Improving the robustness, sustainability, productivity and eco-efficiencies of rice systems throughout Asia

The following collaborators worked on this project:

1. Australia, TIA-UTAS, Holger Meinke, holger.meinke@utas.edu.au

2. Australia, TIA-UTAS, David Parsons, dparsons@utas.edu.au

3. Australia, TIA-UTAS, David Phelan, david.phelan@utas.edu.au

Table of Content

Project Overview

Project Duration	:	3 Years
Funding Awarded	:	US$ 60,000 for year 1, US$ 60,000 for year 2, US$ 60,000 for year 3.
Key organisations involved		1. Australia, TIA-UTAS, Holger Meinke, holger.meinke@utas.edu.au 2. Australia, TIA-UTAS, David Parsons, dparsons@utas.edu.au 3. Australia, TIA-UTAS, David Phelan, david.phelan@utas.edu.au 4. Australia, TIA-UTAS, Lana Shabala, lana.shabala@utas.edu.au 5. Australia, CSIRO, Christian Roth, christian.roth@csiro.au 6. Australia, CSIRO, Don Gaydon, don.gaydon@csiro.au 7. India, ICRISAT, V. Nageswara Rao, v.nageswararao@cgiar.org 8. India, ANGR Agril University, Raji Reddy, dandareddy009@gmail.com 9. India, ANGR Agril University, Dakshina Murthy Kadiyala, dakshu2k@gmail.com 10. India, M.S. Swaminathan Research Foundation, Sivaprakash Ramalingam, sivaprakash.ramalingam@gmail.com 11. India, M.S. Swaminathan Research Foundation, Manjula Madhavan, mmanjumenon@gmail.com 12. Indonesia, CCROM, Rizaldi Boer, rizaldiboer@gmail.com 13. Indonesia, CCROM, Akhmad Faqih, akhmadfaqih@gmail.com 14. Indonesia, CCROM, Andria Anria, andria.anria@gmail.com 15. Indonesia, CCROM, Gito Sugih Immanuel,

gito.kribo@gmail.com

16. Pakistan, Wageningen University, Masood Iqbal Awan, malikcwe@gmail.com

17. Sri Lanka, UOP, Buddhi Marambe, bmarambe@yahoo.com

18. Sri Lanka, UOP, Lalith Suriyagoda, ldbsuriya@yahoo.com

19. Sri Lanka , Department of Agriculture, Punya Delpitiya, punya14@yahoo.com

20. Sri Lanka, UOP, Ruwanga Amarasingha, ruwanga.amarasingha@gmail.com

Project Summary

The demand for rice is expected to double by 2050, a challenging target in the midst of competing demands for land and water, along with a changing and variable climate. Most of these increases have to come from Asia, a region that currently produces 95% of world rice production. Required production increases must be achieved sustainably without negatively impacting on people and the environment. Solutions to raise productivity in rice systems must focus on combinations of intervention actions at all levels. In contrast to the green revolution some 40 years ago, this time we have no 'silver bullets' such as a transition to modern varieties or the introduction of mineral fertiliser. This time the solutions need to be more holistic with an increased emphasis on knowledge generation, dissemination and sound, scientifically informed government policies. Recent advances in the understanding of rice systems now make it feasible to research, foresee and document in detail the economic, environmental and to some extent even the social consequences of the transformational changes that will be necessary to keep up with the rising demand for rice. Systems analytical approaches based on simulation modelling are ideally suited to integrate disciplinary knowledge and providing proactive evaluation of technologies and policies.

Keywords:

Rice, systems modelling, eco-efficiency, sustainability.

Project outputs and outcomes

Project outputs:

A - To collaboratively develop research priorities that can be addressed through farming systems research and simulation modelling.

B - Develop rice systems research priorities for each country in consultation with scientists and stakeholders and organize crop simulation and farming systems workshops in each host country.

C - Address priorities through simulation modelling and farming systems research, linking with and building on existing research projects in areas such as crop physiology, greenhouse gas emissions, resource use, and crop health.

D - Hold collaboration meetings to promote interactions between scientists from different regions and hold workshops with stakeholders to discuss modelling results and develop opportunities for implementation of promising strategies.

Project outcomes:

A - Increased capacity of scientists and their institutions to use simulation modelling and implement farming systems research.

B - Better understanding of the locally specific challenges for developing robust rice systems, agreement upon the most appropriate strategies for focusing research, and communication of this with stakeholders.

C - Increased understanding of rice systems at plant, crop, farm, and regional level.

D - An international, multi-disciplinary network of scientists, committed to developing robust and eco-efficient rice systems that can meet the future demand of a growing population and a changing climate.

E - Improved models that incorporate needed additional structure and are thus better able to realistically simulate rice crops and systems.

This project builds on the successes of an earlier APN project (Applying Climate Information to Enhance the Resilience of Farming Systems Exposed to Climatic Risk in South and Southeast Asia; APN 2004-01-CMY) that established a global network of systems scientists. The project comes at a critical period for the world's food systems. Unprecedented confluences of pressures are resulting in the '2050 challenge': the need to increase global food production by 70% in order to feeding a growing number of people with dwindling resources such as land and water. It also comes at a crucial period in rice systems modelling: recent advances in systems modelling now make it feasible to detail the economic and environmental consequences of transformational changes such as switching from flooded rice systems to aerobic rice. The scientific community and policy makers need to be aware of the technological possibilities for better systems design, community leaders need to understand the impact these technologies can have at local and regional level and key scientists need to be trained in the use of these transformational modelling platforms.

Key facts/figures

- The number of young scientists that were trained throughout the project was ten, spread across four countries.
- The project contributed to and fostered the publication of five peer reviewed journal publications.
- The project also produced three conference publications.

Potential for further work

Rice is an important crop in Asia, particularly South Asia. The region accounts for almost 40% of the world's harvested rice area and almost 25% of the world's population. To maintain regional self-sufficiency in rice, the irrigated and rainfed rice systems must achieve greater yields over the next two decades whilst simultaneously facing many constraints. The key challenge for South Asian rice production is to ensure food security with diminishing water resources. This project focussed on beginning to meet this challenge over the coming years, and part of this work will contribute to meeting these future challenges. Further work would entail the expanded use of systems crop modelling across diverse agricultural climatic zones, to address the constraints in specific regions and differing rice systems, this work would further contribute to meeting the projected demand for rice into the future.

Publications

Journal Publications

Awan, M.I., van Oort, P.A.J., Ahmed, R., Bastiaansa, L. Meinke, H. 2015. Farmers' views on the future prospects of aerobic rice culture in Pakistan. *Land use Policy* 42, 517-526.

Amarasingha, R.P.R.K., Galagedara, L.W., Marambe, B., Silva, G.L.L.P., Punyawardena, R., Nidumolu, U., Howden, M.,Suriyagoda L.D.B. 2014. Aligning Sowing Dates with the Onset of Rains to Improve Rice Yields and Water Productivity: Modelling Rice (Oryza sativa L.) Yield of the Maha Season in the Dry Zone of Sri Lanka. *Tropical Agricultural Research* 25, 277-286.

Amarasingha, R.P.R.K., Suriyagoda L.D.B. Marambe, B., Galagedara, L.W., Silva, G.L.L.P., Punyawardena, R., Wijekoon, R., Nidumolu, U., Howden, M. 2015. Modelling the Impact of Changes in Rainfall Distribution on the Irrigation Water Requirement and Yield of Short and Medium Duration Rice Varieties Using APSIM during Maha Season in the Dry Zone of Sri Lanka. *Tropical Agricultural Research* 26, 274-284.

Amarasingha, R.P.R.K., Suriyagoda L.D.B., Marambe, B., Gaydon, D.S., Galagedara, L.W., Punyawardena, R., Silva, G.L.L.P., Nidumolu, U., Howden, M. 2015. Simulation of crop and water productivity for rice (Oryza sativa L.) using APSIM under diverse agro-climatic conditions and water management techniques in Sri Lanka. *Agricultural Water Management* 160, 132-143.

Kadiyala, M.D.M., Jones, J.W., Mylavarapu, R.S., Li, Y.C., Reddy, M.D. 2015. Identifying irrigation and nitrogen best management practices for aerobic rice–maize cropping system for semi-arid tropics using CERES-rice and maize models. *Agricultural Water Management* 149, 23-32.

Conferences

Amarasinhga, R.P.R.K., Suriyagoda, L.D.B, Galagedara,L.W., Marambe,B., Silva, G.L.L.P., Punyawardena, R., Nidumolu,U., Howden,M., Parsons, D. and Mainke, H. 2015. Yield advantage and water productivity of maize-mungbean inter-cropping systems in the Dry Zone of Sri Lanka; a modelling approach. 17th Australian Agronomy Conference 2015. http://2015.agronomyconference.com/papers/agronomy2015final00399.pdf

M.E.K.K. Fernando, D.A.B.N. Amerasekara, R.K. Amarasingha, L.D.B. Suriyagoda, B. Marambe, L.W. Galagedara, G.L.L.P. Silva, R. Punyawardena, D. Parsons, H. Meinke 2015. Validation of APSIM for long duration rice varieties in different agro-climatic zones of Sri Lanka. 17th Australian Agronomy Conference 2015.
http://2015.agronomyconference.com/papers/agronomy2015final00450.pdf

M.I. Awan, H. Meinke, P. van Oort, L. Bastiaans 2015. Entry points for eco-efficient aerobic rice production system in Punjab, Pakistan. 17th Australian Agronomy Conference 2015.
http://2015.agronomyconference.com/papers/agronomy2015final00145.pdf

Awards and honours

No awards or honours.

Pull quote

'I was fortunate to be a member of UTAS-led rice project, funded by the Asia-Pacific Network for Global Change Research (APN). In this project I had the opportunity to engage with the international collaborative network of rice researchers to propose and design optimal rice-based systems for Pakistan with improved use-efficiencies, in particular for water.'

Masood Iqbal Awan, University of Agriculture Faisalabad, Pakistan.

Final Workshop

The final workshop was held at the Bogor Agricultural University, Indonesia from November 16 to 18, 2016. The workshop provided professional development for the participating project scientists in understanding and analysing rice-based farming systems (rain-fed and irrigated rice). Participating project scientists demonstrated their acquired analytical skills and sytems thinking by presenting summaries and results of their work to their peers. Many of their analyses involved the use of an agricultural simulation modelling platform (APSIM) in order to integrate disciplinary knowledge and to provide proactive evaluation of technologies and policies. In addition the workshop also strengthened the participants' capabilities in making their research more relevant for policy developers in for their representative countries.

Participants

- Sivaprakash Ramalingam - M S Swaminathan Research Foundation (MSSRF), India.
- Manjula Madhaven - M S Swaminathan Research Foundation (MSSRF), India.
- Masood Iqbal Awan - University of Agriculture, Faisalabad, Pakistan.
- Anria - Centre for Climate Risk and Opportunity Management in Southeast Asia Pacific (CCROM - SEAP), Bogor Agricultural University, Indonesia.
- Akhmed Faqih - Centre for Climate Risk and Opportunity Management in Southeast Asia Pacific (CCROM - SEAP), Bogor Agricultural University, Indonesia.
- Lana Shabala – Tasmanian Institute of Agriculture, University of Tasmania, Australia.
- David Phelan – Tasmanian Institute of Agriculture, University of Tasmania, Australia.
- Holger Meinke – Tasmanian Institute of Agriculture, University of Tasmania, Australia.

Summary of all policy briefs

The demand for rice is projected to double by 2050, a challenging target in the midst of competing demands for resources, and a changing variable climate. Required rice production increases must be achieved sustainably. Productivity increases must also focus on combinations of intervention action at all levels. This will be aided by the use of credible simulation models such as APSIM. Model validation must occur across diverse agricultural climatic zones and account for the suitability of genotypic differences as appropriate for different rice systems. A thorough, model-based system analysis will assist in gaining better understanding of the specific causes of rice yield gaps and allow for the mapping of constraints in specific regions and differing rice systems. A major focus of the UTAS-led APN project was to increase the systems analytical capabilities of developing scientists and organisations, while strengthening a network of researchers through building further partnerships and collaborative work with fellow colleagues within the APN framework. The focus of the final workshop was to develop high level capabilities of participants in writing effective policy briefs for each country involved in the project. The workshop was held at the Bogor Agricultural University in Indonesia in late 2016. The workshop provided valuable professional development opportunities for project scientists, an emphasis on rice in the farming systems (rain-fed and irrigated rice) and an understanding of the links between scientific research priorities, effective policy development and impact. Specifically it provided a focus on the role of science in policy development in each of the represented countries. Each participant within the workshop developed a policy brief relevant to their respective study area. These are set out below.

Individual policy briefs

The policy briefs from each participant focused on a single topic that logically related to the purpose of their study. Participants were challenged to identify policy-relevant aspects of their work and present the salient points in a compelling way without losing the scientific rigour. The main purpose of the exercise was to make the topic accessible to non-experts. The following section contains the final briefs developed by the workshop participants:

Creating value from degraded lands - breeding salt tolerant rice is the game changer

Sivaprakash Ramalingam, M S Swaminathan Research Foundation (MSSRF), India

Salinity caused by sea level rise and subsequent salt water intrusion is expected to adversely affect the sustainable development of coastal communities across major rice-producing countries. Although rice is moderately sensitive to salinity, salt intrusion will make large areas of productive lands unfit for rice cultivation. Rice farmers in South-East Asia are looking for cropping systems that are more tolerant to salinity while maintain yield under the changing climate. Moreover, water availability for irrigation has been declining gradually due to rapid urbanization and industrialization in this region. To meet food security needs of 9.3 billion people by 2050, there is an urgent need to explore additional mechanisms imparting salinity tolerance.

Breeding salt-tolerant rice is one of the key priorities of agriculture. Applications of new plant breeding approaches provide South-East Asia with opportunities that conventional plant breeding cannot. Contemporary gene editing techniques can now be deployed to produce GM as well as non-GM cultivars at a fraction of the time and cost of conventional breeding techniques. We now have the scientific capabilities to develop salt-tolerant rice cultivars that can productively grow in salt-affected areas. Recent advances in technologies and methods that enable precise gene modification hold great promise to overcome current constraints by accelerating traits with high salt tolerance in rice without affecting existing valuable traits.

In order to develop salt tolerant rice cultivars, we will employ a rapid, efficient and effective genome-editing approach, CRISPR/Cas9 system. Genome editing is a variant of mutation breeding, with the difference that the generation of particular mutations is more precisely targeted. The major advantage is that these modifications can be obtained in the same way as they are via traditional breeding and crossing experiments. Importantly, while the process uses gene technology, the final product developed using this approach will <u>not</u> contain any foreign genetic material. It will be indistinguishable from conventionally bred rice varieties. Hence, it will have wide acceptance by consumers.

Ultimately, this research will ensure the future economic and environmental sustainability of smallholding farmers in this region and beyond. Achieving such outcomes requires a supportive legislative framework that appropriately governs the use of GM technology for the creation of non-GM crops. Hence, we encourage government to proactively regulate the education and research environment for GM-based breeding technologies. Such regulation will guarantee food safety, consumer confidence and uptake of the new cultivars being

developed. Eventually this will benefit everyone involved in the rice value chain: farmers (especially resource-poor farmers), consumers and government. A welcome by-product would be the international reputational gain for our researchers in India.

Appendix 1. *Sivaprakash Ramalingam* - Developing abiotic stress tolerant rice varieties using biotechnological tools for improved agricultural productivity targeting food security.

Social Gains versus Private Losses: Are Land Use Restrictions on Paddy Lands Justified?

Manjula Madhaven, Girigan Gopi and Vipin Das. M S Swaminathan Research Foundation (MSSRF), India

Paddy farmers in Kerala find themselves in a perennial 'catch 22' situation. On the one hand, the State confers them the title of 'providers of ecosystem services', restricting their business decision through environmental regulations by legislating existing land use practices. At the same time production cost for paddy rice continue to increase without corresponding increases in price. This creates perpetual conflict and puts paddy farmers in an untenable situation.

Comparative Economics of Paddy and Competing Crops (per acre)		
Crop	Yield (in quintals)	Price (per quintal) in US$ (@INR68 per dollar)
Paddy	20 to 25	19 to 26
Banana	26 to 58	38 to 82
Betelnut	25 to 30	1475 (total)

Competing Crops to Paddy & Paddy Field Conversion Stages
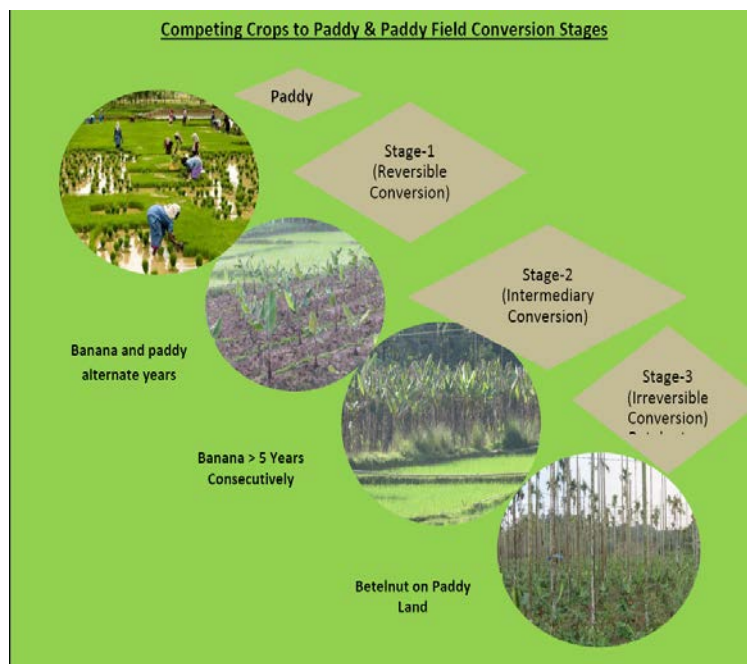
The opportunity cost of conservation of paddy lands are considerably higher than the compensation that is available in the form of subsidies and support price from Government: The proposal to further extend ecological incentive to paddy farmers is yet to be incorporated in the State policies governing paddy lands.

