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Aerobic Rice: Benefits without going to the Gym?

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Rice, a staple food for over 70% of Asians, is also the single biggest user of water, requiring 2-3 times more water per unit of grain produced than crops such as wheat and maize. With growing populations, increased urbanisation and environmental degradation, the supply of fresh water is depleting. Recognising the water constraints to rice yield, the aim of the project entitled 'Developing a System of Temperate and Tropical Aerobic Rice (STAR) in Asia' was to develop water-efficient aerobic rice technologies. This paper highlights the success of that project.

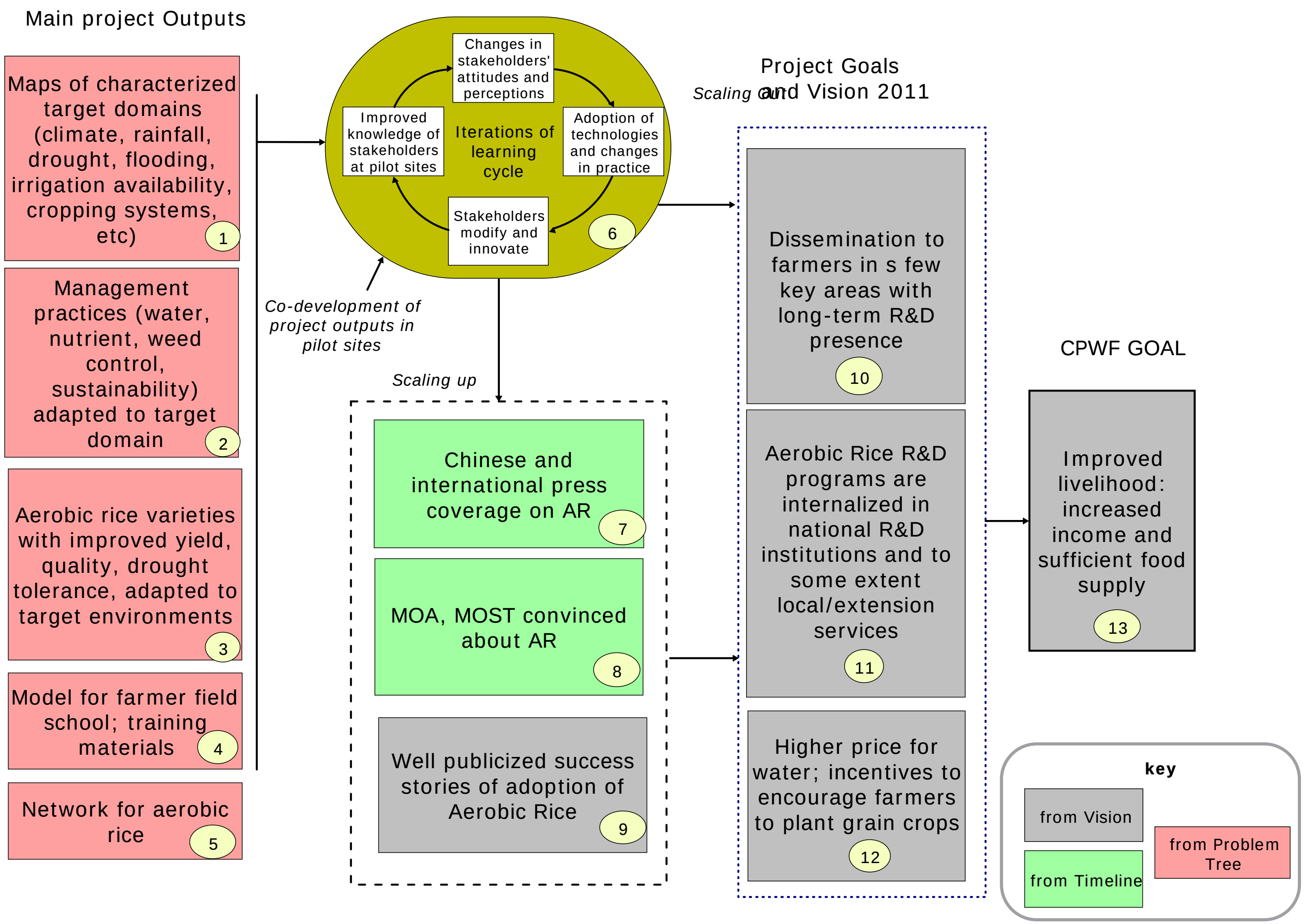
Key Words: Aerobic rice; economic impact

1 Introduction

The purpose of this paper is to evaluate a Challenge Program for Water and Food (CPWF) R&D project entitled 'Developing a Systems of Temperate and Tropical Aerobic Rice (STAR) in Asia', which commenced in October 2004 and ran for 3.5 years, with the aim of developing water-efficient aerobic rice technologies. Aerobic rice is broadly defined as a production system in which input-responsive rice varieties with aerobic adaptation are grown in non-puddled, non-saturated soils. Achieving high yields under aerobic soil conditions requires rice varieties that comprise the drought-resistant characteristics of upland varieties with the high-yielding characteristics of lowland rice. Therefore aerobic rice research, which encompasses both varietal selection and management practices, could be classified as being more adaptive in nature than basic. Nevertheless, given research and adoption lags are typically 5 to 10 years, even for adaptive research, it is early to undertake a full evaluation of the realised economic impact of the project. Hence, this analysis relies heavily on an expert assessment of available information to obtain plausible qualitative and quantitative estimates of *potential* outcomes. Where data allow, farm-level impacts are also examined.

Given the primary purpose of the assessment is to assess the change the STAR project brought about at all levels along the research-to-impact pathway – output, outcome and impact - the analysis is undertaken within an impact pathway framework. Figure 1.1 shows the stylised impact pathway that was first developed by Dr Guanghui Xie on behalf the STAR project team at an impact pathway workshop held in February 2006, and re-worked at the Yellow River Impact Pathways workshop held from 19 – 21 June 2007. This pathway depicts the project team's expectations in terms of outputs, practice change and impact in the Yellow River Basin. The main limitations of Figure 1.1 is that it is not generic (because it was developed to articulate the impact pathway for China), and it does not explicitly include capacity built as an output. Nevertheless, it still provides a guide to the major focal points of the analysis, and to data needs and sources. Capacity build is also implicit in the model Moreover, it helps answer the evaluation question 'Did the project follow the expected impact pathways?'

Figure 1.1: STAR Project: Impact Pathway in China



Very simply conceptualisation of the pathway depicted in Figure 1.1 suggests that the project team expected five main outputs: maps of characterised target domains (Box 1); adapted management practices (Box 2); adapted high-yielding aerobic rice varieties (Box 3); training models and materials (Box 4); and networks for aerobic rice (Box 5). While the outputs depicted in Boxes 4 and 5 are not explicitly stated as planned outputs in the project proposal (sub-section 2.3), they indicate the project teams understanding that effective dissemination of the project results (both scaling-up and scaling out) requires a change in key stakeholders knowledge (capacity built[1]), attitudes and perceptions with regards to aerobic rice (depicted as 'Interactions of learning circle' (Oval 6)). The interactive learning circle is implemented at the pilot research sites which were set up to not only to develop, adapt and validate the new aerobic rice technologies but to do this in partnership with the key stakeholders — scientists, government officials, irrigation managers, extension workers, farmers, etc - that the project wished to influence. It was expected that key stakeholder participation at the pilot sites will lead to individual and collective changes in knowledge, attitudes and perceptions, experimentation, adaptation and adoption (Sub-components of Oval 6) which would inturn lead to scaling-up (Boxes 7, 8 and 9) and scaling-out of aerobic rice technologies to villages and farmers beyond the target sites (Boxes 10, 11 and 12). Widespread adoption of aerobic rice technologies would then result in the CPWF goals of improved livelihoods (increased income and sufficient food supply) being realized (Box 13) being realized.

In line with the impact pathway, the format of this paper is as follows. In Section 2, details of the STAR project and other aerobic rice research are provided. The achievements of the project in terms of intended and unintended outputs are given in Section 3. In Section 4, the realized and potential use or adoption of aerobic rice technologies (outcomes) is examined. The capacity building and farm-level economic impacts of aerobic rice technologies and management practices are examined in Section 5. The conclusions are presented in Section 6.

2 Project Details

2.1 Collaborators, the Research Sites and Budget Details

During the 1980s, the Chinese Agricultural University (CAU) began breeding and selecting rice varieties that were both responsive to agricultural inputs and could be grown under non-flooded conditions (Wang et al 2002). IRRI then commenced collaboration with partners in China on aerobic rice research in 2001. The main purpose of that collaboration, which was supported by the Irrigated Rice Research Consortium (IRRC), was to quantify crop performance and water use, and to examine how alternative water and agronomic management strategies affect the aerobic rice yields. In 2001 and 2002, pilot sites were established for participatory farmer research in, and development of, aerobic rice in villages in the Yellow River Basin. IRRI also started working on aerobic rice in the Philippines in the wet season 2002 with six farmers in Tarlac and four in Nueva Ecija. The activities were mostly evaluation of selected aerobic varieties under aerobic rice management in farmer fields. In India, the activities for aerobic rice started 2003 through the Indian Agricultural Research Institute (IARI). However, overall the activities were modest and the operating budget was small.

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[1] Strictly speaking, the capacity built output is the knowledge and skills gained from he development and implementation of the models, training materials and the networks rather than the models, training materials and networks per se..

The implementation of the STAR project in 2004 enabled acceleration of further understanding and development of aerobic rice systems in China and the initiation of significant research on aerobic rice systems in the Philippines and India. In these countries, the target was aerobic rice systems for water-scarce irrigated areas. In addition, the STAR project enabled initiation of work to identify aerobic rice germplasm suited to favourable rainfed environments in Laos and Thailand. The work was undertaken in collaboration with IRRC (major role in dissemination) and the Consortium for Unfavorable Rice Environments (CURE) (identification and provision of drought tolerant germplasm for testing in Philippines, India, Thailand and Laos) (Table 2.1). Overall the STAR project allowed the researchers to not only increase the number of partners involved, the countries covered and the amount and type of research, but to also undertake scaling-up and scaling-out activities. There were also strong links with the project on 'Developing and Disseminating Water-Saving Rice Technologies in South Asia', supported by a grant from the Asian Development Bank (ADB). Indeed, the achievements of the research on aerobic rice under the IRRC, CURE and the STAR project were important factors that led to the ADB funding of a project aimed at indentifying/developing potential aerobic varieties for a range of locations across South Asia.

