td>If soft conditions and with limited sowing window</td><td rowspan="3">No
2WT drills too heavy for wet paddies (sinkage, blockage), technologies may work in Bakan after sufficient drainage/drying has occurred, subject to evenness of drainage (testing required), delayed seeding as a result</td><td rowspan="3">No
2WT drills too heavy for wet paddies (sinkage, blockage) - impractical for these soil types</td><td>If soft friable conditions and with limited sowing window</td></tr>
<tr><td>Tine/press wheel seed drill (Rogro, ARC Gongli): can operate best in moist, friable conditions, but not too wet - avoid hardset/cloddy situations - can establish rice in stored moisture - suitable for cultivated moist or dry or moist ZT seeding with short/low volume residue. In-furrow seed delivery can be impaired by rhizome weeds, variable seed placement in poorly levelled fields & cloddy conditions</td><td>Yes, but limited sowing window</td><td>Yes, but limited sowing window</td></tr>
<tr><td>Rotary till drill (full or strip till 2BFG-100): technology best for ZT seeding in non-compact and drying conditions, as full disturbance tillage exacerbates soil structure damage and promotes seedbed moisture loss. Strip till concept with straight blades better suited, likely to operate well in moderate quantity of dry residue (testing required)</td><td>Further testing required, likely limited sowing window</td><td>Further testing required, likely limited sowing window</td></tr>
<tr><td>Drum seeder: suitable with good even puddling on levelled paddy with drainage control (refer IRRI leaflet), and timing critical especially for zero-till drum seeding</td><td>Yes</td><td>Yes</td><td>Yes</td><td>Yes</td></tr>
<tr><td>Low lying field specificity (risks of earlier and prolonged flooding)</td><td></td><td>none, same applies</td><td>2WT drills likely too heavy for wet paddies (sinkage, blockage) - impractical for these soil types and low lying toposequence, early sowing required with drum seeder</td><td>none, same applies - delayed sowing with drum seeder in Kpal Po of recession areas</td><td>none, same applies,</td></tr>
</table>

Appendix 8a. Project learnings and recommendations on best practice drum seeding

- Soil suitability:

  Kbal Po soil more suited than Prateah Lang soil (for seedling establishment)

  Prateah Lang soil more suited than Kbal Po soil (for ease of operation)

- Paddy leveling: is a MUST for uniform results

- Land preparation/puddling:

  - Kpal Po soil: puddling only on receding water with harrows/leveling board and 2WT (Hydrotiller technology well suited)

  - Prateah Lang soil: 2 ploughings needed + harrowing/levelling for sufficient puddling

- Seed preparation:

  - a germination test must be conducted prior to check seed viability and suitability to low seeding rate

  - seeds must be cleaned from spikelet and weed seeds

  - soaking for 24hrs and incubating 24hrs before seeding

  - seed germination readiness is when radicle reach not more than 2mm long.

- Drainage: drainage capability is necessary for early sowing

- Timing: after drainage following puddling

  - - Kpal Po soil: mud must settle with some consistency, and not be in liquid state, typical sowing window is 1-3 days

    - Prateah Lang soil: skin must not be dry, some thin water cover should be present. Narrow window of opportunity, drum seeding must be quick, typically within a few hours of puddling and draining.

- Field operation: ensure a slow steady drum seeder action - water/mud must not reach the drum with excessive sinkage - keep seed level between 2/3 and 5-10% of drum capacity

- Post-seeding irrigation: do not apply until seeds are well anchored

Appendix 9. Locations and numbers of participants in the farmer field schools conducted by GDA