Given this background, the M.S.Swaminathan Research Foundation launched a study to examine the ecological rationale for compensation payments to paddy farmers, including their effectiveness and commercial competitiveness.

The study examined the capacity of paddy lands to provide ecosystem services like carbon sequestration and support to faunal diversity vis-à-vis its competing land use, namely banana and betelnut.

Frog Abundance (in Numbers)				
	Min	Max	Mean	CV
Paddy	0	56	32	0.43
Banana	0	18	4	0.81
Betelnut	3	44	10	0.63
Source: Field Level Ecological Measurements				

Soil Organic Carbon (in per cent)				
	Min	Max	Mean	CV
Paddy	0.26	1.47	0.85	0.33
Banana	0.29	1.60	0.90	0.33
Betelnut	0.41	1.63	0.81	0.42
Source: Result from Soil Analysis				

Frog Diversity (in numbers)				
	Min	Max	Mean	CV
Paddy	0	5	3	0.33
Banana	0	3	1	0.54
Betelnut	1	4	2	0.46

Frogs were chosen as bio-indicators of faunal diversity in this region. This is predicated on the fact that frogs are amphibian that can live in both water and on land and hence will be found in all the three land uses.

The study regressed the ecosystem services on land use changes and a set of field level agronomic and farm level socio-economic variables. Results of the analysis show land use had no significant effect on the ecosystem services. However, other factors such as agronomic practices, plot level quantity of fertilizers and pesticides applied had significant, negative influence on faunal diversity.

A key assumption behind the current conservation policy is that converting paddy lands to other land uses will result in ecological damages. Our study and surveys do not support this hypothesis. Instead we found that the restriction on land use changes on privately owned paddy lands unduly burdens paddy farmers without providing any compensation for the cost of conservation paddy land.

Thus the environmental and ecological arguments for the existence of the Kerala State Paddy and Wetand Act 2008 are scientifically irrational on the basis of the ecosystem services documented in the study.

Nevertheless, given the undisputed argument of ground water recharge and flood control services offered by paddy lands in some areas, the State should adequately compensate affected paddy farmers who at the risk of personal economic losses, continue to cultivate paddy for the larger societal benefit. This should be over and above the existing production subsidies for paddy farmers.

Appendix 2. *Manjula Madhaven* - In Search of Ecological Rationale for 'The Kerala Conservation of Paddy Land and Wetland Act'

Farmers can produce more rice and save water, non-flooded rice is now a viable alternative

Masood Iqbal Awan, University of Agriculture, Faisalabad, Pakistan

In Pakistan water is getting scarcer than land. To best use these limited water resources requires a major social, political and scientific discourse. Current farming practices must transition to more water saving systems to become sustainable. Particularly the high water requirement crops like rice are problematic: conventional flooded rice systems are now beginning to be considered unsustainable. The two major concerns with flooded rice systems are scarcity of water and a low income generating ability.

To grow rice confidently and profitably, farmers must be able to accommodate climate variability in the form of extreme events (i.e. droughts and floods). Science can assist by demonstrating the potential value of novel, enabling technologies coupled with appropriate policy settings. This requires collaboration at different levels: scientific, institutional, industrial, social, and governance. In the next 10 years, our rice landscapes will be drier and more mechanized than today. An emerging alternative are non-flooded rice production systems that increase the sustainability and profitability of rice production. The adoption of non-flooded rice will become a major imperative.

Our farmers are skilled in growing conventional flooded rice. We need to work with them and help them with the introduction of these new production systems. Change always brings new opportunities and risks. Some of the associated risk factors with drier, non-flooded rice systems are: unavailability of suitable rice varieties, more weeds, a lack of appropriate production technology, poor soil fertility, and yield penalties.

We evaluated non-flooded rice systems from a biophysical and socio-technological perspective studies. Results clearly indicate the viability of non-flooded rice systems for Pakistan. Evidently, the adoption of non-flooded rice will save farmers about 25-30% water and require less labour. This considerably increases net profitability.
The saved water can be used for:

a) Bringing more area under rice cultivation or
b) Domestic/ industrial purposes.

Our challenge is making rice more resource-use efficient and globally competitive. A proactive approach requires a shift in our policy settings to increase the resilience of farmers

and further the competitiveness of Pakistani rice. Based on our experimental findings and foresighting, we urge policy makers to consider the following recommendations at different levels:

Scientific and technological	Commission targeted research into breeding of suitable basmati varieties. Standardisation of soil and crop management practices for non-flooded rice systems. Mechanical interventions for appropriate seeding, weed control, and harvesting. Reducing post-harvest losses.
Institutional	Awareness campaigns about non-flooded rice systems. Capacity building of farmers, researchers and extension workers. Establish and support extension outreach programs. Document how much of the current unused land can be used for growing non-flooded rice. Identify niches for non-flooded rice in non-rice growing areas. Procurement of carry-over stocks. Establishing the gender sensitisation roles.
Industrial	Ensure quality standards. Branding Of Paskistani rice. Manufacturing of agricultural machinery for weeding, precise seeding and harvesting.
Social	Awareness about water conservation. Empowering status of women and children.
Governance	Ensure availability of good quality biocides and required mechanical interventions. Increase the resilience of farmers through education and training instead of increasing their dependence through direct cash supports and softening policies for agricultural loans. Increase water storage capacity to store excess water during flood periods. Ensure rice quality standards. Implement a better trade policy. Remove export barriers. Stabilisation of price, demand and supply. Integrated resource management.

Appendix 3. *Masood Iqbal Awan* - Resource-use efficient alternate rice production systems for Pakistan.

Modelling rice-based systems; reveal constraint and exploring options to realise maximum yield potential

Anria and Akhmad Faqih, CCROM - SEAP, Bogor Agricultural University, Indonesia

A field trial requires a lot of resources and often does not allow to extrapolate results to other areas or circumstances. A crop growth model that has been calibrated and validated can be used to explore different scenarios, simulate them and give useful information. Often a well-performing model can be used to explore research questions that previously had to be addressed using expensive and time-consuming field trials. Model-based information can support decision making of proper farming management in order to realise potential yield.

Based on our modelling study, we find that very high temperatures during the flowering period of rice cause substantial yield losses. As the temperature increases above 32°C, which is the optimum temperature, spikelet fertility and number of grain will decrease leading to yield losses. Heat-tolerant rice varieties that have higher optimum temperatures are urgently needed. Further, more information of optimum planting times are also required. Such germplasm and knowledge will enable us to adapt rice-based cropping system to a changing climate. Our study is designed to guide new rice breeding efforts.

Appendix 4. *Anria and Akhmad Faqih* - Utilization of Crop Growth Model to Support Climate Change Adaptation Action in Rice Farming System.

New crop breeding strategies to guaranty feeding global population in the future

Lana Shabala, Tasmanian Institute of Agriculture, University of Tasmania, Australia

Food and fibre production will need to increase by 70% to match population growth that is expected to reach 9.1 billion by 2050. Achieving this goal has become increasingly challenging due to shortages of arable land, growing urbanisation and global climate change. At the same time, sustainable food and fibre production worldwide is severely hampered by a range of abiotic stresses such as salinity, drought, heat, flooding resulting in $100 billion p.a. loss that is predicted to increase. The situation is especially critical in the region of South-East Asia that largely rely on rice as a staple food and that is more affected by harsh environmental conditions due to climate change.

Critically, approaches used in agriculture cannot quickly resolve the issue. Conventional breeding requires over five years in field trials, but still doesn't guaranty the positive outcome. On the other hand, genetically modified technology (GM), while being quick and specifically targeting, is currently not accepted by the public. This calls for a major shift in breeding paradigm towards scientifically justified approach that is acceptable by the community.

In the light of these we suggest combining two novel ways for successful breeding: using (a) alternative gene modification technology in combination with (b) the pyramiding approach in crop breeding. Together they will provide conventional way of crop breeding with the latest advances in technologies.

While being new, targeted genome editing approach, CRISP, has already been successfully applied in agriculture. The approach can be used to create germplasm that does not contain any foreign genetic material and is therefore indistinguishable from conventional breeding techniques. This overcomes some of the major concerns that consumers raise in relation to GM.

On the other hand, the pyramiding approach in crop breeding for abiotic stress tolerance has been heavily advocated in recent years. It is based on a traditional breeding and is empowered by using marker assisted selection that enables focusing on specific traits for better crop breeding. The pyramiding approach is based on identification and targeting specific physiological traits that were scientifically proven to be involved in traits of interest and thus would result in more focused breeding.

The two approaches are complimentary and their use in parallel for developing crops that are resistant to harsh environmental conditions would ensure successful outcome of the project. The overall gain however will be feeding growing population in the future.

Appendix 5. *Lana Shabala* – Functional Genomics approaches to food security.

Final report

Introduction

The demand for rice is expected to double by 2050, a challenging target in the midst of competing demands for resources, and a changing and variable climate. Required production increases must be achieved sustainably. Productivity increases must focus on combinations of intervention actions at all levels. This requires systems thinking supported by simulation modelling to integrate disciplinary knowledge and provide proactive evaluation of technologies and policies. This project used in-country RD&E combined with modelling to design more efficient rice systems, in conjunction with increasing the systems analytical capacities of scientists and organisations, and strengthen a network of researchers. On-going communication with all stakeholders, particularly policy makers will be central to the outcome of this project.

The world is running out of rice. A key global food security question is: how can rice production be increased without using more resources such as land, water and nitrogen and reduce its carbon footprint? Simulation modelling offers the best tool for integrating disciplinary knowledge and providing methods for evaluation of technologies and policies. An emerging opportunity is aerobic rice. Recent advancements in rice simulation modelling enable simulation of rice through the transition between aerobic and anaerobic growing conditions. We incorporated in-country R&D combined with simulation modelling to design better farming systems practices that will drastically improve resource efficiency of production.

Rice is an important crop in Asia, particularly South Asia, which is comprised of Bangladesh, Bhutan, India, Nepal, Pakistan, and Sri Lanka. Agriculture in the region provides employment and livelihoods for tens of millions of rural families directly or indirectly. The region accounts for almost 40% of the world's harvested rice area and almost 25% of the world's population (IRRI, 2002). To maintain regional self-sufficiency in rice, the irrigated and rainfed rice systems must achieve much higher yields over the next two decades whilst simultaneously facing many constraints including low soil fertility, pest and disease incidence, competition from weeds, drought in rainfed systems, flooding, soil acidity, poor infrastructure, land fragmentation, land losses due to urbanization, reduced land availability and high cost of inputs (Mutert and Fairhurst, 2002). The key challenge for South Asian rice

production is to ensure food security with diminishing water resources are and population growth of two percent p.a. (Briscoe and Qamar, 2009).

Objectives

1.   Enhance the capacity of researchers and their institutions throughout the rice growing regions of Asia to using modelling tools for addressing rice systems research questions.
2.   Use a farming systems modelling framework to develop climate robust and eco-efficient rice systems that are well adapted to the particular growing environment and socioeconomic circumstances of each study location.
3.   Foster collaboration of key rice systems scientists, centred on the use of simulation modelling for research, policy analysis, and learning.
4.   Engage in an on-going science-policy dialogue between research institutions and policy decision makers to ensure that scientific insights underpin progressive policy decisions that lead to more productive and efficient rice systems.

Technologies which are proven to be beneficial for the rice growing farmers across South Asia can provide economic and environmental benefits. Modelling results based on outputs of crop models can be extrapolated to different regions across South Asia. Policy briefs regarding the feasibility of alternative production systems and theoretical limits of resource use efficiencies were also developed and communicated.

Summary of Outcomes

Across South East Asia the project assisted in training eight people (India, Pakistan, Sri Lanka and Indonesia) in various aspects of rice systems modelling with specific relativity to the local farming systems (rainfed and irrigated rice) applicable to the participating scientists countries. This training in modelling rice-based cropping systems used cropping systems models based on the 'learning by doing' principle, i.e. by using existing or past trial sites as core parameterisation or validation cases, allowing trainees to use the models to explore and extrapolate their own trial data. Training in the parameterisation of models was conducted in a way that the models better reflect farming reality rather than being based on researcher assumptions, making the models more credible and locally relevant. Additionally training was also carried out in the acquisition of high quality data. In the past this has been neglected,

and we proposed to use existing trials to demonstrate key climate and soil characterisation techniques, as well as cost-effective crop, nutrient and soil water monitoring techniques. A particular emphasis was on simulation modelling of rice production systems under multiple projected climate scenarios and irrigation scheduling. Systems thinking supported by simulation modelling and integrated disciplinary knowledge provided proactive evaluation of local technologies and policies. APSIM (Agricultural Production Systems Simulator) is a modelling framework designed to simulate the production and resource consequences of agricultural systems. Today, APSIM is one of the leading simulation platforms in the world for modelling agricultural production systems and, in the aspects of breadth of science coverage, software engineering and IP management, it is arguably the world's most advanced agricultural systems model. APSIM has been widely used in Australia as well in a number of African (Kenya, Malawi, Zimbabwe, South Africa) and Asian cases studies (India, Bangladesh, Sri Lanka, Indonesia). A core strength of APSIM is its ability to simulate long time sequences of multiple cropping sequences. Another differentiating feature is its versatility in programming farmer decision making through the use of a unique programming language in its management module. However, to date exposure to APSIM within South Asia has been limited, mainly because until comparatively recently, APSIM did not have the capability to model rice systems. In the past six years, significant effort has been put into enabling APSIM to also reliably model rice systems. This was achieved in partnership with IRRI, by coupling APSIM to IRRI's rice model ORYZA.

The development of policy briefs concerning redesigning current approaches in resource allocation, agronomy and knowledge dissemination for rice production throughout South East Asia. The project also fostered both paper and report writing as well as policy brief writing. As a result a number of papers have been published from the report.

Timeline of the Project

Three annual meetings were held over the duration of the project, along with an APSIM workshop and individual participants travel (Table 1).

Table 1. Timeline of Activity for the project.

Activity	Location		Occurrence
Inception workshop	Kandy, Sri Lanka		January 29 to 31, 2013
APSIM training workshop	Bogor, Indonesia		August 26 to 30, 2013
Mid-Project workshop	Bogor, Indonesia		September 2 to 4, 2014
Final workshop	Bogor, Indonesia		November 14 to 16, 2016
Individual travel for the project		*Participant*	
Myanmar rice systems	Myanmar	V.N. Rao	February to March, 2015
APSIM training and collaboration	Hobart, Australia	R. Amarasingha	Sept. to November, 2015
APSIM training and collaboration	Hobart, Australia	Ahkmad Faqih	April to May, 2016
APSIM training and collaboration	Hobart, Australia	Anria	May to June, 2016

Inception Workshop (January 29 to 31, 2013. Kandy, Sri Lanka)

The inaugural workshop held at the University of Peradeniya, Sri Lanka, January 29th to the 31st, 2013, bought together mostly young to mid-career scientists from Australia, Pakistan, India, Indonesia and Sri Lanka. The workshop involved a field tour of Sri Lankan rice production systems, presentation of past and present rice systems research by each participant, discussion of the issues relating to sustainable and eco-efficient rice production, identification of important regional themes and research needs, and design of discrete cross-country activities that will contribute to the overall collaborative research program. A range of topics were also presented during the workshop. The presentations were an important activity to enable project members to be aware of research interests and activities, to promote discussion, and to sow the seeds for collaboration.

A feature of the workshop was also the formation of excellent cross-country collaboration. The sub-projects that were designed were deliberately not country focused; each project included at least two countries. The group intuitively realized the importance of mentoring of the early career participants by the more experienced scientists.

Participants

Masood Iqbal Awan - University of Agriculture, Faisalabad, Pakistan.

Dakshina Murthy Kadiyala - Agro Climate Research Center, ANGR Agril University, India.

Raji Reddy - ANGR Agril University, India.

P Vijaya Kumar – ICAR, India.

V Nageswara Rao ICRISAT, India.

Akhmed Faqih - Centre for Climate Risk and Opportunity Management (CCROM), Indonesia.

Andria Anria – CCROM, Indonesia.

Gito Sugih Immanuel - CCROM, Indonesia.

Buddhi Marambe – University of Peradeniya, Sri Lanka.

Ruwanga Amarasingha – University of Peradeniya, Sri Lanka.

Lalith Suriyagoda – University of Peradeniya, Sri Lanka.

Punya Delpitiya - Department of Agriculture, Sri Lanka.

Liz Clarke – Australian National University, Australia.

David Parsons – Tasmanian Institute of Agriculture, University of Tasmania, Australia.

Holger Meinke – Tasmanian Institute of Agriculture, University of Tasmania, Australia.