Table 2.1 Project information summary

Project number	CPWF PN16
Project name	Developing a System of Temperate and Tropical Aerobic Rice (STAR) in Asia
Duration of project	October 2004 to March 2008
Countries	China, Philippines, Laos, Thailand and India
Funding bodies	CPWF, SDC (IRRC)
Funding amount	US$1,605,596
Related CPWF projects	PN11

Source: IRRI 2004

The STAR project research sites were located in three of the CPWF's benchmark basins -Yellow River, Indo-Gangetic, and Mekong - and in several basins in the Philippines. Specifically, pilot research sites were established in China near Kaifeng in the Liuyuankou Irrigation System in Henan, and Changping, Shangzhuang (CAU farm) and Xibeiwang villages near Beijing, and in Menchen County in Anhui Province. In India, the sites were at the Indian Agriculture Research Institute (IARI) in Delhi and in Bulandshahar District, western Uttar Pradesh (near Delhi) and in the Philippines they were located in Tarlac, Nueva Ecija and Bulacan provinces. In the Mekong Delta, the project sites were at Vientiane, Savanakhet and Champasak in Laos, and at Khon Kaen, Ubon Ratchathani and Phimai in Thailand (Table 2.2).

While China, the Philippines, India and Laos and Thailand were all partner countries, as can be seen from Table 2.2, the greatest percentage of activities were undertaken in China (45%), followed by the Philippines (30%) and India (20%). Only 5% of the activities were undertaken in Laos and Thailand combined.

Table 2.2 Country partners by CPWF benchmark basin and share of project activities.

CPWF benchmark sites	Project partner country	Project sites	Activities %
Yellow River Basin	China	Kaifeng in Henan, Changping, Shangzhuang (CAU) and Xibeiwang villages near Beijing, and in Menchen County, Anhui Province	45
Shallow and deep well systems	Philippines	San Ildefonso in Bulacan, Dapdap and Munoz in Tarlac, and Nueva Ecija	30
Indo-Gangetic Basin	India	Bulandshahar District, western Uttar Pradesh, WTC-IARI Station, Delhi.	20
Mekong River Basin	Laos	Vientiane, Savanakhet and Champasak	5
	Thailand	Khon Kaen, Ubon Ratchathani and Phimai	

Source: IRRI 2004

The participating institutions and project team members are listed in Table 2.3. As can be seen there are seven participating research institutes that received some funding from the CPWF and a further three (all in the Philippines) that participated without any funding. In line with all the CPs, a defining characteristic of this project was the multi-institutional and multi-locational nature of the research that brought together scientists from 11 institutions across six countries (and IRRI being an international organisation). Moreover, the research was undertaken by a strong multidisciplinary team that were able to undertake a range of activities including breeding, agro-climatology, plant nutrition, agronomy, water management, crop modelling, sociology and economics.

Table 2.3: Participating institutes and project team members

Country	Participating institute	Project team
Partners with funding from CPWF		
China	China Agricultural University (CAU)	Wang Huaqi, Yang Xiaoguang, Lin Shan, Xie Guanghui, Liping Feng, Tao Hongbin, Zhang Limeng, Xue Changyang, Yan Ying, Yu Jun, Xiao Qindai
Philippines	International Rice Research Institute (IRRI)	B.A.M. Bouman (project leader), G. Atlin, Dule Zhao, Shaobing Peng, C. Kreye, R. Lampayan, P. Moya, R. Bayot, R. Flor, L. Llorca, E. Quicho
Philippines	National Irrigation Administration Tarlac (NIA-Tarlac)	V. Vicmundo, A. Lactauan, T. Norte
Philippines	Philippine Rice Research Institute (PhilRice)	J. de Dios, A. Espiritu
India	Indian Agricultural Research Institute-Water Technology Centre (IARI-W)	Anil Kumar Singh, Viswanathan Chinnusamy, S.K. Dubey
Thailand	Ubon Ratchathani Rice Research Center (URRCR)	B. Jongdee, P. Konghakote (Khon Kean Rice Research Center)
Laos	National Agricultural and Forestry Research Institute (NAFRI)	Kouang Douangsilla, Sipaseuth
Germany	Institute of Plant Nutrition and Soil Science (IPNSS) Christian-Albrechts-Universität zu Kiel	K. Dittert
Partners without funding from CPWF		
Philippines	Central Luzon State University (CLSU)	A. Espino
Philippines	Bulacan Agricultural State College (BASC)	J. Valdez, J Soriano
Philippines	National Soil and Water Resources Research and Development Center – Bureau of Soil and Water Management (BSWM)	B. V. Villanueva

Source: IRRI 2008

The STAR project was funded through the CPWF and the collaborating institutions. The budget requested from the CPWF was US$884,572, with a further US$721,024 (cash and in-kind) as matching funds from the collaborating institutes. In addition further 'in-kind' contributions were made by the three non-funded partners in the Philippines. (A 6-month, 'no-cost' extension was granted to run the final project workshop and write the final report.) The funding contribution by the CPWF and other agencies (cash and in-kind) is provided in Table 2.4.

Table 2.4: Funding provided by cash and in-kind (US$)

	2005	2006	2007	Total
Contributed funds				
CPWF	320,508	315,720	248,344	884,572
Matching funds (cash or in-kind)				
IRRI	165,624	140,503	88,146	394,273
CAU- Beijing	34,500	34,890	35,288	104,678
NIA	13,550	13,746	13,946	41,242
PhilRice	16,055	16,306	16,562	48,923
IARI-WTC	18,750	19,002	19,259	57,011
NAFRI	0	0	0	0
URRRC	0	0	0	0
CAU-KIEL	24,532	24,963	25,402	74,897
Total Matching	273,011	249,410	198,603	721,024
TOTAL	**593,519**	**565,130**	**446,947**	**1,605,596**

Source: IRRI 2004

2.2 Motivation for the Research and Project Objectives

Rice is a staple food for over 70% of Asians, the majority of whom are living below the poverty line. However, even though rice is an important food source for many millions of people, it is also the single biggest user of water, requiring two to three times more water input (rain, irrigation) per unit of grain produced than the major cereal crops, such as wheat and maize. In fact in Asia, 90% of all fresh water is used to irrigate crops; 50% for rice alone (Barker *et al* 1999). But with growing populations, increased urbanisation and environmental degradation, the supply of fresh water for all human activities is depleting. And the situation is getting rapidly worse. For example, it has been estimated that by 2025, 15 million ha of irrigated rice will suffer 'physical water scarcity', and most of the 22 million ha of irrigated dry-season rice grown in South and Southeast Asia will suffer 'economic water scarcity' (Tuong and Bouman 2002). This has serious implications for not only millions of resource poor farmers, but also for poor rural and urban consumers who will be faced with persistent high food prices if both yield and the area sown to rice continue to trend downwards.

Most of the world's rice production comes from irrigated and rainfed lowland rice fields. The majority is grown by transplanting seedlings into puddled soil, with the fields continuously flooded until shortly before harvest. Significant water losses can occur through seepage, percolation and evaporation, both while the crop is growing and prior to crop establishment during soaking and puddling. With increasing water shortage, there is a need to develop technologies that can reduce these water losses. Promising technologies include water management practices such as intermittent irrigation (e.g., alternate wetting and drying), saturated soil culture (where soil is kept between field capacity and saturation by frequent irrigation, but water is not ponded on the field) and growing rice intensively to increase the 'crop per drop' (Bouman *et al* 2002c). However, each of these approaches still requires prolonged periods of flooding and/or wet surface soil, and so water losses remain relatively high. Consequently, to reduce water loss where water scarcity is a problem, technologies that enable rice to be grown in well drained non-puddled and non-saturated soils without 'ponded' water are required.

Recognising the yield constraint imposed by a lack of an adequate and timely supply of water, the overarching goal of the STAR project was *'to ensure food security and increase sustainable livelihoods in rural and urban Asia, by easing water scarcity as a constraint to agriculture, economic development, and nature conservation'* (IRRI 2004, p.10). However, as alluded to above, the STAR project was not the only research project that has attempted to, or still is addressing, the problem of water scarcity. There is a considerable amount of research on this matter in both tropical and temperate areas world-wide (IRRI 2004, pp. 7-8), although most of this research is on technologies such as alternate wetting and drying, saturated soil culture etc. Development of the system of aerobic rice is somewhat different because it brings together direct seeding into non-puddled soil with input responsive varieties able to yield well in aerobic soil. The aerobic rice research undertaken by the CAU with IRRI since 2001 shows that aerobic rice varieties could produce yields of up to 6 t/ha using 50% of the water used in lowland rice in the temperate rice growing regions of north China. However, there had been little progress in the screening and selection of aerobic rice varieties for the tropics and semi-arid tropics. In addition, sustainable crop-soil-water management and crop establishment recommendations were lacking, without which production and environmental sustainability could be threatened. For example, it had already been established that a shift from continuously flooded to aerobic conditions may seriously affect soil health and weed dynamics, which can result in a significant reduction in yield in just three to four years of continuous cropping. Moreover, the environment could be adversely affected from nitrate leaching and herbicide use in aerobic systems. Finally, while the water-scarce areas were broadly recognized, there was a lack of understanding of the bio-physical and socio-economic characteristics of the prime target domains.