Village	Commune	District	Prov	Seasons	Participation	
					Total	Women
Chhouk Khsach	Chhouk Khsach	Baray	KT	WS, 2011	26	15
Serey Riech	Chhouk Khsach	-	KT	WS, 2011	24	12
Serey Sokhom	Chhouk Khsach	-	KT	WS, 2011	25	14
Tbong Krorpeu	Korkoh	Sontuk	KT	WS, 2011	25	12
Chay Chomnas	-	-	KT	WS, 2011	24	16
Sdok Sdom	Chreab	-	KT	WS, 2011	27	14
Roessey Duoch	Salavisay	Brasat Balang	KT	WS, 2011	25	10
Bos Veng	-	-	KT	WS, 2011	24	15
Khmak	-	-	KT	WS, 2011	26	14
Sangke Chhrom	Chhouk Khsach	Baray	KT	DS, 2011-12	24	12
Brasat	-	-	KT	DS, 2011-12	18	15
Bontiey Chas	Tnot Chom	-	KT	DS, 2011-12	25	8
Kirivont	Korkoh	Sontuk	KT	DS, 2011-12	30	23
Chay Mongkol	Chab	-	KT	DS, 2011-12	30	15
Tbeng	Beoung Lvea	-	KT	DS, 2011-12	30	21
Balang Lech	Domrey Chankhla	Stung Sen	KT	DS, 2011-12	25	8
Sneng Krorbey	Kampong Krorbao	-	KT	DS, 2011-12	25	9
Boeng Trav	-	-	KT	DS, 2011-12	27	10
Prey Dom	Choeung Doeung	Baray	KT	WS, 2012	25	10
Pong Toek	-	-	KT	WS, 2012	26	11
Svay Kal	Korkoh	Sontuk	KT	WS, 2012	26	12
Sontuk Knung	-	-	KT	WS, 2012	21	17
Boss Rormoch	Salavesay	Brasat Balang	KT	WS, 2012	27	4
Chay	-	-	KT	WS, 2012	29	19
Svay Thom	Ang Brasat	Kirivong	T	WS, 2012	27	13
Phngeas	-	-	T	WS, 2012	26	6
Sror Ngeo	Boeng Nimol	Chhouk	K	WS, 2012	25	20
Por	-	-	K	WS, 2012	25	23
Tnort Chrom Timuoy	Tnort Chrom	Baray	KT	DS, 2013	25	4
Tnort Chrom Tipi	-	-	KT	DS, 2013	26	6
Tuol Sangke	Kampong Thmor	Sontuk	KT	DS, 2013	26	12
Bongror	Ream Andoeuk	Kirivong	T	DS, 2013	26	8
Koh Kosarl	-	-	T	DS, 2013	30	3
Por Tamok	Ang Brasat	-	T	DS, 2013	23	7
Koh Takov	Prek Kroes	Kampong Trach	K	DS, 2013	25	23
Chong Sourng	Phnom Prasat	-	K	DS, 2013	25	20
Prey Toteong	Ang Supi	-	K	DS, 2013	25	14
Serey Sorpon Konda	Sror Lao	Baray	KT	WS, 2013	25	17
SontukKrao	Korkoh	Sontuk	KT	WS, 2013	26	15
Trorpang Knung	Phangnoeum	Brasat Balang	KT	WS, 2013	25	5
Thnol Lok	Prey Amport	Kirivong	T	WS, 2013	30	8

Tropang Pring	-	-	-T	WS, 2013	26	7
Kon Sat	Kon Sat	TikChhou	K	WS, 2013	25	15
Bosngign	-	-	K	WS, 2013	25	10
Total					1130	552

Appendix 10. Project trials conducted by staff and students of the Royal University of Agriculture (RUA)

Year	Season	Title	reps	Soil type	Variety	Location
2012	WS	Dry direct seeding by Rogro, demo site, cultivated soil (herbicide focus replicated)	1	Prateah Lang	IR 66	RUA
2012	WS	Dry direct seeding by Thai Drill, demo site, cultivated soil (herbicide focus replicated)	1	Prateah Lang	Senpidao	RUA
2012	WS	Zero-till dry direct seeding by Rogro, demo site (herbicide focus replicated)	1	Prateah Lang	IR 66	Tram Kok, Takeo, Prov.
2012	WS	Dry direct seeding by Thai Drill, demo site, cultivated soil (herbicide focus replicated)	1	Prateah Lang	Phkar Rumduol	Tram Kok, Takeo, Prov.
2013	DS	Dry direct seeding by Thai drill in cultivated soil, demo site (herbicide focus replicated)	1	Prateah Lang	IR 66	Tram Kok, Takeo, Prov.
2013	DS	Zero-till dry direct seeding by Rogro, demo site (herbicide focus replicated),	1	Prateah Lang	IR 66	Tram Kok, Takeo, Prov.
2013	EWS	Effect of applying Urea with seeds by Rogro direct seeding in cultivated soil	3	Prateah Lang	IR 66	RUA
2013	EWS	Effect of applying DAP & KCL with seeds by Rogro direct seeding in cultivated soil	3	Prateah Lang	IR 66	RUA
2013	EWS	Comparison of drill performance of Drum Seeder, Rogro and Thai Drill	3	Prateah Lang	IR 66	RUA
2013	WS	Comparison of drill performance of China Drill, Rogro and Thai Drill	3	Prateah Lang	IR 66	RUA
2013	WS	Zero-till dry direct seeding by Rogro. Demo site (herbicide focus replicated), Takeo	1	Prateah Lang	IR 66	Tram Kok, Takeo, Prov.
2014	DS	Comparison of dill performance of Chinese rotary till drill (full till), Rogro and Thai Drill in cultivated soil	3	Prateah Lang	IR 66	RUA
2014	DS	Comparison of drill performance of Chinese rotary till drill (full till, strip-till) and Rogro drill in zero-till conditions	3	Prateah Lang	IR 66	RUA

Appendix 11. Organisations receiving CLEAR training 2011/12

	Number of trainees
Agrisud	9
CEDAC	20
Sustainable development Organisation in Pursat province	30
Ministry of Mines and Energy (staff involved in a UNPD project)	9
Ministry of Agriculture, Forestry and Fisheries (staff involved in an IFAD project)	15
RATCHANA, a local NGO	25
Royal University of Agriculture	12
Royal University of Phnom Penh	50
Institute of Technology of Cambodia	3
Meanchey University	50
Chea Sim University of Kamchay Mea	15
Battambang University	50
University of Management and Economics in Battambang	15
Helen Keller International	10
Vision Fund	20
American Rehabilitation (RAFA)	20
TOTAL	**353**