Website

A website was launched (www.apnrice.com) shortly after the inception workshop. The website included a description of the project, short biographies of project participants, downloadable presentations, video presentations, and progress from project activities. It will be a key platform for sharing project outputs and promoting the project.

APSIM Training Workshop (August 26 to 30, 2013. Bogor, Indonesia)

A one week workshop was held at Bogor Agricultural University in Indonesia, from August 26th to 30th, 2013. The workshop provided training for three members participating in the APN project as well as five undergraduate students who also undertook some initial training in the use of APSIM. A particular emphasis was placed on understanding the APSIM-ORYZA rice crop model and parameterising it for the specific farming systems applicable in Indonesia. A detailed understanding of the APSIM-ORYZA rice crop phenology along with climate impacts and climate variability were also pursued with specific reference to the regional rice farming systems applicable to the participating scientists.

The workshop consisted of working through the APSIM training manual and subsequent use of APSIM across diverse agricultural climatic zones in Indonesia via characterising both the agricultural climatic zones and the suitability of different rice systems. A particular emphasis of the workshop was focussed on understanding specific causes of simulated rice yield gaps and mapping regional constraints under differing rice production systems.

The workshop was very successful, all participants exhibited enthusiasm and capability in understanding and further developing their skills in the use of APSIM. From the beginning of the week the participants were able to work through the basics of the model, culminating by week's end of being capable of initiating simulations replicating local rice systems under various scenarios, both agronomic and climate, a key focus of the workshop.

Key subject matter for the training included:
• Working through the APSIM training manual;
• Familiarization with the capabilities of the APSIM model;
• Training in preparing climate files for use in APSIM, particularly those for selected project study sites, and interpolating missing data;
• Introduction to APSOIL, and creating a toolboxes for collections of local/regional soils
• Calibrating APSIM with local/regional rice field data (agronomic and soil);
• Working through rice system simulations, with various climatic and agronomic scenarios in accordance with improving rice production systems throughout central Java. Sensitivity analysis of sowing times, irrigation and fertiliser regimes and multiple rice crops in one calendar year;
• Focusing on limitations to production (e.g. nitrogen and temperature stress) and learning to identify the causes of yield gaps.
• Altering rice parameters in APSIM via model coding.
• Registering with the APSIM users group and how to post APSIM issues/questions;

Participants

Akhmed Faqih - Centre for Climate Risk and Opportunity Management (CCROM), Indonesia.
Andria Anria – CCROM, Indonesia.
Gito Sugih Immanuel - CCROM, Indonesia.
David Phelan - Tasmanian Institute of Agriculture, University of Tasmania, Australia.
Along with five undergraduate students enrolled within the Bogor Agricultural University.

Mid-Project Workshop (September 2 to 4, 2014. Bogor, Indonesia)

The mid-project workshop was held at the Centre for Climate Risk and Opportunity Management (CCROM), Bogor, Indonesia from the 2nd to the 4th of September, 2014. Again bringing together mostly young to mid-career scientists from Australia, Pakistan, India, Indonesia, Sri Lanka and Vietnam. The workshop involved updates, presentations, planning, and a field tour of Indonesian rice production systems, as well as field training in soil type and texture determination, along with further APSIM training (both beginner and advanced). For the beginner APSIM training, this included a 1-day workshop at Bogor Agricultural University for 12 undergraduate students. Discussions were also held concerning sub-projects, reviewing aims, methods and activities to collaboratively develop future research priorities that can be addressed through farming systems research and simulation modelling.

The team at CCROM also gave the group a detailed update on the work they have been undertaking and this was presented by Akhmed Faqih.

Modelling the effect of rising temperature on rice production in Indonesia

Climate change has become a reality, and is threatening the income and livelihoods of poor farmers in Indonesia. Rice is an important crop supporting the economy of Indonesia and any adverse effect due to climate change will threaten the food security of its increasing population. There is a need to understand the impact of climate change in terms of changing temperatures and rainfall on the production of rice. Farmers cultivating rice could benefit from weather-based crop insurance as an adaptive strategy for climate change. The team at CCROM are developing weather indices for rice-paddy insurance in different regions of the country. Weather indices in rice are innovative in Indonesia, and internationally. This work will help researchers to breed temperature and drought sensitive crop varieties. These will also help planners to make policies and strategies in rice-growing areas for adapting to climate change. Farmers also will be advised to adapt changes in crop and cropping system to suit the future climate conditions.

Participants

Masood Iqbal Awan - University of Agriculture, Faisalabad, Pakistan.
Raji Reddy - ANGR Agril University, India.
Sreenivas Gade - ANGR Agril University, India.

V Nageswara Rao ICRISAT, India.

Akhmed Faqih – (CCROM), Indonesia.

Andria Anria – CCROM, Indonesia.

Gito Sugih Immanuel - CCROM, Indonesia.

Ruwanga Amarasingha – University of Peradeniya, Sri Lanka.

Tran Thi Phuong - Hue University of Agriculture and Forestry, Vietnam.

John Hargreaves – CSIRO, Australia.

David Phelan - Tasmanian Institute of Agriculture, University of Tasmania, Australia.

David Parsons – Tasmanian Institute of Agriculture, University of Tasmania, Australia.

Final Workshop (November 16 to 18, 2016. Bogor, Indonesia)

The final workshop was held at the Bogor Agricultural University, Indonesia from November 16th to 18th, 2016. As detailed earlier, the workshop provided professional development to the participating project scientists with specific relativity to the farming systems (rain-fed and irrigated rice) applicable to the participating scientists. Summaries and results were presented by the participating project scientists where systems thinking supported by simulation modelling (APSIM) to integrate disciplinary knowledge and provide proactive evaluation of technologies and policies were analysed and discussed. In addition the workshop also fostered policy development applicable for the participating project scientists for their representative countries.

Participants

Sivaprakash Ramalingam - M S Swaminathan Research Foundation (MSSRF), India.

Manjula Madhaven - M S Swaminathan Research Foundation (MSSRF), India.

Masood Iqbal Awan - University of Agriculture, Faisalabad, Pakistan.

Anria - Centre for Climate Risk and Opportunity Management in Southeast Asia Pacific (CCROM - SEAP), Bogor Agricultural University, Indonesia.

Akhmed Faqih - Centre for Climate Risk and Opportunity Management in Southeast Asia Pacific (CCROM - SEAP), Bogor Agricultural University, Indonesia.

Lana Shabala – Tasmanian Institute of Agriculture, University of Tasmania, Australia.

David Phelan – Tasmanian Institute of Agriculture, University of Tasmania, Australia.

Holger Meinke – Tasmanian Institute of Agriculture, University of Tasmania, Australia.

Individual Travel throughout the Project of participating members

Myanmar rice systems

In February-March, 2015, V Nageswara Rao visited Myanmar to assess legume crops within rice systems. Rice is a major crop in Myanmar, and six delta districts produce 65% of total rice production. The visit was focused on the central dry zone, which is semi-arid, and contributes approximately 20% of national rice production and 54% of national pulse production. Although Myanmar on the whole has a food surplus, the central dry zone states are chronically food insecure.

Rainfed rice in the central dry zone is affected by ENSO, and produces greater yields in La Niña years. Thus, climate variability is an important variable in agricultural production. Ideally the system could be improved so that farmer cropping decisions are based on rainfall forecasts, resulting in enhanced and sustainable productivity and food security. Another opportunity is intensification of rice fallows with legumes (green gram, black gram, chickpea) to restore soil fertility, enhance carbon sequestration, enhance system productivity and mitigate greenhouse gas emissions.

Appendix 6. *V.N. Rao* - Evaluating the opportunities for intensifying dry season fallows in rice based systems in South East Asia

APSIM collaboration for Sri Lankan student in Australia

Ruwanga Amarasingha visited UTAS, Hobart from September 14 to November 14, 2015. Ruwanga presented two farming systems papers at the Australian Agronomy Conference, held in Hobart. Ruwanga also worked with the Australian modelling team to advance Sri Lankan applications of rice systems research. This involved i) Simulating/evaluating the yield of rice (i.e. short medium and long duration) under different agro-climatic conditions in Sri Lanka, and ii) identifying the potential and risk areas for rice under future climate change scenarios. Ruwanga's work was further developed into two peer-reviewed publications.

Research - Eco-efficient nitrogen management for emerging aerobic rice systems

Decreasing water availability threatens the sustainability of two highly interlinked precious commodities i.e. rice and water. An alternative to the conventional transplanted-flooded rice is 'aerobic rice' that is an emerging production system in South Asia. Aerobic rice entails the growing of direct-seeded rice crop in non-puddled fields under non-flooded conditions throughout the growing season. Besides water economy, the other major driving force

behind aerobic systems is the shortage of labour required for manual uprooting, transportation and transplanting of rice nurseries. Aerobic rice could considerably improve eco-efficiencies in rice-based systems of Pakistan where water, labour, and energy are becoming increasingly scarce. Improved eco-efficiencies of one resource, however, might happen at the cost of declined efficiencies for some other resources. For example, Awan et al. (2014) and Kadiyala et al. (2012) reported that improved use efficiencies of water, labour, and energy in aerobic systems happen at the cost of declined efficiencies for land and fertiliser nitrogen (N).

Reducing N losses in aerobic rice should be an important topic for further research and improvement of the technology (Awan et al., 2014). One of the approaches to improve N availability, reduce N losses, and sustainable management of soil fertility is to apply compost, alone or in different combinations with chemical fertilisers. Adding compost to aerobic fields will improve the use efficiency of N and help conserve soil fertility. Two outdoor pot experiments were undertaken to test this hypothesis.

APSIM collaboration for Indonesian students in Australia

Akhmad Faqih visited the University of Tasmania (UTAS), Hobart from April 7th to May 4th, 2016. Faqih worked with the Australian modelling team (H. Meinke, D. Parsons and D. Phelan) to advance Indonesian applications of rice systems research. Faqih's initial focus of his visit was on the analysis of projected climate data from a Regional Climate Model (RCM), the RegCM4. Faqih concentrated on the validation of the projected GCM climate data against observed historical data via an analysis of both daily data and monthly and annual means for regional West Java. Faqih then quantified the changes in both the climate and climate variability using the projected climate data in comparison to a long term baseline period of 1981 to 2010.

Anria visited UTAS, Hobart from May 9th to June 2nd, 2016. Anria's work followed on from Faqih's in using the projected climate data. Anria also worked closely with the Australian modelling team (H. Meinke, D. Parsons and D. Phelan) to advance Indonesian applications of rice systems research. Anria used the projected GCM data from the RegCM4 for parameterising/validating rice phenology and resultant yields under various agro-climatic conditions in West Java, Indonesia. Additionally, Anria quantified the projected climate impacts, potential rice yield gaps, productivity options and crop phenology.

The training visits to UTAS of both Faqih and Anria strengthened the ongoing project relationship and opportunity to engage with the broader scientific community. The main skills and knowledge gained was a further development in the use of modelling tools (APSIM) to conduct research in rice systems through professional development and participating project scientists.

Methods

In South Asia rice is grow in varying ecosystems, ranging from irrigated lowlands to rainfed uplands. Water and nitrogen efficiencies are very low, and identification of possible reasons for this have the potential to not only improve rice yields but also reduce environment impact. This modelling study is part of a larger research theme relating to resource utilisation in the APN project and builds upon on a data set collected from various ongoing research projects in the South Asian region. Simulation models are an excellent tool to analyse alternative crop management options and to quantify trade-offs between yield potential, resource-use efficiencies and environmental implications. The existing crop models however require continuous improvement. Improved model applications for rice-based systems are urgently required to explore the dynamics of the transitions from anaerobic to aerobic rice systems and to optimize the use of limited resources such as fertilizer and water.

In collaboration with partners in South Asian countries, differing rice growing ecosystems were documented in small manageable pilot areas. The major constraints in each rice ecosystem were studied and the potential transformational technological solutions will be proposed. The APSIM-Oryza model was used to simulate field conditions under different rice systems. The data collected from field experiments was used to parameterise, calibrate and validate the model, this was undertaken in various countries. The APSIM model was then used to study the use efficiencies of water, nitrogen and the impact of both the projected climate and the ENSO index across the south-east Asia region region. Rice crop growth and performance was also analysed to identify possible trade-offs between high water and high N use efficiencies. The use of improved modelling capabilities will help to propose and design optimal systems with improved resource use efficiencies throughout the region. Although the work presented here predominately focused on South Asia (Pakistan, Sri Lanka and India), the work also includes Indonesia, a country where rice production is also vitally important. Following is a summary of each contributors work undertaken for the project, incorporating Sri Lanka, India, Pakistan, Myanmar and Indonesia.

SRI LANKA

Validation of APSIM for long duration rice varieties in different agro-climatic zones of Sri Lanka

Ruwanga Amarasingha

Abstract

Rice (*Oryza sativa* L.) is the staple food for many Asians. In Sri Lanka, rice production is heavily dependent on the rainfall distribution pattern, and would be adversely affected by climate change. Prediction and estimation of yield and resource-use efficiency of commonly grown rice varieties is of immense importance under a variable and changing climate. Agricultural system simulation models are useful tools to assess the performance of agricultural systems under scenarios of changing rainfall patterns. The present study was conducted to validate the Oryza module of the Agricultural Production Systems Simulator (APSIM) model for two long duration rice varieties, Bg403 and Bg379-2 (4 months maturity). Model evaluation was done using secondary data. APSIM simulated the observed rice yields for Bg403 and Bg379-2 with a strong fit (R2 of 0.88 and 0.77, respectively, and CV of 9.9% and 14.4%, respectively). Yield was less when grown under rainfed condition than under irrigation for both the varieties. The highest simulated yield loss was observed at Aralaganwila (Dry-Zone Low Country), where a 10% reduction in the seasonal rainfall was simulated. The validated APSIM-Oryza module can be used in evaluating the potential areas for rice cultivation in Sri Lanka under current and predicted climate change scenarios.

Introduction

Rice (*Oryza sativa* L.) is the staple food for Sri Lankans. Total land devoted to rice is estimated to be about 805,647 ha (Agstat, 2013). Rice varieties are categorized into three types according to the time taken for maturity: short duration (up to 3 months), medium duration (3-4 months months), and long duration (4-4.5 months). Rice varieties in the short and medium duration age classes collectively comprise over 93% of the rice production of Sri Lanka and the balance is long duration varieties (Agstat, 2013). Due to heavy and longer duration rainfall during *Maha* season (major rainy season from October to February), farmers cultivate long and medium duration rice varieties. Short duration rice varieties are cultivated during the *Yala* season (minor rainy season from March to September) when the availability of water is limited. Long duration rice varieties are reported to give higher yields than other types. The total land area devoted to rice is not usually cultivated due to a shortage of water during the season (DCS, 2011). Global climate change projections have raised concerns about the negative impacts on crop production in Sri Lanka (Weerakoon and De Costa,

2009). Therefore, it is important to identify the ways of improving national rice production to meet the rising demand of an increasing population.

Estimation of rice yields are needed for different management conditions, and one approach to achieve this is by using crop models. The APSIM-Oryza was developed by incorporating the ORYZA2000 rice growth model (Bouman and van Laar, 2006) into the APSIM modelling framework. The model has been used in Sri Lanka, to evaluate the nitrogen response in lowland rice (Suriyagoda and Peiris, 2011), and for assessing the yield advantage and water productivity when aligning planting date with the onset of rainfall using short and medium duration rice varieties (Amarasingha *et al*., 2014). The objectives of this study were to (i) validate APSIM-Oryza module for two long duration rice varieties widely grown in Sri Lanka (Bg379-2 and Bg403), (ii) estimate the rice yield in the Dry and Intermediate Zones with and without irrigation water availability during the *Maha* season and, (iii) estimate the rice yield of long duration rice varieties when rainfall is reduced by 5 % and 10 % during the *Maha* season.

To parameterise APSIM-Oryza for rice production in Sri Lankan for three different growing seasons. Short season (three months), medium season (three and half months) and long season (four months) for various rice varieties for different agro-climatic zones under recommended management conditions.

Materials and Methods

APSIM model

The Agricultural Production Systems Simulator (APSIM) version 7.4 was used to validate the phenology and growth of long duration rice varieties Bg379-2 and Bg403 in four locations in different agro-climatic zones in Sri Lanka namely, Maha-Illuppallama (MI; Dry Zone, Low-Country), Bathalagoda (BG; Intermediate Zone, Low-Country), Bombuwela (BW; Wet Zone, Low-Country), and Aralaganwila (AG; Dry Zone, Low-Country) (Fig. 1). APSIM has been previously parameterised for the above rice varieties (Fernando, 2014).
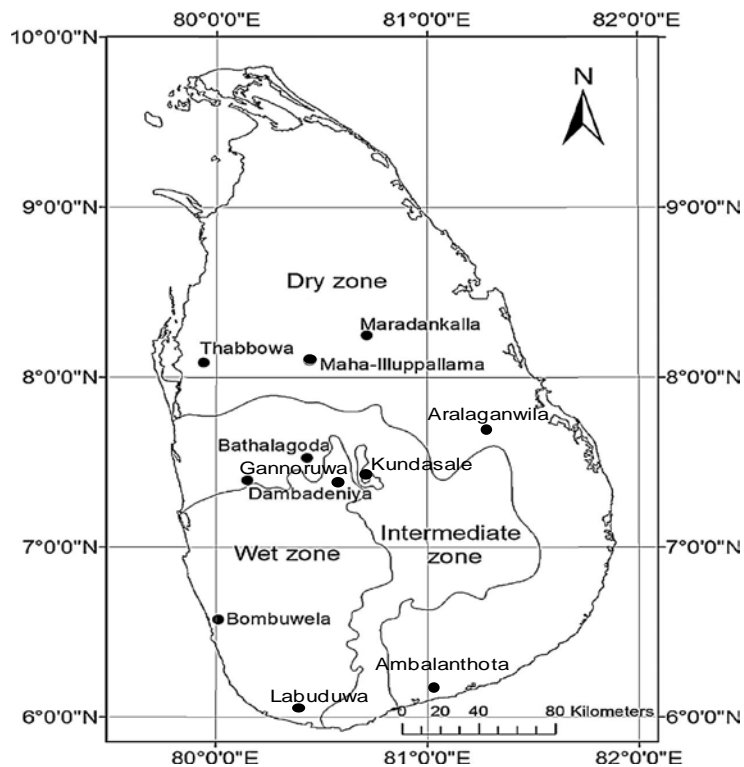
Figure 1. Sri Lankan agro-climatic zones and locations of the four sites.