To address these varietal and management information gaps, the specific objectives of the STAR project were to:

1. Identify and develop aerobic rice varieties with high yield potential;

2. Develop insights into key processes of water and nutrient dynamics;

3. Identify key sustainability issues, and propose remedial measures;

4. Develop practical technologies for crop establishment;

5. Characterize and identify target domains.

To achieve these objectives, the STAR project targeted:

- Irrigated areas where water scarcity restricts lowland rice production – the major focus of the STAR project – for China, Philippines and India;

- Favourable rainfed areas – areas where only rainfed rice can be grown, but where rainfall is sufficiently well distributed and adequate to allow response to inputs (especially fertilisers) – the focus for Thailand and Laos.

It should be noted that while the STAR project comprises five distinct objectives, the in-country research did not encompass all of the objectives in each of the countries. Rather the project was implemented in a way to take advantage of the status of aerobic rice research in each of the target sites of interest. For example, because temperate aerobic rice varieties had already been identified and developed in China, the focus in the China target sites was on objectives 2-5. Indeed, by early 2000, there were reports that Chinese farmers were obtaining yields of up to 6 t/ha growing aerobic rice varieties in water-scarce areas under non-flooded and non-puddled conditions. Similarly, as IRRI has an aerobic rice breeding program in the Philippines, which had identified input-responsive and lodging-resistant improved upland and hybrid varieties as potential aerobic rice cultivars prior to the STAR project, emphasis in the Philippines was again on objectives 2-5. In contrast, in Thailand and Laos, there had been no screening for aerobic conditions prior to the STAR project. Consequently, objective 1 on identifying and developing high-yielding aerobic rice varieties was the primary focus of research in the Thailand and Laos sites. Some on-farm testing under different management methods (objective 4) was also included in Thailand. In India, screening of aerobic varieties was initiated in 2002 by IRRI through CURE. As part of the STAR project, the varietal screening continued and included combined variety screening with water and seed rate experiments (objectives 2 and 4).

2.3 Planned Outputs

As stated in the project proposal the intended outputs included the following components of aerobic rice technology:

1. First generation of tropical aerobic rice germplasm with high yield potential, and improved aerobic rice varieties in China.

2. Basic crop water and crop nutrient relations understood.

3. Prototype aerobic rice production systems focusing on water and nutrient management, crop establishment and weed control, and crop rotations.

4. Key sustainability and environmental impact indicators identified.

5. Trade-offs between water use and yield quantified, and impact on water savings assessed.

6. Potential target domains characterized in biophysical and socioeconomic terms.

The proposed research activities and methodologies to achieve the outputs included pot and on-station controlled experiments for varietal selection, breeding, crop-nutrient-management analysis and nematode ecology. On-farm participatory research was also planned to develop practical technologies for aerobic crop establishment, weed control, and crop rotation. Farmer surveys were designed to examine factors affecting adoption with GIS tools considered to help determine domains likely to be suited to aerobic rice technologies in terms of soil type, climate, hydrology and socio-economic conditions. Simulation modelling was also intended to extrapolate experimental findings to wider environments (soil, weather, and hydrology) and compute irrigation water requirements and yield levels under different irrigation management scenarios.

3 Project Outputs

3.1 Achieved Intended Outputs

Determining the achievements of a R&D project at the output level is generally relatively straightforward. However, in the case at hand, it was not a trivial task because the write-up of the results in the final project document is not directly comparable to the description of the proposed outputs in the project proposal. As such, the description of the outputs provided below follows the final report (IRRI 2008), while in Table 3.1 this information is used to assess whether the proposed outputs were achieved as specified in the project proposal (IRRI 2004, p 15).

Actual outputs from the STAR project, as documented in the final report, include: (a) locally-adapted high yielding temperate and aerobic rice varieties suited to conditions in China, Philippines and India; (b) knowledge of basic crop water and crop nutrient relationships in China, the Philippines and India; (c) limited understanding of the causes and extent of factors that affect the sustainability of continuous cropping aerobic rice; (d) knowledge of the effects of seed rate and row spacing on aerobic rice yields in China, the Philippines and India; and (e) Limited information on potential target domains characterized in biophysical and socioeconomic terms.

Key technical outputs from 3.5 years of project operation are as follows:

(a) Locally-adapted high yielding temperate and aerobic rice varieties suited to conditions in China, Philippines and India (Objective 1, Output 1)

Selection of aerobic rice varieties involved evaluation of advanced breeding lines and existing varieties in all countries, on-station and also in on-farm participatory trials in India and the Philippines. Multi-variety field trials and farmer participatory selection were also undertaken in the Philippines, India and Thailand. In sum, while the STAR project did not breed new rice varieties, it confirmed that aerobic rice varieties can yield 4-6 t/ha using significantly less input water than lowland rice (see below). Moreover, experiments undertaken showed that, even though aerobic rice is water efficient, it can withstand prolonged flooding. The STAR project identified three varieties suitable for aerobic rice production in China (HD277, HD297 and HD502), a further three in the Philippines (PSBRc9 [Apo], UPLRI5, and PSBRc80) and four varieties in India (Pusa Rice Hybrid 10, Proagro6111 (hybrid), Pusa834 and IR55423-01 [Apo1]). All these varieties are available without restriction though private seed companies or national seed distribution channels. However, yields of aerobic rice in farmers' fields in China were usually only around 3-4 t/ha of researchers' yields of 5-6 t/ha, and in China, India and the Philippines, maximum yields of aerobic rice were only about two thirds of achievable yields with traditional lowland rice culture. While promising breeding lines were identified in Laos and Thailand, further breeding is required before suitable lines can be determined and released.

Table 3.1: Achievement of intended outputs

Intended outputs	Achievement status by country				
	China	**Philippines**	**India**	**Laos**	**Thailand**
1. First generation of tropical aerobic rice germplasm with high yield potential, and improved aerobic rice varieties in China.	Achieved: Identified the yield potential and suitability of three main aerobic rice varieties HD277, HD297, HD502.	Achieved: Identified suitable and released varieties Apo (PSBRc9), UPLR15, PSBRc80.	Achieved: Identified suitable and released varieties Pusa Rice Hybrid 10, Proagro6111 (hybrid), and Pusa834.	Not achieved: Progress was made in identifying higher yielding germplasm; further research needed to develop suitable varieties.	Not achieved: Progress was made in identifying higher yielding germplasm; further research needed to develop suitable varieties.
2. Basic crop water and crop nutrient relations understood	Partly achieved: Further research on nitrogen and micronutrients needed.	Partly achieved: Further research on the relationship between soil sickness for aerobic rice and the nitrogen source and management needed.	Partially achieved: Further research needed to determine if yield can be increased by changing fertiliser management.	Not planned. Limited number of experiments on crop nutrient response conducted.	Not planned and not achieved.
3. Prototype aerobic rice production systems focusing on water and nutrient management, crop establishment and weed control, and crop rotations.	Largely achieved: Research on irrigation and agronomic management (e.g., row spacing and seed rate) undertaken in-country and general information on other crop management options provided; no research to date/long-term trials on sustainability	Largely achieved: Row-spacing experiments were undertaken in-country and general information on other crop management options provided.	Partly achieved: Seed rate experiments were undertaken in-country and general information on other crop management options provided.	Not planned and not achieved.	Not planned and not achieved.
4. Key sustainability and environmental impact	Not planned: In-country research activities were not	Partially achieved: Further research needed.	Not planned and not achieved.	Not planned and not achieved.	Not planned and not achieved.

Intended outputs	**Achievement status by country**				
	China	**Philippines**	**India**	**Laos**	**Thailand**
indicators identified	undertaken.				
5. Trade-offs between water use and yield quantified, and impact on water savings assessed	Largely achieved: Field and modelling studies undertaken. Further research needed to quantify actual water savings at field and spatial system scales and "downstream" impacts.	Partially achieved: Further research needed to quantify actual water savings at field and spatial system scales and "downstream" impacts.	Partially achieved: Further research needed to quantify actual water savings at field and spatial systems scales and "downstream" impacts.	Not planned and not achieved.	Not planned and not achieved.
6. Potential target domains characterized in biophysical and socioeconomic terms	Largely achieved.	Not achieved.	Not achieved.	Not achieved.	Not achieved.

(b) Knowledge of basic crop water and crop nutrient relationships in China, the Philippines and India (Objective 2, Output 2) and tradeoffs between water use and yield quantified, and impact on water savings assessed (Objective 2, Output 5)

During the life of the project, water and nutrient dynamics were examined through a number of on-station and in-field experiments conducted in several sites in China, the Philippines and India. In addition, further insights were obtained through simulation modelling for China. Nitrogen and row spacing experiments were undertaken in the Philippines and N, P and K experiments were carried out in China and Laos. In terms of increased understanding, elucidation of the difference in the relationships between input water and yield for aerobic and lowland rice was important because it helped to define, in terms of water availability, which production system (aerobic or irrigated lowland) is likely to optimize yield for a given location. It also highlights the usefulness of generating water-responsiveness data for other regions to determine where aerobic rice systems might be appropriate.

(c) Limited understanding of the causes and extent of factor that affect the sustainability of continuous cropping aerobic rice (Objective 3, Output 4)

Earlier research in Japan, the Philippines and Brazil has shown that continuous mono-cropping of upland rice varieties results in declining yield (George et al 2002; Nishizawa et al 1971; Pinheiro et al 2006). While possible causes for this are believed to be due to a build-up of nematodes (Nishizawa et al 1971), soil pathogens, toxic substances from root residues (Nishio and Kusano 1975) or a decline in nutrient availability (Lin et al 2002), evidence to date is inconclusive.

Research activities undertaken within the STAR project were undertaken to see if the same yield decline would occur in continuously cropped aerobic rice and to determine the causes of any documented decline. The pot and field experiments designed to determine the causes and severity of yield decline in continuous aerobic cropping systems were largely undertaken at IRRI in Los Baños, Philippines (both prior to, and as part of the STAR project). The variety Apo (PSBRc9) was used for all the experiments. The yield effects from continuous cropping were very clear – yield declined by 2.5 t/ha by the 7th season. Nematode counts were found to be higher in aerobic fields than in the continuously flooded fields, although no correlation was found between nematode counts and grain yield.