Data for model calibration and evaluation

Secondary data collected for over twenty years from both *Yala* and *Maha* seasons included planting date, time taken for flowering, 50% heading and maturity, and yield. These data were sourced from the Rice Research and Development Institute (RRDI) at BG and its regional station at BW, and the Field Crop Research and Development Institute (FCRDI) at MI and its regional station at AG under the National Coordinated Rice Variety Trials (NCRVT). Daily weather data (maximum and minimum temperatures, rainfall, and solar radiation) from 1976 to 2011 for MI, 1993 to 2013 for BG, 2002 to 2012 for BW, and 2001 to 2012 for AG were obtained for both *Yala* and *Maha* seasons from the Natural Resource Management Centre (NRMC) of the Department of Agriculture (DOA). Soil characteristics of the study sites were obtained from Mapa *et al*. (2010).

Management practices

All crop management practices were conducted according to the recommendations of the DOA (DOA, 2014). Planting dates and planting methods (direct seeding), irrigation, and fertilizer management strategies were parameterised in the model simulations as recorded from the sites. In the simulation process, a maximum ponding depth of 8.0 cm of water was maintained in the field either through rainfall or irrigation. Irrigation water was available only at the MI, BG, and AG and therefore, model simulations were run with supplementary

irrigation for those sites. At the BW site, irrigation water is not available and hence simulations were run as a rainfed system.

Definition of the scenario modelled

Rainfall distribution may change as predicted by the climate change models. Specifically, the reduction in amount of rainfall received during *Maha* season may affect rice production. The simulated scenarios were:

Scenario A: With and without irrigation

Simulations were run with supplementary irrigation and without (*i.e.* rainfed).

Scenario B: Reduced rainfall in the Maha season

The weather files of the BG, MI, AG and BW sites were changed to reduce the daily rainfall by 5% and 10%. The *Maha* season is the major rice cultivating season in the Dry and Intermediate Zones.

Results and Discussion

The model could simulate the time taken for 50% flowering of Bg403 and Bg379-2 varieties in different locations. The CV values for Bg403 and Bg379-2 were 2.6% and 3.2%, respectively. The RMSE values for Bg403 and Bg379-2 varieties were 2.2 and 3.0 days and the R2 values were 0.71 and 0.70, respectively (Fig. 2).
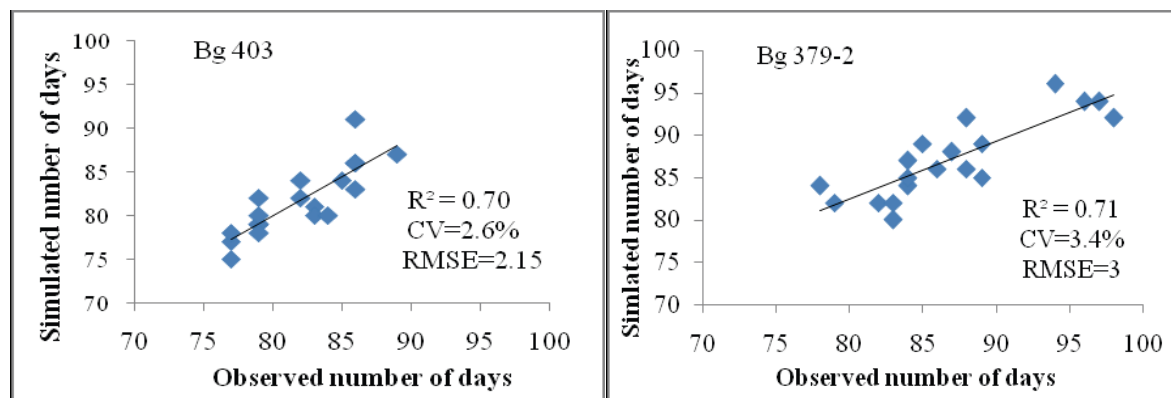

Figure 2. Observed and simulated days required for 50% flowering of Bg403 and Bg379-2 rice varieties grown during *Yala* and *Maha* seasons at Maha-Illuppallama, Bathalagoda, Aralaganwila and Bombuwela, in Sri Lanka.

The model estimated the rice yield at different locations with a strong fit. For Bg403 and Bg379-2, R2 values were 0.89 and 0.77, respectively while the CV values were less than 15

% (Fig. 3). Therefore, this model can be used to predict the grain yield of Bg403 and Bg379-2 with high accuracy.
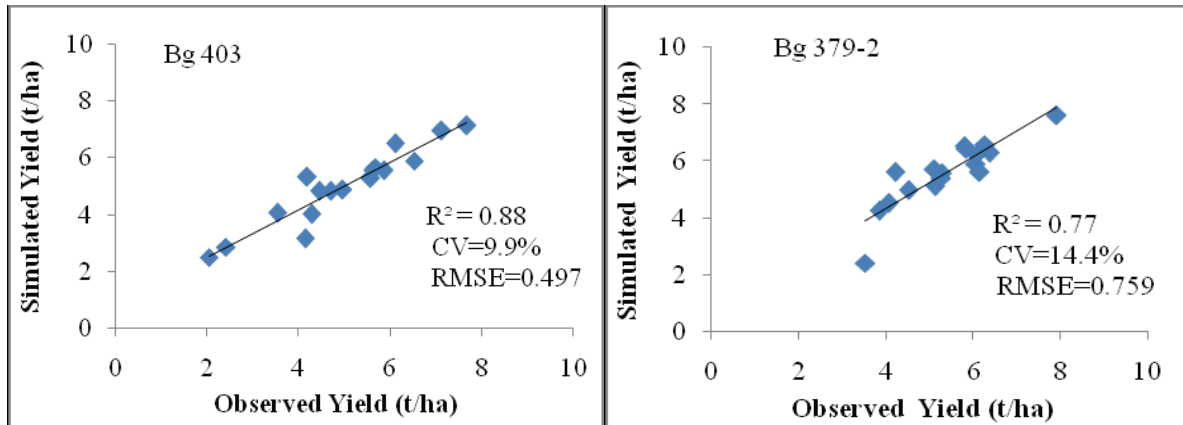

Figure 3. Observed and simulated grain yield of Bg403 and Bg379-2 rice varieties grown during *Yala* and *Maha* seasons at Maha-Illuppallama, Bathalagoda, Aralaganwila and Bombuwela, Sri Lanka.

There was a wide variability in soil physical and chemical properties among different locations (Mapa *et al.*, 2010). Even under such variable conditions the parameterized APSIM-Oryza model could estimate the grain yield of rice with a high accuracy. The average expected grain yield of long duration rice varieties is higher than the short and medium duration rice varieties. However, due to various reasons, the yield potential of those varieties has not been achieved under field conditions. As APSIM-Oryza can incorporate the changes in soil moisture, nutritional aspects, and agronomic management decisions, the validated model can effectively be used in exploring yield-limiting factors. In these simulations supplementary irrigation was available when estimating the yields at MI, BG, and AG if the rainfall was not adequate; whereas at BW rice yield was simulated as a rainfed crop. Therefore, the different sites and years represented varying levels of soil moisture stresses which was a major factor affecting low observed yields across locations and years. Even under such diverse soil moisture availabilities, APSIM-Oryza could simulate the grain yield with a strong fit.

The highest observed yields were recorded at AG (Bg 379-2: 5.9 t/ha and Bg 403: 6.1 t/ha). The model can be used to estimate the expected yield under different management conditions such as a reduction in irrigation water availability. At BW, the observed yield recorded was lower than other locations tested (Bg 379-2: 4.5 t/ha and Bg 403: 3.2 t/ha). Possible agronomic interventions can be tested using simulation models to understand whether rice productivity can be improved through different management decisions. The precision achieved for the long duration rice varieties in this study is comparable with or

even better than the level of precision reached by Amarasinghe *et al.* (2014) for short and medium duration rice varieties grown in in Sri Lanka.

Scenario analyses

The validated model was used to simulate yield performances under different scenarios. In the simulation of Scenario A (with and without irrigation), the yield was reduced at all the sites, with the greatest reduction at BG (69 % reduction) (Fig. 4A). At AG the yield reduction was less (15 %) than that observed at MI (50 %).
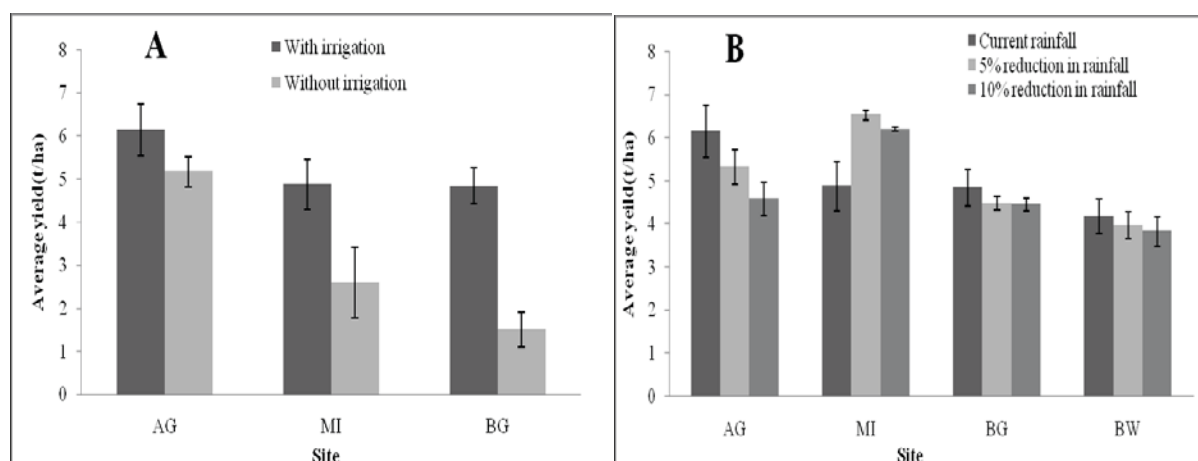

Figure 4. Average yield of rice with and without access to irrigation water supply (A), and under different levels of rainfall (B) during *Maha* season at Aralaganwila (AG), Maha-Illuppallama (MI), Bathalagoda (BG) and Bombuwela (BW) in Sri Lanka. Vertical lines indicate the standard error of the means, n=10.

The reason for the greater dependency of irrigation water at BG is due to the lower amount of rainfall received during the *Maha* season (average rainfall of 587 mm, n=10) than that received at AG (average rainfall of 1346 mm, n=10). The dependency of irrigation water can be reduced at least partly if the planting date is adjusted with the onset of rainfall season (Amarasinghe *et al.*, 2014). The average rice yield was reduced at all the sites except at MI when the simulated amount of rainfall was reduced by 5 % and 10 % below recorded data. The AG site experienced the greatest reduction in grain yield with the reduction in rainfall (Fig. 4B) and thus would be more affected by a possible reduction in rainfall in the future. At BG and BW sites, the reduction in grain yield was less than 8 % and 10 % when rainfall was reduced by 5 % and 10 %, respectively. Rice productivity increased at MI, and the exact reason for this response is not known and needs to be assessed further.

Conclusion

The APSIM-Oryza model was evaluated with high precision for two long-duration rice varieties (4 months to maturity; Bg403 and Bg379-2) for different agro-climatic zones in Sri Lanka. The capability of the model to simulate the time required for 50 % flowering, physiological maturity, and grain yield for both rice varieties was satisfactory.

INDIA

Climate-smart Agriculture Practices for Myanmar: Seasonal rainfall forecast based crop management options for the Central Dry Zone of Myanmar
V. N. Rao

Introduction
Myanmar is the world's sixth-largest rice-producing country. Rice is the country's most important crop and is grown on over 8 million ha, or more than half of its arable land. Rice production in Myanmar has steadily increased with some area expansion and yield increase accounting for the improved rice production. In spite of a decreasing use of fertilizer, rice production grew at 3% per year for the period 2005 to 2010. Modern varieties are cultivated extensively but because of lower inputs (e.g., fertilizer and herbicide), farmers are not achieving the yield potential of these modern varieties. Despite this rice yields increased to 4.1 t/ha in 2010 from approximately 3 t/ha in 1995.

Climate variability and crop production in Myanmar
The rice ecosystems of Myanmar include irrigated lowland, rainfed lowland (including late-sown and Mayin area), deepwater, and upland. Late-sown rainfed lowland is the region sown during the monsoon period. Mayin rice can be transplanted only after the monsoon when floodwater recedes. Rainfed lowland (the largest of the ecosystems) and deepwater rice are confined to the delta region and coastal strip of Rakhine State. Approximately 60% of the delta region of Lower Myanmar, is cultivated with rainfed rice. Because of rainfall and hydrologic patterns, irrigation is critical in Myanmar's central dry zone, whereas, in the delta, there is more concern about drainage and flood protection. The country's upland area is mostly in Mandalay, Sagaing, and Shan states. Myanmar has tropical monsoon climate driven by South West Monsoon from May to October and North East monsoon from December to February, this is classified as a typical bimodal rainfall pattern. Post monsoon season in October and November provides a break in the rainfall season. Myanmar has three distinct climatic zones;

1. Costal - areas receiving the highest annual rainfall of about 5000 mm with mean temperature around 32°C.
2. Central Dry zone - records the lowest rainfall, ranges from 500 to 1000 mm influenced by orography, and temperature range varies from a minimum 10°C in winter to a maximum of 40°C during hot dry months. The area most affected by droughts has been the central dry zone.

3. In the Northern and hilly areas, temperatures range within 10° to 40°C, but extreme low temperatures below freezing point were recorded in both Chin and Shan states.

Myanmar's economy is largely dependent (70% population) on agriculture, and contributes 45% to the national Gross Domestic Product (GDP). Rice is a major crop produced in Myanmar, from 6 delta districts considered as rice bowl of Myanmar, contributing about 65% of annual total rice production. Whereas, the semi-arid Central dry zone of Myanmar which occupies 13% of the country's total land area contributes about 20% of country's rice production, 54% of total pulse production and also regarded as country's oil pot. Although Myanmar is considered to be able to produce food surpluses at a country level, the world food programme (WFP, 2012) indicated that parts of central dry zone, Shan and Chin states have been chronically food insecure. Livestock, freshwater and marine fisheries are also key sources of protein in the diet of Burmese.

ENSO effects on Crop Productivity

Paddy rice and rainfed rice are major cropping systems in the irrigated costal belt and in central dry zones respectively. Although the geographical pattern of the impacts of El Niño/Southern Oscillation (ENSO) on seasonal temperature and rainfall and the impacts of ENSO on regional yields are well established, no global map has been constructed to date that describes ENSO's impacts on crop yields, although there is limited information concerning ENSO's impacts on yields in a few locations. Such limited information makes the overall impacts of ENSO on yields uncertain, and hinders the quantification of the impacts. While the extent of harvested area affects total crop production, more critical is large year-to-year variability in yields associated with climatic factors such as ENSO. This study reports that within Myanmar mean annual rice and pulse yields within the central dry zone during La Niña years are greater in comparison to the El Niño and Neutral phases of ENSO (Fig 1.)
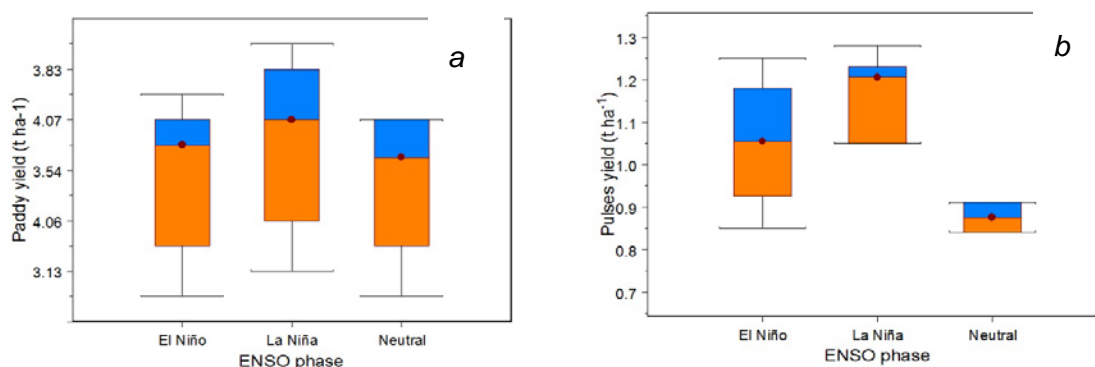
Figure 1. Mean annual rice production (t/ha) for each of the three phases of ENSO within the central dry zone (a) and mean annual pulse production (t/ha) for each of the three phases of ENSO within the central dry zone (b) of Myanmar.

Pulse crops yields are also greater during La Nina years and these yields are significantly low when the Neutral phase of ENSO prevails during a cropping year. Our analysis indicates that two major commercial crops of Myanmar, cotton and sugarcane' yields are also much affected by El Niño phase of ENSO in central dry zone of Myanmar. Climate variability, extremes and change is found to impact on agricultural production and quality throughout Myanmar.

ENSO based Rainfall Variability

Department of Meteorology and Hydrology (DHM) upon the analysis of 40 years of historical weather data reported that during El Nino the warmer phase of ENSO, results in deficit rainfall and higher temperatures. During the La Nina phase, the cold phase tends to bring higher rainfall and lower temperatures in Myanmar. October, November and December rainfall distribution is most effected by the ENSO phases, this follows with a trend of greater rainfall in La Niña years and lower rainfall in El Niño years as observed from rainfall analysis for both stations of Magway and Pokakku (Fig. 2).
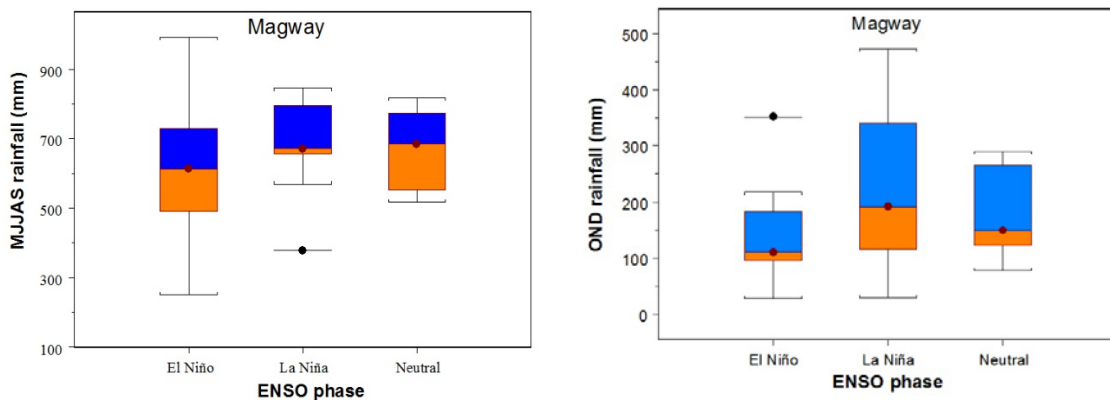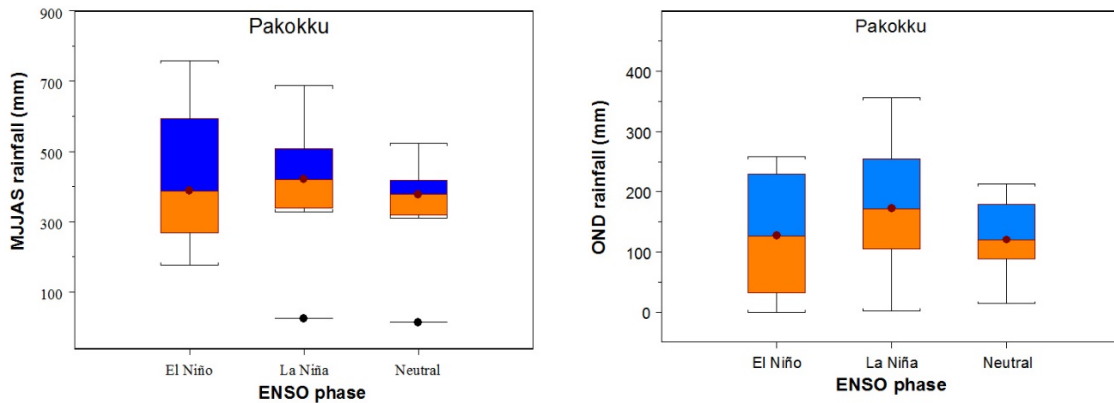
Figure 2. Mean monthly rainfall (May, June, July, August and September) and mean monthly rainfall (October, November and December) for each of the three phases of ENSO for Magway and Pakokku, Myanmar.

Challenges

Although rainfall forecasts are available at various time scales from the Department of Meteorology and Hydrology within Myanmar, generational use of location-specific forecasts for improving crop management decision-making to minimize risk and improve productivity is conspicuously absent in Myanmar. There also exists an absence of institutional mechanisms to share data available among various institutions within Myanmar. Further, the distribution of Meteorological observatories is inadequate (Romano, 2010) to sufficiently capture rainfall variability for modelling crop yield forecasts.

Issues remain concerning communicating forecast decisions for the understanding of policy makers and stake holders to take appropriate cropping decisions along with uncertainties in seasonal rainfall forecast and skill levels. Communicating the right information to farmers at the right time is one of the greatest challenges in the application of seasonal climate information in farmer decision-making.

Expected outcomes

Farmers' decisions for appropriate improved cropping options are tailored based on rainfall forecasts, resulting in enhanced and sustainable productivity and food security. Intensification of rice fallows with legumes (green gram, black gram, chickpea) restores soil fertility and enhance's carbon sequestration besides enhancing system productivity and mitigates GHG emissions.

Based on seasonal rainfall forecasts, dryland cropping systems may be intensified with soybean in rainy seasons, short season legumes in post-rainy season during favourable

seasons to improve WUE and NUE of these systems. Analyses of climate change scenarios for Myanmar helps to develop climate smart (heat tolerant, water logging tolerant) cultivars to fit into cereal-legume cropping systems for future food security in Myanmar.

PAKISTAN

Entry points for eco-efficient aerobic rice production system in Punjab, Pakistan

Masood Iqbal Awan

Abstract

Major issues challenging the sustainability of conventional flooded rice systems in Pakistan are: low input conversion efficiencies, productivity stagnation, rising costs of production, and shortage of water, labour, and energy. An emerging opportunity is an alternative, eco-efficient production system called 'aerobic rice', which entails the growing of direct-seeded crops in non-puddled fields under non-flooded conditions. Eco-efficiency is about achieving more agricultural output per unit of input, through substitution of production factors including knowledge. We evaluated the aerobic rice system in Punjab, Pakistan from biophysical and socio-technological perspectives employing a combined approach of experimentation (i.e. field trials on resource-use efficiencies and growth chamber studies on phenology) and farmer surveys. Our findings suggest that the aerobic rice system is a rational approach for improving the eco-efficiencies of water, labour, and energy. However, for subtropical conditions, the knowledge-intensive system is still very much in the development phase, thus requiring a thorough understanding of the entry points (i.e. opportunities and threats). Based on our findings, the entry points for aerobic rice systems are: availability of fine grain basmati varieties; savings on water, labour, and energy; net profitability; extension outreach programmes to raise awareness among farmers; good quality biocides; prospective areas for crop diversification; optimisation of agronomic practices such as seed rate, water, and fertiliser inputs; land levelling; and mechanical interventions for appropriate seeding and weeding. In order to balance production and sustainability, risks of crop failure can be reduced by optimisation of scarce resources and provision of suitable genotypes.

Introduction

Water is becoming scarcer than land in Pakistan. Water productivity of different crops is among the lowest in the world. Current practices in some parts must transition to water-saving systems for sustainable crop production, in particular for 'water-guzzling' crops like rice. Rice crop, essentially grown on irrigated fields in Pakistan, covers 2.6 million hectares (Mha) with an annual production of about 6 million tonnes. Rice based cropping systems are rice-wheat, rice-berseem, rice-pulses, rice-vegetables and rice-fallow (GOP, 2014; Chapagain and Hoekstra, 2011). The rice-wheat system covers 2.2 Mha and is the second largest cropping system after cotton-wheat. Paddy rice is typically grown by transplanting 30–35 day old rice seedling in continuously flooded conditions with ponding depths of 50–75 mm for most of the growing season, requiring 15 to 25 irrigations. Total water application

ranges from 1200 to 1600 mm over a 100–150 day growing period. (Ahmad et al., 2007). The stagnation of productivity threatens the sustainability of intensive systems via the degradation of soil and water resources. Water shortage, low plant population per unit area due to labour shortage at critical time of transplanting, falling water tables and concomitant rise in energy requirement for pumping groundwater are the major limitations for rice production. With low income generating ability and low conversion efficiencies for the scarce inputs, the conventional transplanted flooded rice system is now showing its limitations for resource poor farmers. (Farooq et al., 2011; Ladha et al., 2003).

Emerging global resource constraints have led to a renewed focus on improving the overall eco-efficiencies of agricultural systems (Keating et al., 2010). Conceptually, eco-efficiency is achieving more agricultural outputs in terms of quality as well as quantity with less inputs of land, water, nutrients, energy, labour, or capital, thus covering both the ecological and economic aspects of sustainable agriculture. An emerging opportunity is an alternative and eco-efficient productions system called 'aerobic rice'. Aerobic rice entails the growing of direct-seeded rice crop in non-puddled fields under non-flooded conditions throughout the growing season. We used the term 'aerobic rice system' for the whole package of agronomic practices and biophysical and socio-economic boundary conditions. Aerobic rice could considerably improve eco-efficiencies in rice-based systems where water, labour, and energy are becoming increasingly scarce. The aerobic rice system is gaining momentum in South Asia as an alternate to the conventional transplanted flooded rice system (Mahajan et al., 2013). Under Pakistani conditions, water economy is the main driver behind aerobic rice systems. Changing the current production system to non-flooded aerobic rice could considerably increase resource use efficiencies. However, for subtropical conditions, such as those in Pakistan, the non-conventional system is still very much in the development phase. Aerobic rice systems are knowledge-intensive thus requiring careful management interventions, heavily relying on biocides for managing weeds and nematodes. Essential plant nutrients (e.g. N, P, K, Fe, Zn, and Mn) may become deficient under aerobic conditions (Kreye et al., 2009). Management practices should be developed to enhance resource-use efficiency especially for water and nitrogen (N) which are the most limiting factors. Accurate prediction of the timing of different events in plant development is crucial to facilitate timely resource application, which is crucial for optimising resource use of scarce inputs. In this paper we outline the main entry points (i.e. opportunities and threats), which are critical for further technology development and dissemination.

Approach

This paper is based on an interdisciplinary project (Awan, 2013). In the interdisciplinary project, we employed a combined approach of experimentation and farmer surveys to contribute important information on aerobic rice crop performance, pre-flowering photothermal responses, and farmers' perspective. Two seasons of field experiments (2009 and 2010) at the research station of the University of Agriculture, Faisalabad–Pakistan tested three local (KSK133, IR6, RSP1) and two exotic (Apo, IR74371-54-1-1) genotypes against different combinations of irrigation levels (Total water input through irrigation and rainfall in 2009-10: 1278-1318 mm (high), 934-979 mm (moderate), 701-938 mm (low)) and nitrogen (N) rates (0, 170, 220 kg N/ha) under aerobic conditions. The experimental site lies in the non-traditional rice belt, which is an important target domain for aerobic rice. Understanding phenology × environment interactions is essential to devise management practices that improve resource use efficiency in environments with sub-optimal resource supply. To disentangle photoperiod (PP) and temperature effects, we used a two-step approach. The PP-response was determined in growth chambers, through a reciprocal transfer experiment with variable daylength (10, 12.5 and 15 h/d) conducted at a fixed temperature of 26°C. Consecutively, the temperature response was determined by combining the obtained PP-parameters with data from field experiments. To supplement the basic biophysical research, we conducted farmer surveys in three major cropping systems of Pakistan Punjab viz. rice-wheat, mixed-cropping and cotton-wheat to understand farmers' views about the future prospects of aerobic rice system. Respondents (n = 215) were grouped using two criteria: (1) their current cropping system and (2) their experience with rice and specifically aerobic rice system. The second criterion led to a distinction between three groups: group I (n = 70) were informant farmers from the rice–wheat system who had tried aerobic rice in a participatory research trial in 2010; group II (n = 97) were rice-growing farmers from each cropping system who did not participate in the trials; group III (n = 48) were non-rice-growing farmers with experience in mixed-cropping or the cotton–wheat cropping system (Awan et al., 2015). Based on the results of the interdisciplinary project and relevant information on aerobic rice experiences in other parts of the world, we have identified the key entry points in this paper.

Key findings and their implications

Eco-efficiencies of water, N, labour, and energy

Grain yield (GY) is a basic measure of eco-efficiency. The GY levels of tested genotypes were generally within the target GY of 4–6 t/ha for aerobic rice systems i.e. 80% GY attainable under transplanted-puddled rice system. Under aerobic system, the GY penalty in

Pakistan and India ranged between 7.5–28.5% (Kumar et al., 2011). The exotic genotypes (Apo and IR74371-54-1-1) better coped with water stress, clearly lowering the risk of obtaining low GY. Under different irrigation regimes, the exotic genotypes recorded GY (t/ha) levels of 4.34 (high), 3.57 (moderate), and 2.64 (low) respectively as against the GY levels (i.e. 4.56, 2.55, 1.78) of the benchmark local genotype KSK133. The exotic genotypes clearly lower the risk of obtaining low GY under water stress conditions but under more optimal water supply conditions the local genotype KSK133 was better. Under aerobic system, we found water productivity (WPg; g grain/kg total water input through rainfall and irrigation) values of up to 0.38, which is more than double the national average of 0.16 for the conventional flooded system in Pakistan. Compared to the gross water requirements of 1600 mm, the total water use (~1300 mm in the high irrigation treatment) resulted in a 20% water savings, which might save farmers three to four irrigations and also reduce energy requirements for pumping groundwater through diesel or electric pumps. Farmers ranked labour savings in direct-seeded aerobic system higher than water saving. Under subtropical, semiarid conditions as in Pakistan, producing more rice per unit area and with less water is rarely possible: reduced water input in our study increased WPg but decreased the GY compared to the flooded system. Pakistan is one of the most water-stressed countries in the world, hence aerobic systems are more advantageous in terms of saving both water and labour compared to the direct seeded rice systems, which mainly focus on labour saving. The GY was positively correlated with total N uptake but we found small differences between the three N application rates, which suggest that a significant amount of the applied N was not taken up by the crop. The process of alternate wetting-drying is known to stimulate the decomposition of soil organic matter and nitrification–denitrification processes. Although we have insufficient experimental data to quantify the complete N (and hence energy) balance, we hypothesise that atmospheric N losses were a major factor in the overall N balance (Awan et al., 2014). In aerobic systems, the improved eco-efficiencies of water, labour, and energy might happen at the cost of declined efficiencies for N and land.

Resource-use in relation to phonological development
All four tested genotypes (KSK133, RSP1, Apo and IR74371-54-1-1) were PP-sensitive. The crop duration (i.e. sowing to maturity) extended under aerobic conditions. The extended crop duration under aerobic conditions is probably one of the reasons for failure of long duration fine grain basmati genotypes under limited irrigation regimes like aerobic rice. Since the crop duration has direct implications for resource use and the sowing window, aerobic rice genotypes should be early-maturing. The significant variation in optimal flowering time and PP-sensitivity among tested genotypes could be exploited by breeders to develop genotypes that can avoid adverse environmental conditions such as pre- and post-monsoon drought.

A good understanding of developmental processes such as PP-sensitivity and their interactions with other environmental factors (temperature, water, and N, in particular) is essential to avoid resource limitations during critical growth stages.

Farmers' perspective

More than half of respondents never heard of aerobic rice; yet most of them (76%) were positive about trialling the non-conventional aerobic rice system. Rice farmers, who have already heard about aerobic or dry direct-seeded rice, often call it broadcast or dry rice which reflects their appreciation for either shrinking labour or water resources. The most often mentioned positive attribute of aerobic rice was reduced labour requirement followed by water saving. Other positive attributes were: ease of operation due to direct seeding instead of laborious puddling and transplanting activities; good income; improved physical condition of the soil. The negative attributes or the associated risks were: weed infestation; diseases; increased spikelet sterility; poor germination; higher irrigation frequency; more seed rate; unavailability of suitable varieties; GY penalty (Awan et al., 2015). The greater water use efficiencies (yield per unit of water) are often associated with lower land use efficiencies (yield per unit of land). An optimal system is then a system that maximises resource use efficiency of the most limiting resource (in this case water) while keeping possible efficiency losses for other resources within acceptable limits.

Entry points for aerobic rice systems

To feed over nine billion people by 2050, agricultural systems will rely on transformational technologies. For rational use of scarce resources, 'knowledge' as a production factor will play a decisive role. Aerobic rice is a knowledge-intensive technology that requires precise/timely management practices. Identifying the knowledge-based entry points can answer this basic question: how can aerobic rice technology pick up momentum to be able to spread in the target domains? Our interdisciplinary study underpins the potential for increasing use-efficiency of scarce resources of water, labour, and energy. However, the aerobic rice technology is still evolving and much needs to be done to increase its adoption rate. Identification of the technological and knowledge gaps can value add to the on-going research on water-saving rice cultivation. Farmers need to be educated through extension activities to raise awareness about the non-conventional system and to tackle the associated risks like weed infestation. Field level studies on resource-conservation technologies documented the potential for water saving. To upscale the results at basin level, there is a need to adopt the required precursor technologies (e.g. laser land levelling) and to identify alternate uses of saved water. For example, the saved water can be used rationally for

bringing more area under rice cultivation, thus compensating for yield penalty under aerobic rice systems. With the extension of irrigation system e.g. development of a 'Greater Thal Canal' in a region supporting pulses-based cropping systems, there is a need to identify alternate crop rotations, which might give a niche for aerobic rice systems.