The same research also showed that yield decline could be reversed through crop management practices that incorporated crop rotations, fallowing and/or flooding. The results of the research showed that flooding for three consecutive seasons or fallowing for two seasons were equally effective in restoring aerobic rice yields but cropping with upland crops such as soybean, sweet potatoes or maize was even more effective. On the other hand, the application of micro-nutrients such as P ad K had no effect but crop growth was consistently improved with N fertiliser application. The research also showed that after the 10th season yields increased spontaneously suggesting a self-regenerating mechanism – although this is little understood.

Despite the research undertaken at IRRI, by the end of the STAR project, the precise reasons for, and extent of, yield collapse in continuous cropping aerobic rice in Asia were still not fully understood. Hence, further research is required to fully identify key sustainability and environmental impacts. In the meantime, it is recommended that consecutive crops of aerobic rice should not be grown on the same field.

(d) Knowledge of the effects of seed rate and row spacing on aerobic rice yields in China, the Philippines and India (Objective 4 and part of Output 3) and initial management options and guidelines with respect to aerobic rice establishment, irrigation, weed control and fertilization (Objective 4, Output 3)

Multi-factor experiments were undertaken to determine the effects of seed rate and row spacing under different water and N regimes on the yield of aerobic rice. These experiments were limited to China (seed rate and row spacing) and India (seed rate) and the Philippines (row spacing). The main conclusions to be drawn from the experiments are that the yields of dry-seeded aerobic rice varieties (Apo in the Philippines and HD297 in China) are not very responsive to row spacing between 25 cm to 35 cm or seed rates between 60 to 135 kg/ha. In India, the yield of Pusa hybrid rice variety was unresponsive to seed rates between 40 and 80 kg/ha but fell substantially when the seed rate was below 40 kg/ha. It was suggested that the relative unresponsiveness to row spacing and seed rates will provide farmers with some flexibility; while higher seed rates may suppress weed growth, it will cost more.

The STAR project provided some initial management options and guidelines for aerobic rice production. These covered crop establishment methods, seeding rates, row spacing, irrigation requirements and fertiliser application (quantity and timing). For example, it is suggested that before seeding, the plot should be ploughed and harrowed to obtain smooth seed beds. Seeds can then be dry seeded at a depth of 1-2 cm in clay soils and 3-4 cm in loamy soils. (Alternatively, seedlings can be transplanted in to saturated clay soils that are kept wet for a few days after transplanting.) While the experiments did not show that yields are responsive to seed rate or row spacing (within reason), it is suggested that optimal seed rates are around 70-90 kg/ha and row spacing could be in the order of 25-35 cm. If grown in the dry season, the prime irrigation recommendations are to apply 30 mm after sowing to promote emergence and then, depending on rainfall quantity and pattern, irrigate around flowering. As aerobic rice is not grown in permanently flooded soils, weeds can be a problem. To control weeds a pre- and/or post-emergence herbicide (plus some manual or mechanical weeding) is recommended. Fertiliser requirements will depend on the level of nutrients already available to the crop. Leaf colour charts (LCC) can be used to determine site-specific nitrogen (N) needs. In the absence of LCCs and the knowledge and skills in site-specific nutrient management, it is recommended that around 70-90 kg N/ha is a good starting point – with adjustments made as necessary. The nitrogen should then be split into three applications. In the case of direct seeding, the first application should be applied 10-15 days after emergence, the second split at tillering and the third split at panicle initiation. It may also be necessary to apply phosphorous (P) and zinc on high pH soils.

(e) Information on potential target domains characterized in biophysical and socioeconomic terms (Objective 5, Output 6)

Target domain analysis was undertaken to determine the bio-physical and socio-economic suitability of the aerobic rice technology beyond the research sites. The main focus of the domain analysis was China. The components of the domain analysis undertaken solely in China included field experiments (Changping, Beijing), variety zoning (whole of country), crop modelling and linking with GIS (Beijing, Tianjin, Shandong, Hebei, Henan), and household surveys (Kaifeng, Tianjin, Shandong, Hebei, Henan). Global extrapolation domain analysis was also initiated based on site similarity analysis (poverty, climate) with the project pilot sites in all project countries except the Philippines, and taking into account slope, presence of irrigated lands and presence of rice growing – although at the time of the final report this work was still underway (Rubiano and Soto 2008).

The main findings of this research were:

- In northern China, the target domains are areas where water availability (with and without irrigation) is 400 to 900 mm during the cropping season, with HD297 and HD502 (among others) being the most suitable varieties.

- Yields of 5 to 6 t/ha are attainable in the central part of the Yellow River Basin (Kaifeng area), and in most of the North China Plain.

- In these areas of China, farmers currently obtain 3 to 4 t/ha of aerobic rice, providing them with returns largely comparable to those from upland crops such as maize and soybean. If farmers could achieve aerobic rice yields of 6 t/ha, then aerobic rice would be more profitable than the upland crops. The respondents from farmer surveys stated that the main advantages of growing aerobic rice are being able to grow rice, the ease of establishment, low labour requirements and good eating quality. The main disadvantages highlighted by the respondents are low yield, difficulty in controlling weeds, insufficient support from extension agencies and limited market acceptance (despite the good eating quality).

- Extrapolation domain analysis at a 70% probability of finding similar socioeconomic and climatic conditions to the pilot sites in Asia, Africa and Latin America suggests that aerobic rice can have large impact in India, followed by China, Thailand and Burma (Rubiano and Soto 2008).

3.3 Achieved Unintended Outputs

Capacity built

The STAR project is a prime example of an R&D project within which capacity building was an integral part of the project activities. Much of the capacity building was done through 'learning-by-doing'. This hands-on experience was an important part of training for the 22 graduate and undergraduate students who were directly involved in the project[2]. Several graduate students and researchers from the STAR project countries were also trained at IRRI through direct participation in the aerobic rice experiments. In addition, aerobic rice was a component of many training courses on water management. These training courses were facilitated by the STAR project and the Water Working Group of the IRRC. The majority of the courses were undertaken in the Philippines although they were also undertaken it Bangladesh, Myanmar and Vietnam. The course topics included applied science, water management and extension. As such, the courses were not designed for farmers but rather for farmer intermediaries who could in turn pass on some of their new knowledge, understanding and skills to the farmers. Trainees included staff from institutes, universities, extension agencies and irrigation system administrators. It is estimated that in total 1589 attendees received training on aerobic rice from 2004 to 2008 (IRRI 2008).

Therefore, even if not explicitly stated as an output in the final project report, a significant achievement of the STAR project is capacity built. This was recognised as at the impact pathway workshops held in February 2006 and June 2007. Relative to the level of capacity prior to the commencement of the project, the change in capacity that can be directly attributed to the project's activities cover four main categories:

- Development of skills, knowledge and confidence of the researchers, extension agents, farmers and others, in the partner countries including networks or linkages of researchers formed.
- Development of the stock of knowledge available to researchers within the organisation and/or the wider research community.
- Development of research tools such as methodologies, databases, specialised equipment (e.g., crop growth simulation models such as ORYZA2000, IMPACT-WATER Model, extrapolation domain analysis and GIS)
- Organisational capacity to undertake research efficiently and effectively and attract research funding, and organisational linkages formed.

In China, the knowledge and skills the scientists at CAU gained through the STAR project enabled them to conduct rigorous research (including undertaking a multi-disciplinary approach to aerobic rice research), collect and analyse scientific data and write-up the

[2] Of the 22 students, 14 were enrolled in CAU, three and Central Luzon State University(Philippines), two at the University of the Philippines, Los Baños, two at Wageningen University (Netherlands) and on at the Universita degli Studi di Firenze (Italy)

results. The scientists were also exposed to the concept of being impact-focussed – that is thinking beyond the life of the project – at the impact pathways workshops held in Vientiane in February 2006 and June 2007. Exposure to GIS, simulation modelling and socio-economic indicators, increased awareness of the suitability of aerobic rice technologies beyond the targeted project sites. In addition, links between CAU scientists and scientists in other countries were established through formal and informal networks. These networks not only further increased the knowledge and skills of the CAU scientists, but also gave them the opportunity to pass on their experiences with other scientists through the networks and at international conferences and workshops. Overall the stock of knowledge available to researchers within the CAU and to the wider research community increased as is evident from the number of key research papers that were published in a number of international journals (e.g., Bouman et al 2006, 2007; Feng et al. 2007; Lixiao et al 2007; Xue et al 2008).

All of this culminated in the CAU having a reputation, both nationally and internationally, for undertaking relevant and robust research on aerobic rice technologies, which enhanced their ability to attract further funding for aerobic rice research from both national and international sources. For example, the CAU is receiving US$50,000 (CNY350,000) as part of the US$1.5 million (CNY10 million) Ministry of Agriculture-funded project entitled 'Creating new technology platform to discover profitable genes in crops' (2006-2010). The role of the CAU in this project is to develop drought tolerant rice varieties and discover relevant new genes in rice. In addition, the CAU is collaborator in a European Union (EU) US$2.2 million (EUR1.7 million) project entitled 'Developing drought-resistant cereals to support efficient water use in the Mediterranean area (Europe Union-FP6 2006~2008)'. As part of this project, the CAU is receiving around US$130,000 (EUR100,000) to develop drought tolerant rice varieties and identify germplasm field drought tolerance for the Mediterranean area and partners.

Capacity built was also a significant output in the Philippines. The capacity of scientists and/or students at PhilRice, CLSU, BASC and BSWM to undertake aerobic rice research was increased. For example, BASC added an aerobic rice component to their applied research program focussing on crop management and varietal selection. Also BASC and BSWM jointly initiated numerous applied research and demonstration activities passing on their knowledge of aerobic rice technologies to farmer groups. In addition, farmer training, demonstrations and field days were funded through local government units (LGU) and village leaders and BASC and BSWM became successful in applying for national R&D grants (IRRI 2008).