Improved eco-efficiencies of water, labour, and energy might happen at the cost of declined efficiencies for N and land. Eco-efficient N management strategies (e.g. using composts and farmyard manure) and bringing the culturable wasteland under cultivation by provision of the saved irrigation water are some of the proposed measures for improving the productivity and sustainability of agricultural systems. Currently, the non-traditional rice belt of Punjab and Sindh province are the main target domains as coarse grain non-basmati varieties, which are comparatively better adapted to aerobic conditions, are grown there. In the typical rice belt of Punjab, the abode of world's famous aromatic basmati varieties, non-availability of well-adapted aerobic varieties of basmati rice is a major constraint for expansion of the aerobic rice systems. The on-going breeding efforts should screen rice germplasm for developing basmati varieties adaptable to heat and water stress conditions. Based on the results of farmer surveys, farmers already growing rice, in particular those having large size of landholding and farms with clayey soil types are most likely to be early adopters of the technology. Introduction and dissemination of aerobic rice technology will depend on filling the technological gaps: mechanical interventions for seeding and weeding; good quality biocides; optimisation of agronomic practices such as seed rate and balanced nutrition; quantitative estimation of potential areas for intensification or crop diversification.

Conclusion

Aerobic rice is a viable eco-efficient option to improve water productivity in regions like Pakistan where water is getting scarcer than land. The developing technology will benefit from well-informed knowledge based entry points to fill the identified technological and attitudinal gaps.

Indonesia

Utilization of Crop Growth Model to Support Climate Change Adaptation in Agricultural Sector: Climate Variability, Climate Change and Rice Productivity in Indramayu Regency

Anria and Akhmad Faqih

Introduction

Although Indonesia is the third-largest country regarding global rice production, it is still a net rice importer. This situation is commonly the result of farmers' use of non-optimal production techniques combined with large per capita rice consumption (by a large population). Climate change adaptation is also required in order to ensure the sustainability of rice production. The agricultural sector, especially rice cultivation remains a crucial sector as long as rice remains as staple food of Indonesian. Not only as a source of staple food for more than 95% of Indonesia's population, but also as a source of livelihood for 25 million farmer households. Thus the fluctuations of rice production and its distribution also influence the national stability (BPADI 2009). In 2008, approximately 28.3 million people worked in agriculture fields, this value was 40% greater than the number of agriculture workers in 1993 (SPI 2010).

Rice is grown in all major islands in Indonesia, ranging from Sumatra to Papua, albeit with different productivity. Based on National Statistical Agency data (BPS 2014a), Java is the island with the greatest rice production with an annual average of 37,493,00 tons from an area of 6,467,073 ha (Figure 1). It is more than half of the national production (52.6%), and is regionally split in West Java province (17%), Central Java (14.5%), East Java (16.9%) and other provinces (4.2%).
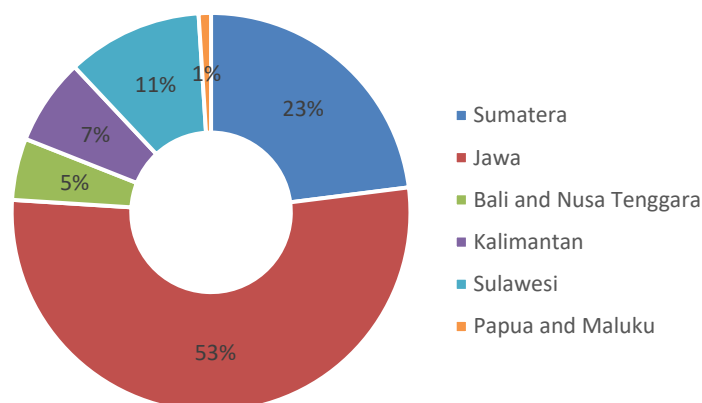

Figure 1. Indonesian island rice production (Source: BPS, 2014a).

Indramayu, one of regency in West Java, is known as the national granary. The regency contributes the highest rice production in West Java province, of approximately 1,435,900 ton, equivalent to 11.88% (BPS 2014b). Greater rice production in Indramayu is supported by the availability of land, suitability of both land and climate to rice production, as well as the availability of labour. From the total land area of 209,942 ha in Indramayu rice is grown on approximately 116,759 ha, or more than 50% of its total land area (BPS 2013). Based on PODES (Village Potency) data in 2011, it is known that 43% of the 523,799 households in the district of Indramayu are farmer households (equals to 227,044 household). Additionally from the 316 villages, the main income of the residents in 279 villages is from rice farming (BPS 2011).

Temperature and rainfall are two major climatic factors in rice production. Temperature is a primary factor affecting the rate of plant development. Warmer temperatures associated with climate change and the potential for more extreme temperature events will impact plant productivity. Jagadish et al. (2010) reports that the increase in both frequency and intensity of high temperature, along with large variability, is emerging as a potential threat to the sustainability of rice production. Sufficient water supply is one of the most important factors in rice production (Datta 1981; Peng 1995). Indramayu regency, an area affected by El Niño Southern Oscillation (ENSO) phenomenon, has challenges relating to water supply. During El-Niño events, the amount of rainfall is below average and thus water supply for rice planting becomes very limited (Subagyono and Surmaini 2014). Reducing the area planted and directly leading to reduced total rice yields.

To anticipate the impact of climate change on rice production, adaptation measures need to be taken (Las et al. 2011a; Las et al. 2011b; Irawan 2012). Adaptation action to face of climate change can be realized through the adjustment in the farming management. Such as the selection of varieties, fertilizer application, plant spacing and utilization of post-harvest hay as well as several other technical issues that will affect the rice production. Harmoko (2014) states that technological innovations generated through research will reduce the impact of climate change on the sustainability of agricultural production. Technological innovation to increase rice production can be applied in several ways, including the selection of rice varieties, improved irrigation management, efficiency in fertilizing as needed, integrated pest and disease management (IPM) and the further development of mechanised agricultural machinery.

Crop growth models were developed three to four decades ago (Vanderlip et al. 2004), and are a vital tool in developing innovative crop management and can assist in the decision making process. Simulation models of agricultural systems are frequently useful in quantifying the performance of the multiple scenarios in various agricultural systems. The modelling of rice farming systems is commonly undertaken to address a variety of issues such as estimates of crop yields, development of specific recommendations in the management and decision support systems, exploring the impact of climate change and adaptation options as well as comparisons to similar research conducted in different locations or environments (Suriadi 2009; Ahmed and Hassan 2011). APSIM (Agricultural Productivity SIMulator) is a crop growth model which can be used to simulate various crops with adequate precision. In this study the APSIM-Oryza module from APSIM (version 7.7) was used to simulate rice production under three different scenarios. The selected study areas were Indramayu regency in West Java Province, Indonesia. Indramayu was chosen due to its role as national granary. In line with that, adaptation action is needed to support the sustainability of rice production in this district. The objective of this study was to parameterized APSIM-Oryza module for IR64 rice varieties which is largely cultivated in the region, to parameterise the model then use the model for investigating the impact of climate variability and climate change on rice productivity in the region.

Materials and methods

Study regions

The selected study area for this research is Indramayu regency which is part of West Java Province. This district is located between 107^0 52' - 108^0 36' E and 6^0 15' - 6^0 40' S. This Regency, an area of 2,099.42 km^2 is located in the north coast of the Java island. Rice farming is the dominant farming system in Indramayu district. Indramayu regency land area in 2012 was 209,942 ha with rice fields covering more than 50% of it, aproximately around 116,759 ha (BPS 2014). The rice fields in Indramayu region can be classified into three regions; the north, central and south (**Figure 2**). Area of rice fields in northern areas is approximately 19%, central (59%) and south (22%). The northern and central regions are largely irrigated rice fields (87%), while the southern region is predominalty rainfed (Estiningtyas 2012).

Figure 2. Three study regions in Indramayu Regency (North, Middle and South).

Rice varieties

From 1943 to 2004, Indonesia has released 184 rice varieties, including the introduction of IRRI varieties. In West Java, up to 2003, IR64 variety dominated 36% area of lowland rice, followed by Ciherang variety (27.55 %) and Way Apo Buru (12.27 %) variety on the second and third place respectively (Table 1). In this study, IR64 rice variety was calibrated and then validated and further was then used for long term simulations.

Table 1. Adoption of rice varieties in West Java Province 2002-2006 (Balai et al. 2006).

Variety	Adoption (% of total rice planted area)				
	2002	2003	2004	2005	2006
IR64	41.41	36.06	28.14	29.76	20.52
Way Apo Buru	19.32	12.27	7.01	5.18	2.31
Ciherang	12.88	27.55	40.68	48.66	47.00
Varietas lain	8.70	8.49	3.75	0.25	12.31
Widas	6.99	7.07	8.14	8.02	10.49
Cilamaya Muncul	2.36	1.15	0.66	0.24	0.25
Memberamo	2.27	1.36	2.37	0.71	0.52
Cisadane	1.81	1.53	0.96	1.70	0.47
Way Seputih	0.63	0.24	0.24	0.01	-
Cilosari	0.63	0.33	0.29	0.15	0.04
Towuti	0.60	0.98	4.63	2.09	1.57
Cisanggarung	0.51	0.54	0.12	-	0.01
PB 42	0.49	0.49	0.56	0.79	0.84
Cirata	0.39	0.12	0.10	-	-
Cibodas	0.35	0.19	0.10	0.14	-
Sarinah	0.33	0.43	1.85	0.86	-
Sintanur	0.32	1.20	0.26	0.47	-
Mekongga	-	-	-	-	0.06
Cigeulis	-	-	0.15	0.72	2.96
Situ Bagendit	-	-	-	0.24	0.65

Parameterisation and Validation of APSIM-Oryza module

APSIM-Oryza does not provide IR64 as one of rice variety on its list. Therefore, parameterization process was done first. The observed data required for the parameterisation process was the historic climate data from Kandanghaur sub-district during the 1st planting season in 1997-1998, as well as physical and chemical properties of soil on that sub-district along with common farming management practice.

Observed and simulated data were plotted on a 1:1 graph having an intercept of 0 and slope of 1 to identify the difference and/or similarity between the observed and simulated yield for IR64. Coefficient of determination or R-squared (R^2), coefficient of variation (CV) and Root Mean Square Error (RMSE) were used as the statistical tools to evaluate the simulated yield from the model. Equation and criteria for each of them is given below:

$R^2 = 1 - \frac{residual\ sum\ of\ squares}{total\ sum\ of\ squares}$; R^2 = 1 indicates that the regression line perfectly fits the data

$CV = \frac{Stdev}{mean}$; Coefficient of variation < 20 % is generally considered as a good model.

$RMSE = \frac{\sqrt{\sum_{i=1}^{n} + (Simulated_i - Observed_i)^2}}{n}$

Climate Variability and Rice Productivity

The impact of climate variability on rice productivity was specifically addressed in relation to El-Niño. Information about El-Niño years were found from other research studies (Rojas et al. 2014). Based on that study, an El-Niño occurred in the years of 1991/1992, 1994/1995, 1997/1998, 2002/2003 and 2004 in Indonesia. The relationship between the El-Niño years and APSIM simulations, based on observational climate data from 1991 to 2005 was then quantified.

Climate Change and Rice Productivity

The impact of climate change was assessed for the 1st planting season (October – January) and 2nd planting season (February – May) separately. Climate data used in this long term simulation was RegCM4 (10 km grid resolution) with the RCP4.5 emission scenario. Analysis of the results for long term simulation is conducted by classifying the data based on the three different periods, i.e. 1981-2005 as a baseline, 2011-2035 and 2041-2065 as the medium-term and long term respectively. The relationship between rice productivity and

climate change were also quantified by consecutive dry (days) and maximum temperatures above 32°C.

Results and discussion

Parameterisation and Validation of APSIM-Oryza module for IR64 varieties

Parameterisation of the APSIM-Oryza module for IR64 varieties was specifically done through adjustment of its phenology.

Table 2. Adjusted value for phenology of IR64 varieties

| Parameter	Description	Value	Unit
DVRJ	development rate in juvenile phase	0.00786	^{0}C/day
DVRI	development rate in photoperiod sensitive	0.00758	^{0}C/day
DVRP	development rate in panicle development phase	0.00521	^{0}C/day
DVRR	development rate in reproductive phase	0.01218	^{0}C/day
Tb	base temperature for development	8	^{0}C
Topt	optimum temperature for development	32	^{0}C
Tmax	maximum temperature for development	42	^{0}C
WGRMX	maximum individual grain weight	28	gr/grain
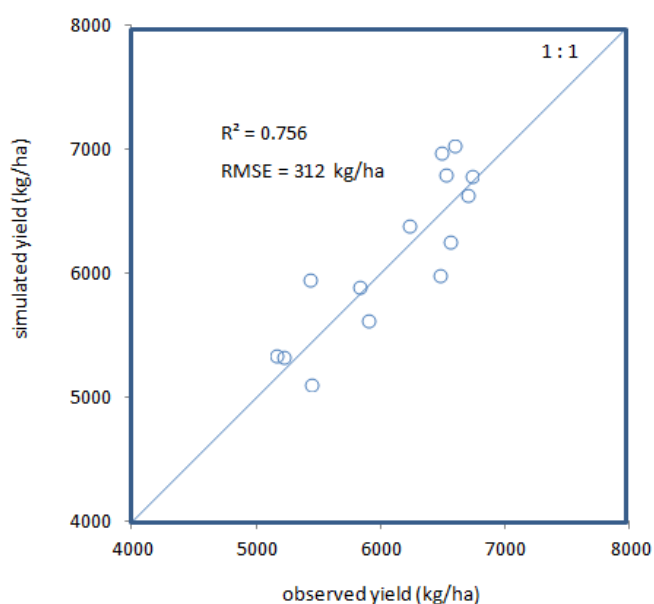
Figure 3. Linear regression between observed and simulated yields.

By using observation data of rice yield from Cikedung and Haurgeulis district during 1994-2000, the parameterised APSIM-Oryza module returns an acceptable simulation of IR64 rice productivity (n=14, R^2 = 0.756, RMSE = 312 kg/ha, CV = 9.48%). A value of R^2 which is close to 1 and CV which is less than 20% indicate that the model performed adequatley (**Figure 3**).

Climate variability and rice productivity

Sufficient water supply is one of the most important factors in rice production. Indramayu regency, as an area which affected by El Niño Southern Oscillation (ENSO) phenomenon, has challenges related to the water supply. El-Niño occurred in 1991/1992, 1994/1995, 1997/1998, 2002/2003 and 2004 in Indonesia. During the El-Niño events, the amount of rainfall is below average and thus water supply for rice planting is limited. The simulation results indicate that reduction of rice yield in Indramayu regency were occurred during El-Niño years, specifically during moderate to strong El-Niño condition in 1992/1993, 1997/1998 and 2002/2003 (Figure 4). Further confirmation was achieved by overlapping between negative anomaly of rainfall (blue line) and negative anomaly of rice productivity (red curve). Additionally rice yields were reduced from 1991 to 2005 by up to 2000 kg/ha (Figure 4).