The incorporation of aerobic rice in the applied sciences programs and extension activities of the various partner institutes, and the ability of the institutes to obtain further funding for aerobic rice research provides a strong indicator that the knowledge and technical and management skills of the individuals and the institutes as a whole were increased as a direct result of their involvement in the STAR project.

In addition to the capacity built through formal research and education platforms, national and local partners in both China and the Philippines facilitated demonstration and training workshops aimed at building the awareness, knowledge and skills of next and final users of aerobic rice technologies. In China, the CAU organised large-scale training and demonstration sessions in Fengtai, Mencheng, Kaifeng, Funan and Fengyan with a minimum of 50 to 100 participants attending each training activity. For example, in September 2005 an aerobic rice demonstration and training session was held in Fengtai County. The 150 participants came from seven counties and consisted of farmers, technicians from extension stations, managers of seed companies and rice mills, and government officials. In the Philippines, the irrigation managers (NIA-Tarlac), extension workers and farmers learnt about locality-specific promising aerobic rice varieties and management strategies through the capacity-building activities of the project.

An indicator of the capacity built from demonstrations and training workshops is the results of post-training competency tests. However, these were not undertaken so a direct measure of the degree of any increase in knowledge and skills is not available. Nevertheless, given the number and background of the participants, it would be reasonable to expect that the capacity of the participants of the aerobic rice demonstrations, meetings and field days would have been increased.

4 Adoption

Clearly, outputs will not translate into impact unless they are used. This section describes how the outputs set out in the previous section are being used by the next (researchers, irrigation managers, and farmer intermediaries) and final users (famers). The discussion examines what has happened to date, as well as making an assessment of future adoption. However, it should be noted that while all participating countries were covered in Sections 1 to 3, in the remaining sections the focus is on China and the Philippines. The reason for this is threefold:

- As shown in Table 2.2, 75% of the project activities were conducted in China (45%) and the Philippines (30%).
- Aerobic rice technologies are more advanced in China and the Philippines.
- Due to time and resource constraints, the 'ground-truthing' activities undertaken as part of this assessment were limited to China and the Philippines (See Tables 4.1).

Table 4.1. Key informants

Date	Place	Key informant(s)
Philippines: Tarlac and Bulacan Provinces		
5 March 2008	National Irrigation Administration Office, Tarlac City, Tarlac, Philippines	Dr. Vicente Vicmudo (Manager), and Mr. Armilito Lactaoen (Researcher)
5 March 2008	Barangay Canarem, Victoria, Tarlac, Philippines	Mr. Ramon Ganiban (Farmer), and Mr. Manuel Apolonio (Farmer)
6 March 2008	Bulacan Agricultural State College, San Ildefonso, Bulacan, Philippines	Dr. Junel Soriano (Director for Research, Extension and Training)
6 March 2008	Norzagaray, Bulacan, Philippines (Field Day)	Farmers from Barangay Bangkal, Barngay Banaca, Barangay Matiktik, Barangay Partida, and Barangay Tigbi in Norzagaray, Bulacan. Representatives from Bulacan Provincial Agricultural Office, Municipal Office of Norzagaray, the National Economic and Development Authority, and Bulacan Agricultural State College
6 March 2008	San Ildefonso, Bulacan, Philippines	Mr. Nemencio Concepcion (Farmer)
China: Anhui and Beijing Provinces		
13 October 2008	China Agricultural University, Beijing, China	Dr. Wang Huaqi, Dr. Yang Xiaoguang, Dr. Lin Shan, Dr. Xie Guanghui, Dr. Tao Hongbin (CAU staff who are involved in the project)
15 October 2008	Fengtai county, Anhui province, China	Mr. Liu Shichong (County Official)
15 October 2008	Shangtang town, Fengtai county, Anhui province, China	Mr. Li Guomin (Town Official) Mr. Wang Chenguo (Farmer)
16 October 2008	Market place, Shangtang town, Fengtai county, Anhui province, China	Cheng Longfei, An Fenli, Li Zhifu, Wang Li, Sun Fangli (Farmers)
16 October 2008	Shangtang town, Fengtai county, Anhui province, China	2 aerobic rice farmers and 2 lowland rice farmers Mr. Hu Qilin (Agricultural Supply Shop Owner)
17 October 2008	Funan county, Anhui province, China	Mr. Xiang Tianfu and Mr. Ding Guangli (Funan Agricultural Science Research Institute) Mr. Hou and Mr. Zhao Wei (Seed distributors)
17 October 2008	Heshong village, Funan county, Anhui province, China	4 aerobic rice farmers
17 October 2008	Collective farm producing seeds, Funan county, Anhui province, China	3 farmers
17 October 2008	Fupo village, Funan county, Anhui province, China	3 aerobic rice farmers
18 October 2008	Dingzhai village, Funan county, Anhui province, China	5 farmers
18 October 2008	Rice mill, Funan county, Anhui province, China	Mr. Xiang (Town official), and Mr. Lei (ATES staff)
18 October 2008	Collective farm producing lowland rice (direct-seeded), Funan county, Anhui province, China	Mr. Zhang (providing technical support to farmers)
19 October 2008	Xincai county, Henan province, China	Mr. Gao Junshan (Manager of a seed company) Mr. Ren (ATES staff)
20 October 2008	Xincai county, Henan province, China	Mr. Ma (Xincai Bureau of Agriculture)
20 October 2008	Fuyang city, Anhui province, China	Mr. Ren Yiming (Manager of a seed company)
22 October 2008	China Agricultural University, Beijing, China	Dr. Wang Huaqi, Dr. Yang Xiaoguang, Dr. Lin Shan, Dr. Feng Liping, Dr. Dingming Kang (CAU staff who are involved in the project)

4.1 Capacity utilisation

The knowledge and skills that the researchers in China and the Philippines gained through their participation in the STAR project led to numerous practice changes. In China, one of the most significant changes was the type of aerobic research undertaken at the CAU. Prior to being involved in the STAR project, aerobic rice research was primarily undertaken by plant breeders. It is now undertaken by a multidisciplinary team with hydrologist, agronomists, crop scientist, social scientists and modellers joining the plant breeders to undertake collaborative research with the common goal of developing locally-adaptive aerobic rice varieties. Research was also undertaken in the farmer fields, rather than just at the research station, and the scientists became actively involved in farmer participatory field monitoring and socio-economic surveys. In addition, because of exposure to the international aerobic rice community, through the networks established by the STAR project and attendance and participation in international forums, the researchers gained an international perspective on the type and extent of the aerobic rice research being undertaken, and methods being used, which influenced the design of their experiments. In particular, issues surrounding yield collapse due to mono-cropping aerobic rice varieties, the need for appropriate crop management practices to be developed and 'packaged' with the promising aerobic rice varieties, and the benefits of undertaking long-term experiments, now feature in the research being undertaken by the aerobic rice research team at CAU.

In the Philippines, the original partners engaged in the STAR project were PhilRice and NIA-Tarlac. They used the knowledge and skills gained to organise and participate in numerous national training programs and workshops on aerobic rice which attracted other institutes who became non-funded partners in the STAR project (see Table 2.3). These partners then used some of their knowledge and skills in their research, teaching, training and/or extension activities (as mentioned above).

4.2 Factors affecting adoption

Past experience shows that even if a R&D project achieves the planned outputs, it does not necessarily follow that they will be adopted by the intended users. Broadly speaking, there are a number of special challenges to adoption, and hence impact:

- The requirements of the intended users need to be clearly understood;
- Change is often complex and depends on numerous factors outside the control of the researchers;
- Researchers have little control over the final processes or steps towards impact as someone else is usually responsible for working with the final users;
- Adoption and impact often occurs long after the project is finished.

The key informant interviews undertaken in both China (October 2008) and the Philippines (March 2008) suggest that all these challenges were considered in the design and implementation of the STAR project.

Meeting the needs of farmers

In China, the areas visited for the key informant interviews were typically both drought- and flood-prone (Table 4.1). In line with these climatic conditions, a prime reasons for growing aerobic rice (as stated by government officials, farmer intermediaries, and the famers themselves) is that aerobic rice is both drought and water logging resistant (see table 4.2). The key informants stated that there had been significant crop losses in the past with other summer crops such as maize and soybean due to water logging because of flooding. As a result of these yield losses, aerobic rice is seen as a profitable alternative.

Another important characteristic of aerobic rice technology that meets the requirements of farmers is that management is relatively simple, saving on labour inputs. This is important in an area now characterised by labour shortage due to outmigration. In fact, Ding et al (2008) found that labour saving was the most important attribute of aerobic rice systems for farmers.

Interestingly, key informants also stated that another benefit of growing aerobic rice is that the yield is stable even after growing aerobic rice in the same field for five consecutive years. Yield decline was not a problem in Anhui and Henan provinces, probably because aerobic rice is grown only in summer; wheat is grown in the winter.

While weeds once inhibited adoption, according to the Director of the Xincai Agriculture and Extension Service and some farmers, the weed control is no longer a major issue as good post-emergence herbicides are now available (Table 4.2). It was stated that the increased and/or renewed interest in aerobic rice was due to the availability of the herbicides and the increase in farmer skills in chemical weed control.

The farmers also stated that they are happy with the eating quality of aerobic rice in general, although there is a strong relationship between varietal choice and whether or not the rice is an indica or japonica. For example, the CAU varieties are japonicas, which are generally preferred in the north. In the south, both japonica and indica varieties are accepted. However, as can be seen from Table 4.2, preference can be localised. In Fengtai County, the farmers grow japonicas (HD 277, 502); in Funan county japonicas (HD209, 277, and 502) and indicas (Lvhan1); and in Xincai county indicas are the preferred variety (e.g., Lvhan1, Xinhan1, 2 and Zhenhan).

In Tarlac and Bulacan provinces in the Philippines, farmers have shown considerable interest in aerobic rice as a summer crop as it addresses some of their pressing needs. In short, this interest is largely driven by the four-fold increase in the cost of deep and shallow-well irrigation (due to the increase in fuel prices) and the need to increase farm income in rainfed areas by providing farmers with a means of producing two crops per year. Another factor affecting the farmers' decision to grow aerobic rice is soil quality. While the farmers will also grow maize in the dry season, it can only be grown on the portion of their land that has sandy soil. In addition to maize production, other upland crops that are grown include sweet potato, peanuts and vegetables. However, these upland crops cannot be produced on a large scale because of the lack of processing, transportation and retail facilities.

Table 4.2 Information from key informant interviews: Anhui and Henan Provinces, China October 2008: Area, yield, variety and factors affecting adoption

No	Location	Informant	Lowland rice area (ha)	Lowland rice yield (t/ha)	Aerobic rice area (ha)	Aerobic rice yield (t/ha)	Aerobic rice varieties	Problems with or reasons for not growing aerobic rice	Benefits of growing aerobic rice	Aerobic Rice dissemination
Anhui Province, Fentai County										
1	Fentai	County Official	570000	7.5 - 7.9	10,000	3.7 - 6.0		Enough water to grow lowland rice, which is higher-yielding than aerobic rice; drought and flooding also not common	Change in government subsidies for grain crops has led to a reduction in non-grain crops. Cost of pumping has increased significantly	Farmers obtain some crop information from Agricultural Technology Extension Station (ATES). However, most farmers obtain aerobic rice information from seed company/distributors/ agribusinesses and from the fact sheets, posters, and brochures these businesses produce.
2	Shangtang Township	Town Official	23000	7.8	2300.0	5.0		Weed problem; no subsidy for aerobic rice	Requires less water than lowland rice, stable yield, less pesticides, less labour, lower irrigation costs.	Not stated
3	Shangtang Township	Farmer – President of (natural) village			0.05	5.2		No subsidy for aerobic rice; weed problem; insect problem	Grows aerobic rice in low-lying areas because higher returns than soybean and not enough water for lowland rice	Agribusiness (primarily Mr Hu) provides information on varieties and appropriate management strategies

No	Location	Informant	Lowland rice area (ha)	Lowland rice yield (t/ha)	Aerobic rice area (ha)	Aerobic rice yield (t/ha)	Aerobic rice varieties	Problems with or reasons for not growing aerobic rice	Benefits of growing aerobic rice	Aerobic Rice dissemination
4	Shangtang Township Market	Group of farmers randomly selected at the market place (2 lowland rice; 3 aerobic rice)		6.0 - 8.2		4.5 - 7.5	HD502	Not suitable for upland area, water scarcity not a problem	Labour and water shortage, irrigation costs are too high; stable yield	Agribusiness (primarily Mr Hu) provides information on varieties and appropriate management strategies
5	Cuihai Village	Group of farmers (2 lowland rice; 2 aerobic rice)		6.0		5.2	HD502, 277	Water scarcity not a problem for lowland rice; high altitude so grows maize	Water became scarce but land is still flood-prone; labour saving; stable yield	Agribusiness (primarily Mr Hu) provides information on varieties and appropriate management strategies
6	Shangtang Township	Manager of Agri-bussiness	1530		200		HD502, 277			The manager of the agri-business is the main source of information to the farmers in nearby villages. He and is family own several shops selling agricultural inputs. Around 60 farming households obtain aerobic rice seed from Mr Hu. In total around 90 farming households grow aerobic rice.

No	Location	Informant	Lowland rice area (ha)	Lowland rice yield (t/ha)	Aerobic rice area (ha)	Aerobic rice yield (t/ha)	Aerobic rice varieties	Problems with or reasons for not growing aerobic rice	Benefits of growing aerobic rice	Aerobic Rice dissemination
Anhui Province, Funan County										
7	**Funan**	Manager of seed company/ agri-business	30% of total rice area is dry season lowland rice Zhongyou Zhao 5	7.9	35% of total rice area is aerobic rice = Zhonghai 209, 201; 35% of total rice area is aerobic rice = Lvhan1	6.0 – 6.5	HD 502 (2000→02); Lvhan1 (2005→); Zhonghai209, 221 (2006→)	Dry season lowland rice variety is shorter duration; weeds are a problem so farmers need to use herbicide.	Flood prone area; good yield; low labour and irrigation costs c/w paddy.	Government-advertised variety; magazine; asks friend to bring new varieties for the seed distributor to test. Provides farmers with information on aerobic rice varieties and optimal management strategies – such as weed control and irrigation rate (3 times in dry year).
8	**Funan**	Seed distributor / agri-business	20% irrigated lowland rice	8.4	50%	6.5	Lvhan1	Direct-seeded lowland rice varieties in aerobic soil are common in the county	Less labour; lower production cost; good profit due to high and stable yield	He receives information on aerobic rice varieties from seed dealers, ATES, internet and magazines. Provides farmers with information on aerobic rice varieties and optimal management strategies (seed density = 4kg/mu; irrigation = 2-3 times in drought year; weed control = use herbicide
					10%	6.75	Zhonghan209			
					10%	5.5 – 6.5	HD502			
					10%	5.5	Xinhan1			

No	Location	Informant	Lowland rice area (ha)	Lowland rice yield (t/ha)	Aerobic rice area (ha)	Aerobic rice yield (t/ha)	Aerobic rice varieties	Problems with or reasons for not growing aerobic rice	Benefits of growing aerobic rice	Aerobic Rice dissemination
9	Funan	Director of ASTI					The local research station – under the Bureau of Agriculture tests varieties for local adaptability. The most promising varieties: Lvhan1, HD209, 502		Benefits include good yield, simple management - less labour, less water. Overall aerobic rice has a bright future as it is well suited to the local environment.	Long history of aerobic rice production (including direct-seeded lowland rice varieties in the aerobic soil) in the county. Varieties from other sources - e.g. CAU. Prof Wang held training courses in 1994. The Agricultural Technology Extension Station (ATES) now collaborates with CAU. The MoA established national variety experiment plots for aerobic rice and other non-aerobic rice varieties. Aerobic rice is now part of the regular training/demonstration activities. The main focus of the training, which targets agricultural technicians and farmers, is to introduce new varieties and management techniques.
10	Hesheng	Farmers			80% of	6.0	HD277	Weed problem	Labour and water	One farmer had

No	Location	Informant	Lowland rice area (ha)	Lowland rice yield (t/ha)	Aerobic rice area (ha)	Aerobic rice yield (t/ha)	Aerobic rice varieties	Problems with or reasons for not growing aerobic rice	Benefits of growing aerobic rice	Aerobic Rice dissemination
	Village - Xiau Dai Natural Village				farmers	6.7 8.2	HD502 906		saving	participated in a varietal selection activity organised by Prof. Wang in 1996.
11	Fumeng State Farm	Leader of collective farm; 73 ha and 110 farmers	60% soybean		20% 12% 8%	7.2 6.3 ns	Lvhan1 HD209 Other	Soybean has lower economic margin than aerobic rice but also requires less labour and water and can be grown in lower quality soil	Higher returns than other summer crops. Increased demand for seeds has led to doubling of the area grown to aerobic rice - from 13 ha to 27 ha.	The Fumeng State Farm provides farmers with aerobic rice seeds
12	Fupo Village	3 farmers plus head of commune.				6.7 6.7	Lvhan1 - Better disease tolerance, maturity, colour and drought tolerance HD502-Better taste		All 3 farmers grow aerobic rice because higher yield/better returns than other summer crops. It also uses less labour, water and pesticides than lowland rice	Originally it was seed distributors who disseminated aerobic rice technologies. They are still the main source of information. However, in 1996 the Bureau of Science and Technology held training workshops and the town technicians passed their knowledge and skills to the village technicians who in turn taught the farmers. The training workshops and demonstrations are held for all crops, not just for aerobic rice. .

No	Location	Informant	Lowland rice area (ha)	Lowland rice yield (t/ha)	Aerobic rice area (ha)	Aerobic rice yield (t/ha)	Aerobic rice varieties	Problems with or reasons for not growing aerobic rice	Benefits of growing aerobic rice	Aerobic Rice dissemination
13	Dingzhai Natural Village	5 farmers			95%	7.9 6.0 - 6.5	Zhonghan 209, Zhongyou Zao 5, which is a lowland rice variety, is also direct seeded grown as aerobically) HD502, 277	Weed problem - need herbicide; more complicated than growing paddy, not enough varieties to chose from	The farmers do not grow other summer crops because of soil quality and water logging. They like aerobic rice because it requires less labour, less water and the yield is high and stable. They receive government support	Prof. Wang told them about aerobic rice originally and provided training. The obtain information about new varieties and crop management from ATES and local technicians
14	Dingzhai Natural Village	Local Miller	70%		30%			Brokens higher in aerobic rice		
15	Funan	Large farm	800	7.5	53	5.4 – 6.0	HD502 Lvhan1 Jinggoa1 some from other province	Aerobic rice has a long history in the area but weeds were a big problem so farmers stopped growing. Last year farmers started to grow again because of new varieties and availability of post-emergence herbicide.	Prefer to grow aerobic rice or dry season lowland rice than soybean or maize which have a lower yield because of water logging problem. Profit 20-40% greater than other summer crops	The farm manager was aware of aerobic rice technologies through his earlier associated with Prof Wang (CAU). Farmers come to him for advice on aerobic rice - varieties and management. In this county aerobic rice accounts for 25% of the summer crops. In the surrounding 10 km, the used for aerobic rice seed production will increase because of the increased demand.