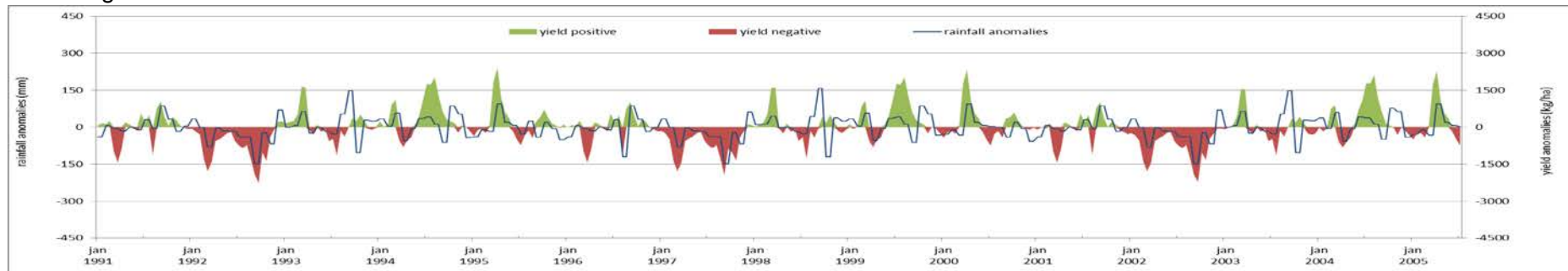North region
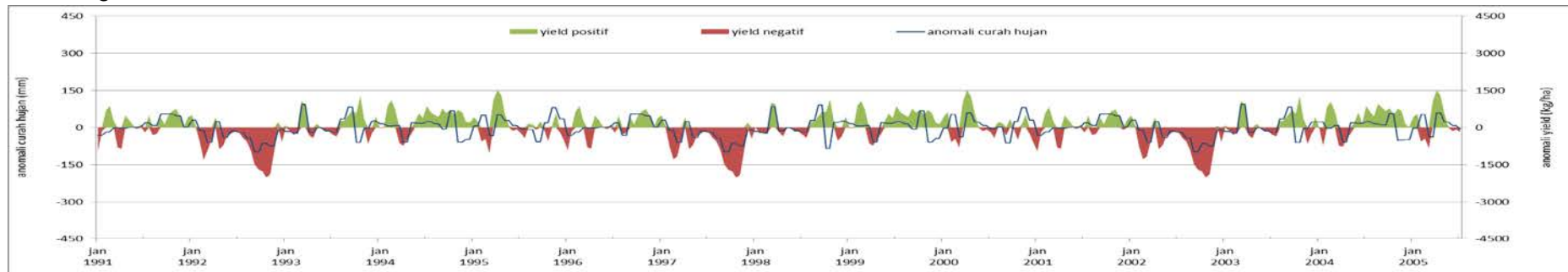
Middle region
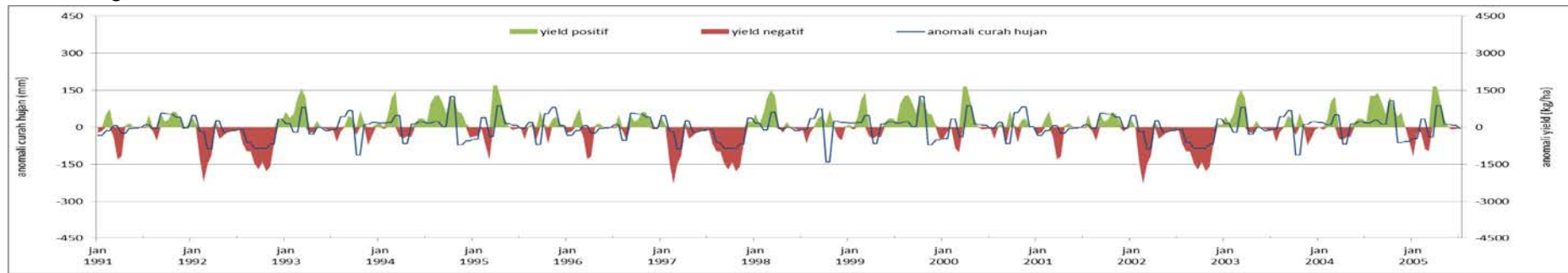
South region

Figure 4. Rainfall anomalies and rice production.

Climate change and rice productivity

The relationship between the observed climate data and the projected RegCM4 climate data from 1991-2005 is shown in Figure 5. The coefficient determination value (R^2) was above 0.9 for all three regions, indicating that RegCM4 climate data can be used with confidence in projecting rice productivity.
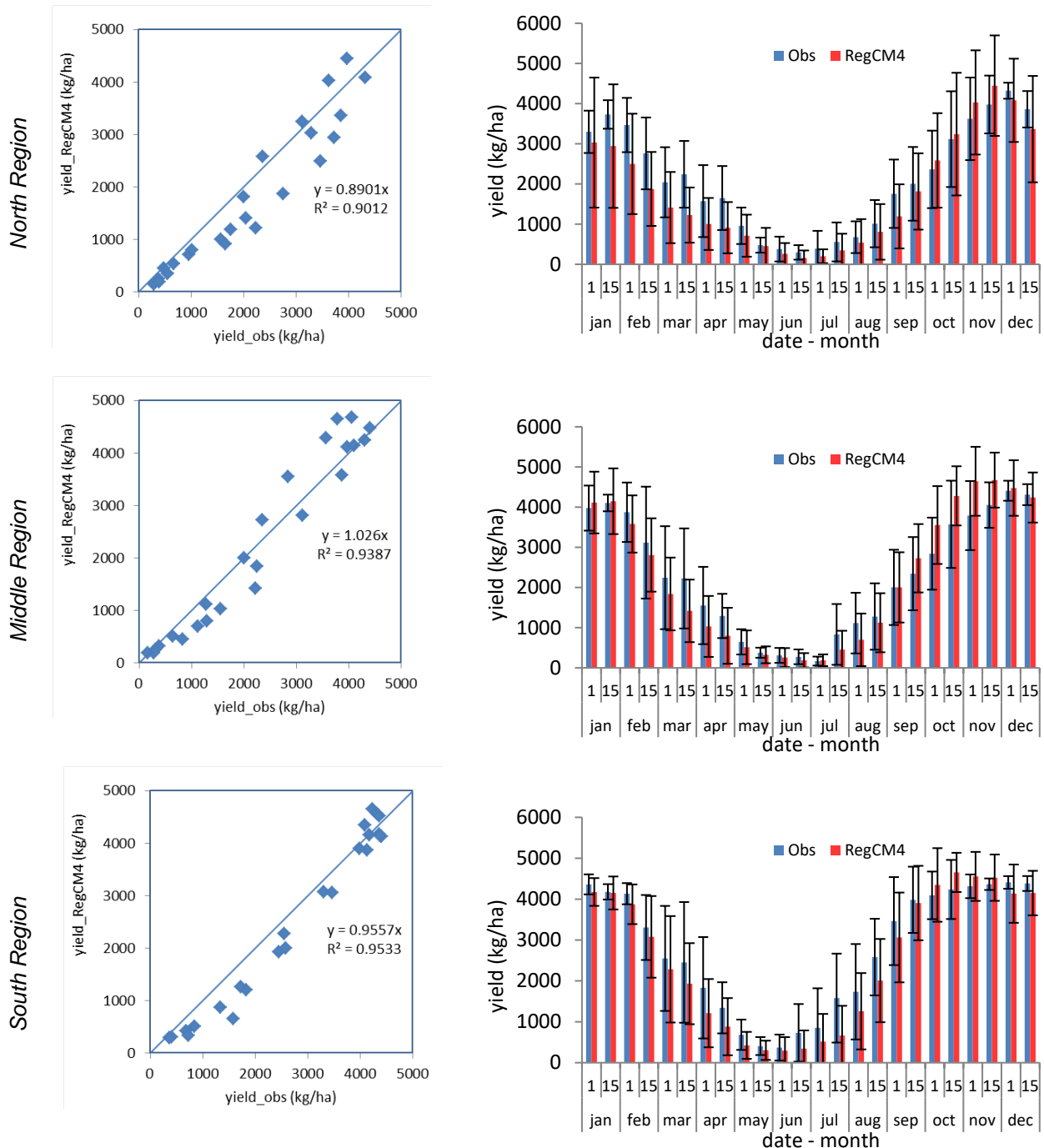

Figure 5. Comparison between the observed climate data and the projected RegCM4 climate data for the period of 1991 to 2005.

In this study, two observed climate parameters were used of rainfall and temperature (**Figure 6**). Cumulative dry days (CDD) were treated as a representation of rainfall condition, while the number of days with maximum temperature above 32°C (T>32°C) for temperature condition. As shown in Figure 6, CDD and T>32^0C will increase in the future. CDD can be related to drought condition and water supply for rice planting. Long CDD may affect to the reduction of planted area and directly leads to the reduction of rice yield. Maximum temperature above the upper threshold of optimum temperature (32°C) will also affect plant growth and reduce productivity.
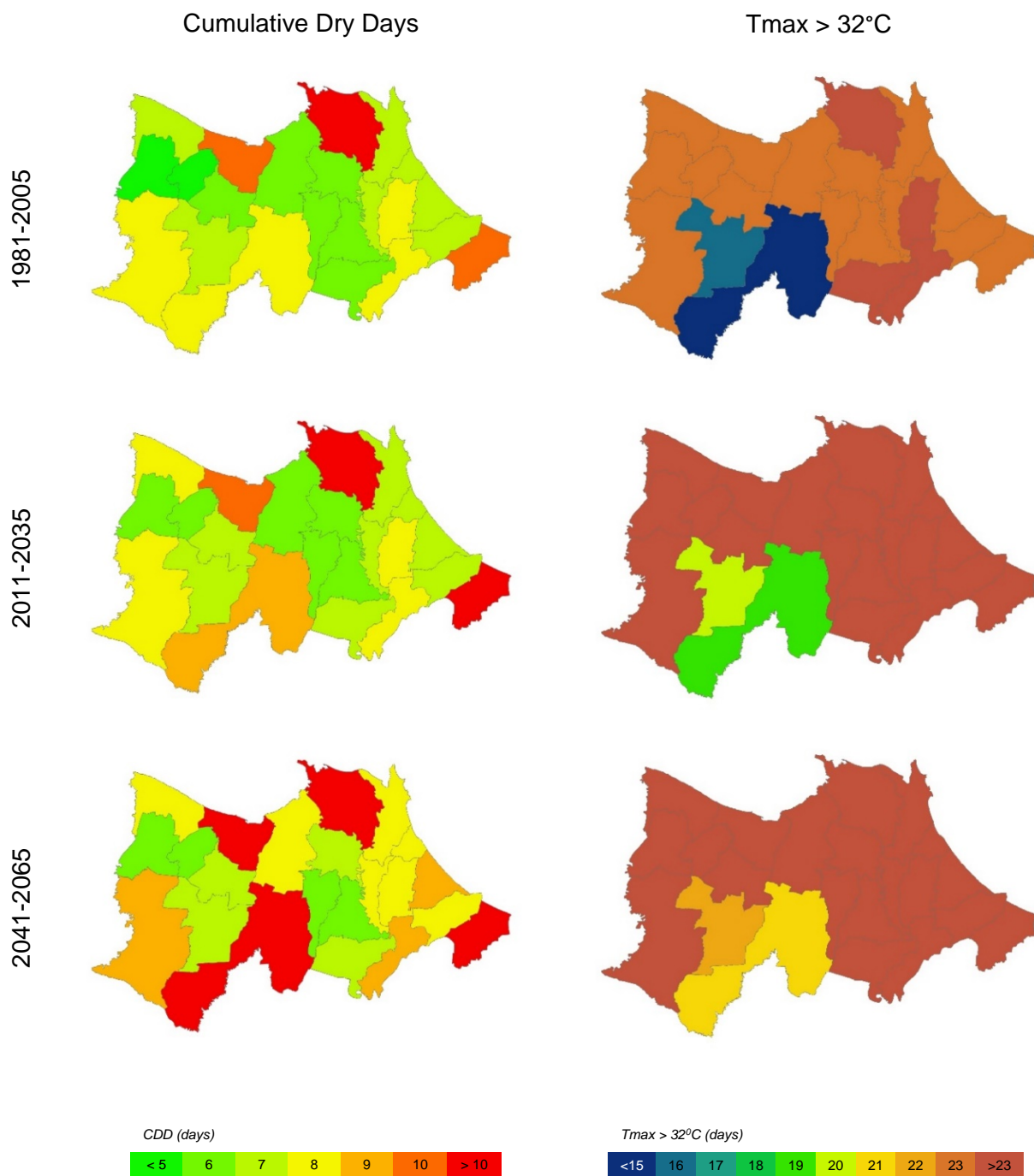
Cumulative Dry Days   Tmax > 32°C

CDD (days)   *Tmax > 32^0C (days)*

< 5   6   7   8   9   10   > 10   <15   16   17   18   19   20   21   22   23   >23

Figure 6. Cumulative dry days and number of days with Tmax > 32°C annually for each period.

The simulations show that rice productivity in all areas of Indramayu regency is projected to decrease in the future (**Figure 7**). This reduction in rice productivity correlates with increasing CDD and T>32°C. Reduction in rice productivity was observed by up to 13% where the greatest reduction in yields is in the 2nd planting season.

1st planting season (October - January)   2nd planting season (February - May)

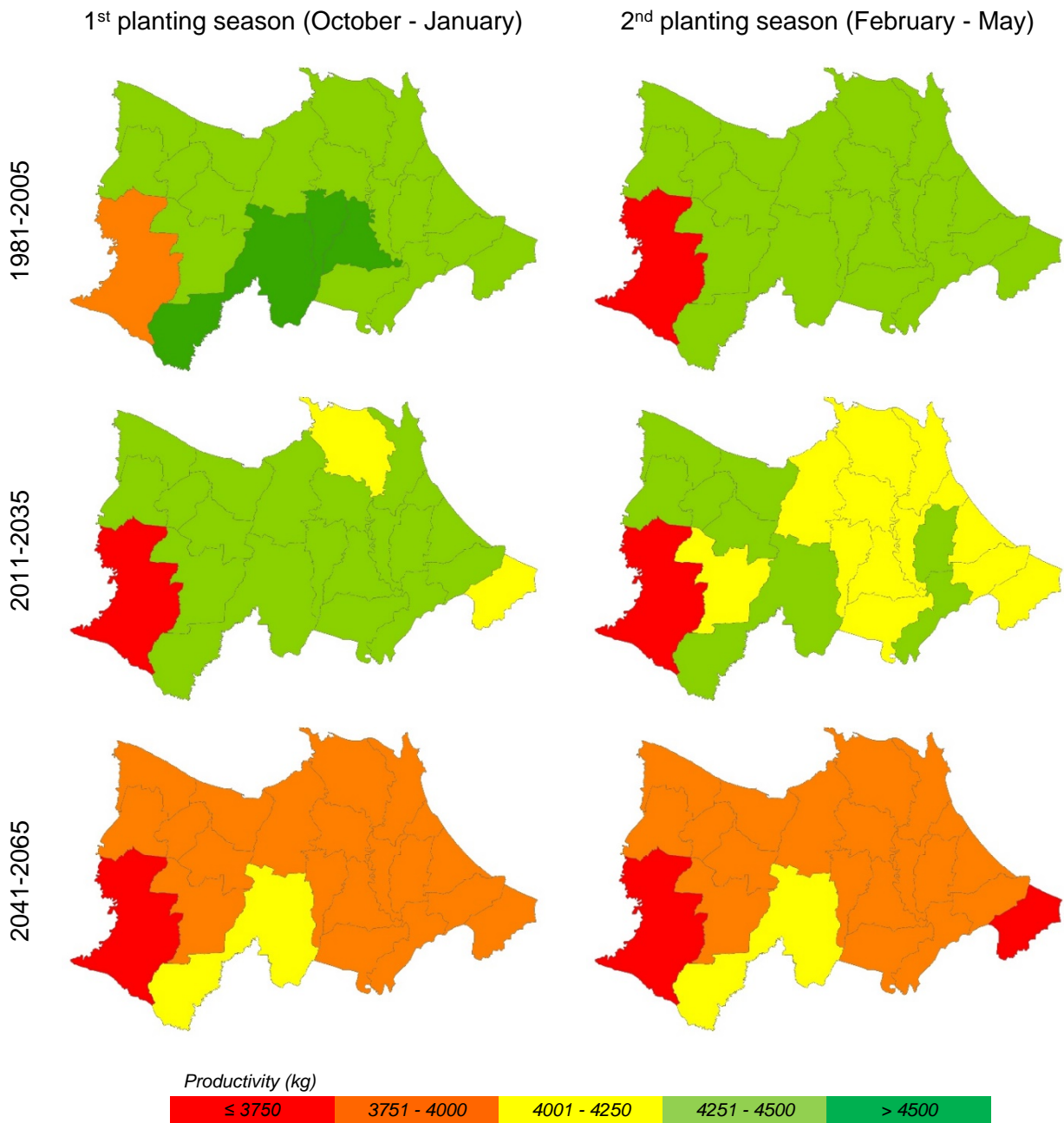| Productivity (kg)				
≤ 3750	3751 - 4000	4001 - 4250	4251 - 4500	> 4500

Figure 7. Rice productivity for two planting times and three time periods with the RegCM4 climate data.

Adaptation Action

As stated in the previous section, CDD and T>32^{0}C are projected to increase in the future. In order to adapt with these conditions, a drought tolerant variety that is not susceptible to low water supply, and a heat tolerant rice variety which has higher limit of optimum temperature is needed to ensure reliable rice production in the future. Climate-based projections in agricultural simulation studies can help agriculture decision makers to understand the long-term impact of climate change on agricultural productivity, while using climate-based projections in agriculture could help to decide optimum planting time in the shorter time periods, especially for operational purposes. Both long- and short-term climate information are required to reduce the impact on rice productivity in the future.

Conclusion

The parameterised and validated APSIM-Oryza module, for IR64 variety in Indramayu regency is able to adequately simulate rice productivity (n=14, R^2 = 0.75, RMSE = 312 kg/ha). Long term simulations of future climate scenarios from the RegCM4 model, under the RCP4.5 emission scenario indicates that a reduction in rice productivity is projected in the future (2011-2035 and 2041-2065) in comparison to the baseline period of 1981-2005 of up to 13%. We report that the projected reduction in rice productivity is correlated with both increasing CDD's and T>32C, having a negative impact to rice productivity. In terms of adaption we suggest that both drought tolerant and heat tolerant cultivars will be required.

Project Conclusions

The world is running out of rice. A key global food security question is: how can rice production be increased without using more resources such as land, water and nitrogen while reducing its carbon footprint? Simulation modelling offers an ideal tool for integrating disciplinary knowledge and providing methods for evaluation of technologies and policies. An emerging opportunity is aerobic rice. Recent advancements in rice simulation modelling enable simulation of rice through the transition between aerobic and anaerobic growing conditions. In this project, we incorporated in-country R&D and combined with simulation modelling to design better farming systems practices that will substanially improve resource efficiency of rice production.