No	Location	Informant	Lowland rice area (ha)	Lowland rice yield (t/ha)	Aerobic rice area (ha)	Aerobic rice yield (t/ha)	Aerobic rice varieties	Problems with or reasons for not growing aerobic rice	Benefits of growing aerobic rice	Aerobic Rice dissemination
Henan Province, Xincai County										
16	Zaolin Natural Village	4 farmers				6.7 7.0	Zhenghan2 Xinhan1	Not enough aerobic rice seed available	Yield higher than other crops and better profit	Seed Company
17	Gaowan Natural Village	5 farmers			61%	6.7	Zhenan2	Weeds were a problem but now have good herbicides so started to grow again in 2003	Water logging not a problem; yield is higher than other summer crops; requires less labour; good eating quality	Seed Company (Mr Gao) - it is his family village
18		Breeder / seed company	The company was Xincai Rice Research Association from 1993 to 2007 when it was privatised. At that time the current Manager of the seed company (Mr. Gao Junshan) retired from the Bureau of Agriculture as a Senior Agronomist. The company provides aerobic rice seeds to the local farmers. Xincai County suffers from waterlogging. In view of this problem, the government extension workers recommended aerobic rice as a summer crop. Aerobic rice was introduced to farmers through the media – primarily the Henan Daily. In 1991, several aerobic rice demonstration plots were established in Xincai county. The interest in aerobic rice has increased over time. . This is because the yield is higher than it is for other summer crops. It also requires less labour and has a good eating quality. As such Mr Gao believes the interest in aerobic rice will continue to grow – from around 60% of farmers interested in growing aerobic rice now to 90% by 2020. Mr Gao developed Xinhan1 and Xinhan3.								
19		Director of Xincai Agric. Ext. Service				6.5	Zhenghan1,2,3 Xinhan1,2 Handao502 Chaoyou1	The Director believes that aerobic rice has a bright future as the development and promotion of aerobic rice is well seated in the National Grain Industry Development Policy for food Security. Aerobic rice suits the local environment because 29,000 ha (out of a total agricultural area of 98,667 ha) is flood-prone. In addition, over the past 59 years there have been 19 droughts. About 70% of summer crop production losses are due to water logging and 20-30% of lowland rice losses are due to drought. As a result of the severe water logging problem, and intermittent droughts, the local government is promoting aerobic rice. Over time, the yield of aerobic rice has increased from 3 t/ha to 6.8 t/ha because of the development of improved varieties, more effective use of		

No	Location	Informant	Lowland rice area (ha)	Lowland rice yield (t/ha)	Aerobic rice area (ha)	Aerobic rice yield (t/ha)	Aerobic rice varieties	Problems with or reasons for not growing aerobic rice	Benefits of growing aerobic rice	Aerobic Rice dissemination
								herbicides and pesticides and because of the government support – training subsides and agricultural infrastructures.		
20		Deputy Director Xincai Bureau of Agric.	2,000		8,000	6.0 – 7.5			Simple management, no irrigation necessary in normal year. Significant increase in aerobic rice over past 3 years replacing soybean, cotton, maize, sesame. Maize area has also increased and is the main summer crop (40,000 ha). Cotton is labour intensive and soybean has lower profit.	Dissemination of aerobic rice is undertaken primarily by private seed companies - not the Bureau. The Bureau trains staff and can support technicians. Demonstration and training activities are supported by ATES. The Deputy Director believes aerobic rice has a bright future.
21	Fuyan	Manager of seed company;			There will be 13 ha aerobic rice seed producti on in 2009	6.0	Farmer prefer Indica varieties	Farmers do not like Handao277, 297, 502		Mr Ren has close association with Prof Wang. Co-op invites farmers of demonstration

Source: Information obtained from key informant interviews: October 2008; Professor Wang, CAU 2008, pers. comm.

Note: The high yields for aerobic rice are largely due to the exceptionally good season in terms of the timing and quantity of rainfall

Change depends on factors outside the researchers' control

There are many factors outside the control of researchers that will affect adoption of the results of agricultural research. One of the highest-order factors is a country's political environment. In both China and the Philippines, the current agricultural agenda is one of strongly encouraging grain production. This is not surprising given the recent 'food price crisis'. The shift in political will is particularly evident in China. Prior to 2004, grain production was subject to an output tax; inputs used for grain production are now subsidised and per unit production payment for growing improved varieties of the major grain crops (e.g., wheat, maize and rice) is paid into the farmers account. In total, farmers now receive US$175-200/ha worth of output payments and inputs subsidies for growing grain crops. In the Philippines, the government is not only subsidising Bt corn seeds but is also actively promoting rice production. As a result of these payments, the profitability of growing aerobic rice in the dry season is increased, which will have a positive influence on adoption.

Another factor outside the control of the researchers is the outmigration of labour from rural areas. This seems to be of particular concern in China where the average size of the household is smaller than in the Philippines. As stated above, the fact that aerobic rice requires less labour than lowland rice and other summer crops means that it is well suited to this change in demographics.

Oil prices can also affect adoption of aerobic rice. This is particularly true in the areas visited in the Philippines (see Table 4.1). As stated above, farmers in Tarlac and Bulacan are interested in growing aerobic rice because of the four-fold increase in irrigation costs due to the rise in the price of oil. One could surmise from this that the reverse could also be true: aerobic rice growers may 'switch-back' to lowland rice if the economic constraints to irrigation are eased.

Someone else is usually responsible for working with the final users

A major downfall of some R&D projects is the failure to recognise and account for the fact that others may be responsible for ensuing the project results are passed onto the final users. This does not apply to the STAR project, which actively undertook communication and dissemination activities, including a large number of training demonstrations, through the collaborations and the networks formed. These activities all served to pass on the results of the STAR project to a wide-ranging group of next users.

In China, scientists at the CAU were not only responsible for undertaking aerobic rice research but also became involved in both scaling-up and scaling-out activities. As part of these activities, managers of seed companies and seed distributors were invited to the field days and training demonstrations. This was important because agricultural technologies are often disseminated through the seed delivery system in China. While public extension stations are part of the seed system, it is the private sector (private seed companies and local seed dealers) that is the main channel for the promotion and spread of new technologies such as aerobic rice. Results from the farm-level surveys undertaken in 2007 indicate that local seed dealers supplied 73% of the surveyed farmers with aerobic rice seeds (Ding et al, 2008). Farmer seed exchanges also played an important role, with 19% of famers obtaining aerobic rice seeds through farmer-to-farmer exchanges (Ding et al, 2008). These results were confirmed during the key informant interviews undertaken in October 2008, which showed that private seed companies and distributors provided farmers with new locally-adapted aerobic rice varieties and information on management strategies (Table 4.2). However as pointed out by Ding et al (2008), while private companies have a financial incentive to promote new technologies, in the case of aerobic rice they may not have the capacity to provide intensive training and/or set-up demonstration sites. Therefore, there is a need for the public sector to be involved in these activities. In China, while the public sector involvement in aerobic rice extension has been limited, there has been some government support through the National Program of Aerobic Rice Regional Trials, which is on-going.

In contrast to China, where most of the dissemination activities are done through private seed companies, in the Philippines, the various project collaborators are involved in the adaptive and/or participatory research, training and dissemination. The means of technology dissemination is largely through demonstration farms, farmer field schools and trained technicians. There is also substantial local government support in the targeted provinces. In addition, the National Irrigation Authority is actively passing on information about the benefits of growing aerobic rice in water-scarce but also flood-prone areas.

Adoption and impact often occurs long after the project is finished

It has been well established that lags of several years can occur between the time when the research commences and the time when the effects on agricultural productivity are realized. In general, adaptive and adoptive research projects build on earlier work and have relatively short lag periods, while more basic or applied research can have extremely long lags. Moreover, even if the technology is successful in terms of meeting farmer needs and is being promoted by farmer intermediaries, it can still take many years before uptake of the technology reaches a maximum level. The rate and level of adoption will depend on many factors such as the strength of the countries extension system, the willingness of farmers to follow the practice of early adopters, and the availability of substitute technologies. Each of these factors has, to varying degrees, affected the adoption of aerobic rice in both China and the Philippines.

4.3 Current adoption of aerobic rice

China

As previously stated, aerobic rice research started in China over 25 years ago. By 1985, there were around 400,000 ha of aerobic rice growing in China (Table 4.3). Of this, 12% of the cultivated area was sown to varieties developed by the CAU. By 1995, this figure had fallen to 266,000 ha. The reason for this fall was because there were no new varieties released and the increased supply of irrigated lowland rice led to a fall in the price of rice in both absolute terms and relative to other crops. In 2000, collaborative research between IRRI and the CAU led to the release of two new japonica varieties, HD277 and HD297.

Table 4.3 Area sown to aerobic rice: 1985 to 2008

Year	Total area	CAU's contribution		CAU key cultivar used
	000' ha	000' ha	%	
1985	400	50	12	Qinai
1995	266	7	3	Qinai, Handao2
2000	300	60	20	HD277, 297
2005	333	33	10	HD277, 297, 502
2008	350	53	15	HD277, 297, 502

Source: Professor Wang, CAU 2008[3], pers. comm.

During 2003-2005, 35 new aerobic rice varieties were released bringing the total to 58 varieties nation-wide. Five of the certified varieties (HD9, HD65, HD277, HD297, HD502) released in 2003 were from the CAU, with the sixth CAU variety (HD271) released in 2005. While the STAR project didn't start until October 2004 (after the release of some of these varieties), it provided evidence that the CAU varieties, such as HD227, HD297 and HD502, outperform lowland rice varieties in water-scarce areas. This confirmation served to increase confidence in promoting aerobic rice.

The release of new varieties was reinforced by the National Program on Aerobic Rice Regional Trials that started in 2000. There are 69 sites for breeding trials. In this program, HD297 and HD277 are used as check varieties. The main objective of the regional trials is to increase aerobic rice yields.

In addition to varietal selection, and as a result of the STAR project, the CAU also undertakes adaptive management research for aerobic rice systems. The technologies include direct dry seeding, seed coating, and water, weed and nutrient management. The CAU also works closely with a number of private seed companies and local seed distributors, with the aim of accelerating adoption of aerobic rice in China.

The increased research and dissemination effort since the start of the STAR project, combined with the change in the government policy on grain production, and the increase in outmigration of labour, appears to have accelerated the rate of adoption in recent years. Ding et al (2008) point out that while adoption of aerobic rice in Funan county dates back to the 1990s, aerobic rice was not adopted in Fengtai and Yingshang until 2003 with over 60% of aerobic rice farmers not growing aerobic rice until 2006.