The APSIM-Oryza model was evaluated and parameterised for two long-duration rice varieties for different agro-climatic zones in Sri Lanka. The capability of the model to simulate physiological maturity and grain yield for different rice varieties was considered acceptable. Employing the parameterised model for experimental simulations focussing on a anticipated reduction in rainfall we report that the average rice yield was reduced at all the sites when the simulated amount of rainfall was reduced by 5% and 10% below recorded data within Sri Lanka. The reduction in rice production was less than 8% and 10% when rainfall was reduced by 5% and 10%, respectively. Conversely, rice productivity increased at one site under a reduction in rainfall, although the reason for this response is not known and needs to be assessed further.

Within Myanmar, paddy rice and rainfed rice are major cropping systems across the irrigated costal belt and in central dry zones. Rice yields are heavily reliant on rainfall, which is highly variable in accordance with the strong impact the El Nino-Southern Oscillation (ENSO) has on this region. We found that rice productivity during La Niña years is higher compared to El Niño and the neutral phases of ENSO in Myanmar. Simulation results that take into account seasonal rainfall forecasts indicate that there might be scope for intensification of the dryland cropping systems: during the rainy season, growing soybean could be considered, while in the post-rainy season a short season legumes might be an opportunity in cases when the rainfall forecast is favourable. Both these options would increase the overall water and nitrogen use efficiencies of these systems.

We also evaluated the aerobic rice system in Punjab Pakistan, from biophysical and socio-technological perspectives employing a combined approach of field experimentation and farmer surveys. The results indicate that the aerobic rice system offer great potential for

improving the eco-efficiencies of water, labour, and energy within the Punjab province of Pakistan. However, aerobic rice is what is known as a 'knowledge intensive' technology, requiring far more management skills than traditional rice production systems. Particularly for subtropical conditions, optimal management for aerobic rice is still very much in the development phase. While many farmers have indicated in-principle interest in the technology, their lack of experience constitutes a major hurdle for the broad adoption of the technology. Further, aerobic rice technology is not without trade-offs: often the improved eco-efficiencies of water, labour, and energy comes at the cost of declined efficiencies for N and land. Eco-efficient N management strategies (e.g. using composts and farmyard manure) and bringing wasteland back into production through the provision of the saved irrigation water are some of the proposed measures for improving the productivity and sustainability of agricultural systems within Pakistan.

Rice cultivation in Indonesia has a long tradition of considerable economic importance. Rice remains a staple food for 95% of Indonesia's population. It is also as a source of livelihood for 25 million farmer households across the nation. Hence, fluctuations in rice production and its distribution also influence the national stability. Thus projected climate change studies are critical for Indonesian rice production, and where currently rice production in Indonesia is greatly affected by short-term climate variability, the industry may be impacted upon significantly by long-term climate change, especially that of increasing temperatures. We report from simulation modelling undertaken within regional Indramayu that reductions in rice yields by up to 13% may be expected with a changing climate. We conclude that very high temperatures during the flowering period are a primary cause in a reduction of rice productivity. As the temperature increase beyond 32°C, spikelet fertility and number of grains decreased leading to a reduction in harvestable yields. Reliable water supply is also projected to become a growing issue, increasing the need for more waterstress tolerant cultivars.

Rice is an important crop for all of South Asia, which is comprised of Bangladesh, Bhutan, India, Nepal, Pakistan, and Sri Lanka. Agriculture in the region provides employment and livelihoods for tens of millions of rural families, either directly or indirectly. The region accounts for almost 40% of the world's harvested rice area and almost 25% of the world's population. To maintain regional self-sufficiency in rice, the irrigated and rainfed rice systems must achieve much higher yields over the next two decades whilst simultaneously facing many constraints. The key challenge for South Asian rice production is to ensure ongoing food security while water resources are declining. This project was focussed on beginning to

meet this challenge over the coming years, and part of this work will contribute to meeting these future challenges.

The project addressed all APN goals through supporting regional co-operation, strengthening interactions among scientists and policy makers, and cooperating with and developing scientific and technical capabilities of participating organisations and nations. The project addresses APN's science agenda primarily in the areas of climate change and variability (effect of climate on rice production), land use (intensification of rice systems and potential expansion into new land areas), and resource utilisation (water, nitrogen and other production inputs). The project linked research with policy and decision making processes with respect to sustainable rice production.

Future Directions

The demand for rice is projected to double by 2050, a challenging target in the midst of competing demands for resources, and a changing variable climate. Required rice production increases must be achieved sustainably. Productivity increases must also focus on combinations of intervention action at all levels. Further, this will entail the validation of APSIM across diverse agricultural climatic zones via characterising agricultural climatic zones and suitability for different rice systems, as well as understanding specific causes of rice yield gaps and mapping constraints in specific regions and differing rice systems. A major focus of the UTAS led APN project was to increase the systems analytical capacities of developing scientists and organisations, while strengthening a network of researchers through building further partnerships and collaborative work with fellow colleagues within the APN framework.

A further objective of the project was to make the science outcomes more relevant for policy makers. Unless policy takes relevant scientific insights into account, the science will be limited in its impact. It will also imped the benefits that could flow to societies. The final phase of the project therefore focused on developing a better understanding amongst the scientists involved about the policy process and the communication skills required in order to make excellent science policy relevant. Project participants were challenged to develop policy briefs for each country involved in the project based on their research. The final workshop, held at the Bogor Agricultural University in Indonesia in late 2016 focused on this science – policy nexus. The workshop provided professional development to the participating project scientists with specific attention to the farming systems (rain-fed and irrigated rice) applicable to the participating scientists. Summaries and results were presented by the participating project scientists. The project team emphasised systems

thinking supported by simulation modelling (APSIM) to integrate disciplinary knowledge. Using such skills, the team evaluated and discussed technologies, management options and relevant policies.

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Appendix

Conferences/Symposia/Workshops

Amarasinhga, R.P.R.K., Suriyagoda, L.D.B, Galagedara,L.W., Marambe,B., Silva, G.L.L.P., Punyawardena, R., Nidumolu,U., Howden,M., Parsons, D. and Mainke, H. 2015. Yield advantage and water productivity of maize-mungbean inter-cropping systems in the Dry Zone of Sri Lanka; a modelling approach. 17th Australian Agronomy Conference 2015. http://2015.agronomyconference.com/papers/agronomy2015final00399.pdf

M.E.K.K. Fernando, D.A.B.N. Amerasekara, R.K. Amarasingha, L.D.B. Suriyagoda, B. Marambe, L.W. Galagedara, G.L.L.P. Silva, R. Punyawardena, D. Parsons, H. Meinke 2015. Validation of APSIM for long duration rice varieties in different agro-climatic zones of Sri Lanka. 17th Australian Agronomy Conference 2015. http://2015.agronomyconference.com/papers/agronomy2015final00450.pdf

M.I. Awan, H. Meinke, P. van Oort, L. Bastiaans 2015. Entry points for eco-efficient aerobic rice production system in Punjab, Pakistan. 17th Australian Agronomy Conference 2015. http://2015.agronomyconference.com/papers/agronomy2015final00145.pdf

Final workshop

Appendix 1. *Sivaprakash Ramalingam* - Developing abiotic stress tolerant rice varieties using biotechnological tools for improved agricultural productivity targeting food security.

Appendix 2. *Manjula Madhaven* - In Search of Ecological Rationale for 'The Kerala Conservation of Paddy Land and Wetland Act'

Appendix 3. *Masood Iqbal Awan* - Resource-use efficient alternate rice production systems for Pakistan.

Appendix 4. *Anria and Akhmad Faqih* - Utilization of Crop Growth Model to Support Climate Change Adaptation Action in Rice Farming System.

Appendix 5. *Lana Shabala* – Functional Genomics approaches to food security.
Individual travel throughout the project

Appendix 6. *V.N. Rao* - Evaluating the opportunities for intensifying dry season fallows in rice based systems in South East Asia.

Appendix 7. *Valentine Gueneau* - Impact of Water and Nitrogen in direct seeded rice in regional Sri Lanka: A case study.

Appendix 8. List of Young Scientists

Dakshina Murthy Kadiyala
Agro Climate Research Center, ANGR Agril University
Hyderabad, India.

Dakshina is presently working as Scientist (Agronomy), Agro Climate Research Centre, ANGR Agril University, Hyderabad. Current responsibilities include 70% Research 20% Extension and 10% Capacity Building. Main research responsibilities include development of best management practices for suitable cropping systems in semi-arid tropic regions of Andhra Pradesh using field experimental data and simulation modelling (DSSAT, APSIM etc.,). Up calling of experimental results to district, watershed scales linking crop models with GIS and RS to identify most profitable cropping systems for the rainfed regions of AP state

Dakshina started his career as a Scientist (Agronomy) at Acharya NG Ranga Agricultural University, Hyderabad, India mainly focusing on ground nut agronomy and cropping systems research. Later moving to Rice Research Station at Maruteru, ANGRAU to conduct research on rice based cropping systems and developing best management practices for rice-rice system. During the 2008 Dakshina received a fellowship to pursue PhD at the University of Florida, Gainesville, USA. His PhD research involves solving an important piece of a complex challenge in rice production system. Dakshina studied developing water saving rice production technologies using field experimentation and simulation modelling. Insights from his research would directly help rice growing farmers and enhance water productivity in these ecosystems.

Raji Reddy
Acharya N. G. Ranga Agricultural University (ANGRAU)
Hyderabad, India.

Raji is presently acting as Director, Agro Climate Research Centre, ANGR Agril. University, Hyderabad. Current responsibilities include 30% Administration, 50% research and 20% extension. Conducting research and teaching related to Agrometeorology, crop modelling, crop weather relations in major crops. Preparation of crop contingency plans, drought monitoring and development of mitigation strategies.

Renowned agrometeorologist and agronomist with many years experience working in Asia. Recently became Director, Agro Climate Research centre, ANGRAU, India. Having 30 years of research experience mainly focusing on crop weather relation, crop modelling and cropping systems research.

V Nageswara Rao
International Crops Research Institute for the Semi-Arid Tropics (ICRISAT),
Hyderabad, India.

VN Rao worked as a lead Scientific Officer in the systems modelling of Research Program: Resilient Dryland Systems, International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), India.

He was a conjoint PhD candidate (Agricultural Sciences) at PERC, Wageningen University and Research Centre (WUR), The Netherlands, and at the School of Land and Food (SLAF), University of Tasmania (UTAS), Australia. We mourn his untimely death.

Anria
Centre for Climate Risk and Opportunity Management in Southeast Asia Pasific (CCROM - SEAP),
Bogor Agricultural University,
Jawa Barat, Indonesia

Anria is a Research Assistant at CCROM SEAP (Center for Climate Risk and Opportunity Management in South East Asia and Pacific) since 2012. He was student at Applied Meteorology program in Bogor Agricultural University and received his B.Sc. tittle on December 2011. He granted JASSO (Japan Student Services Organization) scholarship for PARE (Population, Activities, Resources and Environment) program to study at Hokkaido University from October 2015 to February 2016. These programs involve seven universities from Indonesia, Thailand and Japan. Andria has interest in climatology, hydrology and agriculture. He has experience in operating several crop models and has done some research related to rice production systems such as agro-climatic zoning, modelling of water availability and rice harvest yield, and yield gap analysis.

Akhmed Faqih
Centre for Climate Risk and Opportunity Management in Southeast Asia Pasific (CCROM - SEAP),
Bogor Agricultural University,
Jawa Barat, Indonesia

Faqih is a lecturer at the Department of Geophysics and Meteorology, Faculty of Mathematics and Natural Sciences, Bogor Agricultural University (IPB). Currently Faqih is also responsible as a Head of Climate Modelling Division at the Centre for Climate Risk and Opportunity Management in South East Asia and Pacific (CCROM-SEAP), a research centre in IPB that focus its research areas and activities on climate risk management. Faqih received his PhD degree in Climatology (Physical Science) from the University of Southern Queensland, Australia. Prior to this Faqih, in 2003, graduated with a bachelor degree in Agrometeorology at IPB.

Recently Faqih has been actively involved in research studies and consultancies conducted in CCROM-SEAP and in the Department of Geophysics and Meteorology, IPB. Faqihs main research interest is mostly on climate science that involve analyses of climate variability and change as well as on climate modelling aspects.

Gito Sugih Immanuel

Centre for Climate Risk and Opportunity Management in Southeast Asia Pasific (CCROM - SEAP),
Bogor Agricultural University,
Jawa Barat, Indonesia

Gito is a young researcher at Center for Climate Risk and Opportunity Management in Southeast Asia and Pacific (CCROM SEAP), Bogor Agriculture University (IPB). Gito has major studies in Applied Meteorology and also a minor in Expert System. During his studies, Gito has had an opportunity as a Lecturers assistant for agricultural simulation model in the Department of Geophysics and Meteorology and also had an experience to work as a Technical assistant for Relationship between Climate Change and Food Production Strategic: Independent Review Policies in the Field of Trade and Development in SEAMEO BIOTROP. These experiences along with Gito's interest in spatial analysis and modelling system, has built up his competence in environmental and modelling of climate and agriculture.

Ruwanga Amarasingha

University of Peradeniya, Kandy, Sri Lanka.
Ruwanga is an early career researcher at the University of Peradeniya, Sri Lanka. Her major areas of research incorporates systems modelling, with an emphasis on rice production systems throughout Sri Lanka under both rainfed and irrigated conditions. Ruwanga has continued throughout the duration of this project continued to build her scientific capacity in rice systems modelling.

Dr. Sivaprakash Ramalingam

Department of Biotechnology,
M S Swaminathan Research Foundation (MSSRF),
Chennai, India

Dr. Sivaprakash Ramalingam is currently working as a Principal scientist at M S Swaminathan Research Foundation (MSSRF), Chennai, INDIA. He obtained his PhD from

Madras University, INDIA. During his doctoral research, he was involved in biofortification of rice (iron), targeting endosperm specific expression of Avicennia marina ferritin in indica rice using transgenic approach. He was also involved in isolation and characterization of ESTs from the mangrove species (halophyte), Avicenna marina. After his PhD, he spent seven years at John Hopkins University, Baltimore, USA as a Post-doctoral researcher. He worked on targeted genome modification, using custom ZFNs/TALENs to reduce their cytotoxicity and off-target cleavage. His work at John Hopkins using gene-editing nucleases has resulted in several publications and has potential applications in translational research including targeted genome modifications in human cells. Currently, he is working on targeted genome engineering in plants using CRISPR/Cas9 approach to develop transgene-free salt tolerant crop plants. His work with gene-editing nucleases has resulted in two patents and several publications in high impact factor journals. He is a recipient of the prestigious Ramalingaswami Re-entry Fellowship awarded by the Department of Biotechnology, Government of India (2014). He has more than 16 publications to his credit. His work has been cited more than 900 times with an H-index of 13 from his publications (Google Scholar).

Manjula Madhaven
M S Swaminathan Research Foundation (MSSRF),
Chennai, India

Ms. Manjula.M works as Principal Scientist at the M.S.Swaminathan Reserach Foundation, Chennai. She is a post graduate in Agricultural Economics from Tamil Nadu Agricultural University, Coimbatore and is pursuing her Ph.d on 'Household Energy Choice and Demand' from Madras University. She is currently working on issues related to community based adaptation to climate change through risk management strategies and strengthening livelihoods through value chain development.

As an Agricultural Economist, her work involves studying the existing community level practices and knowledge systems using quantitative and qualitative research tools, facilitating participatory development of context specific, viable and eco-friendly adaptation measures for resource poor farmers in the rainfed farming systems and designing appropriate interventions in the case of value chain development. Measuring the outcomes and impacts of the project interventions on the target community is another major aspect of her work as a social scientist in the organization to establish the evidence based research for sharing and up scaling.

Masood Iqbal Awan

Ph.D. (Wageningen University, The Netherlands)

Assistant Professor (Agronomy)

University of Agriculture Faisalabad

Pakistan

Awan has ingrained enthusiasm for science that matters for society. With a background in Agronomy and Crop Physiology, Awan is prepared to acquire knowledge and learn the latest techniques in the field of rice systems research. In Awan's PhD project at Wageningen University, I focused on 'improving resource use efficiency in rice-based systems of Pakistan'. As an alternate to the conventional transplanted-flooded system, he evaluated the so-called 'aerobic rice system'. Awan also attended several professional courses aimed at skill development and competence strengthening during his stay in the Netherlands (2007-2013). Awan was able to absorb and effectively apply the tips, tools and techniques that he learned in Wageningen University courses such as project and time management, interpersonal communication, information literacy, imaging science, interdisciplinary research, mobilising scientific network and techniques for scientific writing. Awan is also an active member of an international collaborative network of rice researchers, funded by the Asia-Pacific Network for Global Change Research (APN) (http://www.apnrice.com/profil/biography-masood-awan). In this project Awan engages with the international collaborative network of rice researchers to propose and design optimal rice-based systems for South Asia (particularly Pakistan and India) with improved use-efficiencies, in particular for water. In future, Awan would like to apply the knowledge and expertise gained at Wageningen University to enhance his understanding of rice-based systems of South Asia against the challenges of climate risks and food insecurity. Awan's aim is to excel in the fields of his research interests: Eco-efficient cropping systems, Alternate production systems, Crop modelling, Robustness, Sustainability, Food security.