By 2008, the total area grown to aerobic rice was still 50,000 ha below the 1985 figure. Nevertheless, the key informant interviews held in October 2008 indicate that the interest in aerobic rice has increased markedly over the last 12 months, largely due to an increased awareness of the benefits of growing aerobic rice, and a greater understanding of appropriate management techniques, and the favourable government policies for growing grain crops (H. Wang 2008, per comm., key informant interviews 2008)[4]. In fact, in some

[3] Professor Wang leads the aerobic rice team at the CAU. He has been actively engaged in aerobic rice research in China for around 30 years.

[4] Professor Ding (who was responsible for the household surveys undertaken in 2007) acted as a translator

instances farmers have stated that the reason they have not been able to grow aerobic rice is because the seed was not available. The increased demand for aerobic rice seed in some locations is reflected in the increased price of aerobic rice seed from the previous year and the increase in the area used for seed production in 2008 (e.g., in Xincai County – see Table 4.2).

Philippines

In the Philippines, there has been very little adoption of aerobic rice varieties to date, despite the considerable interest shown by farmers during the key informant interviews undertaken in March 2008. The main reason for the lack of adoption is because further varietal and management adaptive research is required to ensure that the yield potential of the varieties and management package delivered to the farmers is largely attainable in the farmer fields. For example, in 2005, six demonstration farms were set up in Bulacan with almost 50 farmers growing aerobic rice varieties. However, the farmers did this without fully understanding the correct water and nutrient management strategies. As a result, the average yield was 2-3 t/ha rather than 4 t/ha. Subsequently, the National Economic and Development Authority Region II (NEDA-Region II) initiated a training and extension proposal (including the production of aerobic rice seed).

In April 2008, two demonstration farms in six municipalities in rainfed areas are being set up (1.5 ha each site). This initiative has the support of the Bulacan Provincial Office with BASC training technicians. The training and extension is through the farmer field schools (FFS) and covers land preparation through to harvesting. Information on aerobic rice will be passed on to the farmers via farmer field schools (FFS) and the trained technicians. While at the time of the key informant interviews it was stated that in 5 years, there will be 50% adoption of aerobic rice varieties in the target areas (Dr Junel Soriano 2008 pers. comm.), this statement was made when oil prices reached record highs. Now that there has been a substantial fall in the price of oil, adoption may not be as high as originally predicted – at least not in the short-term.

4.4 Future adoption of aerobic rice

While information from the key informant interviews indicates that farmer interest in, and uptake of, aerobic rice is increasing, determining an adoption profile is not an easy task and requires a significant degree of subjective assessment. However, the plausibility of the assessment can be increased by considering all the relevant information from, for example, secondary data, the key informant interviews, project reports and related research, and previous household surveys. For the case at hand, an important first step is to consider the agro-climatic domains where aerobic rice could not only be grown but would also have a comparative advantage over either lowland rice or upland (summer) crops. Very broadly, these agro-climatic domains include irrigated areas where water availability is insufficient to grow lowland rice and/or the cost of irrigation makes it uneconomical to do so and rainfed areas where flooding (or soil type and quality) causes significant yield losses in non-rice

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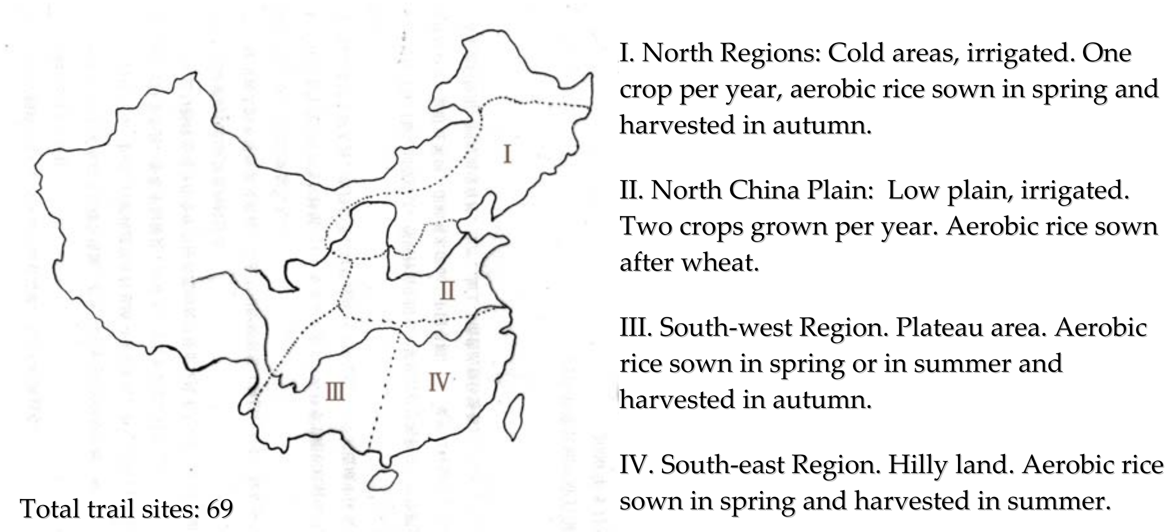
during the key informant interviews in October 2008. He also commented on the marked increase in the use of and interest in aerobic rice in just 12 months (Ding 2008, pers. comm.)

summer crops.

China

There are four main regions in China – (I) the North Region (comprising the North-east and North-west Regions); (II) the North China Plain; (III) the South-west Region; and (IV) the South-east Region - where aerobic rice is currently grown and across which the 69 trial sites under the National Program of Aerobic Rice Regional Trails are located (Figure 4.1). The spread of these trails across China indicates that aerobic rice is potentially suited to a range of climatic conditions.

Figure 4.1: National Program of Aerobic Rice Regional Trials in China



Source: Professor Wang, CAU 2008 pers. comm.

Data on the estimated aerobic rice areas by province are presented in Table 4.4. The information contained in this table was obtained by the CAU through field visit, interviews, meetings and official annual reports. The key informants include local government offices, agricultural extension agencies, seed companies and farmers. As can be seen from Table 4.4, the actual area planted to aerobic rice is small relative to the agro-climatic areas where aerobic rice production may have a comparative advantage over either lowland rice or other upland (summer) crops such as maize and soybeans. For example, in the North Region, it is estimated that around 30% of the 4.6 million hectares of irrigated lowland rice suffers potential yield losses because of water shortages and yet only 65,600 ha is grown to aerobic rice. In the North China Plain, where an estimated 86,000 ha is used to grow aerobic rice, around 10 million ha of low-lying upland crop areas become water-logged or saturated during June to September, resulting in six million ha of upland grain crops suffering yield losses and an additional 660,000 ha of land either only single cropped (winter wheat) or lying fallow all year because of flood-induced water logging problems. In the rainfed plateau of the South-west Region, of the two million hectares with an annual rainfall greater than 1,000 mm, only an estimated 150,000 ha is sown to aerobic rice. Finally, in the South-east Region, three million ha of lowland rice is threatened by summer or autumn drought and yet the area sown to aerobic rice is estimated to be around 47,000 ha. Hence, the estimated 348,600 ha currently sown to aerobic rice represents less than 3% of the 13 million ha that could potentially, according to agro-climatic considerations, be used.

Table 4.4: Estimated aerobic rice areas and distribution in provinces: China 2008

Province	Area (ha)
I. North-east Region (Cold, low plain and irrigated)	
Liaoning	35,000
Helongjiang	15,000
Jilin	6,000
Neimenggu	600
I. North-west Region (Cold, dry and irrigated)	
Xinjiang	4,000
Shanxi	3,000
Ningxia	2,000
Gansu	0
Qinghai	0
Xizang	0
II. North China Plain (Temperate, low plain and irrigated)	
Henan	20,000
Anhui	20,000
Jiangsu	20,000
Shandong	15,000
Hebei	8,000
Tianjin	2,000
Shanxi	500
Beijing	500
III. South-west Region (High mountainous and rainfed)	
Yunnan	100,000
Guizhou	20,000
Guangxi	20,000
Sichuang	8,000
Chongqing	2,000
IV. South-east Region (Sub-tropical, hilly and rainfed)	
Zhejiang	8,000
Fujian	7,000
Taiwan	6,000
Jiangxi	6,000
Hunan	5,000
Hubei	5,000
Guangdong	4,000
Hainan	4,000
Shanghai	2,000
Total	**348,600**

Source: Professor Wang, CAU 2008, pers. comm.

Table 4.5: Current aerobic rice area to potentially suitable agro-climatic domains

Broad Geographic Regions	'Suitable' Agro-climatic Domain	Estimated Aerobic Rice Area	
	ha	ha	%
North China	1,380,000	65,600	4.8
North China Plain	6,660,000	86,000	1.3
South China	5,000,000	197,000	3.9
Total	**13,040,000**	**348,600**	**2.7**

Source: Prof. Wang, CAU 2008, pers. comm.

Naturally the agro-climatic condition of any location is not the only factor that affects adoption. There are also a number of socio-economic variables that will affect the uptake of aerobic rice such as the relative profitability of aerobic rice compared with other crops, the farmers' desire to produce the family rice requirement rather than purchase rice and to provide a diversified diet, the farmers' awareness of, and ability to grow aerobic rice and to be able to afford the necessary inputs (fertiliser, pesticides etc) to maximise yield or returns, the availability of a range of high-yield varieties that not only suit the local physical environment but also have the taste and cooking qualities demanded by consumers, the availability of seeds, and so on.

Recognising this, both bio-physical and socio-economic variables were taken into account to determine the suitability of the aerobic rice technology beyond the research sites as part of the extrapolation domain and scenario analysis undertaken within the STAR project (Rubiano and Soto 2008) (Objective 5, Output 6). The potential extrapolation domain (ED) areas for aerobic rice were calculated using Homologue and Weights of Evidence modelling to identify agro-ecological and socio-economic conditions that are similar to those found in project pilot sites. The results of the ED analysis show that the sum of the extrapolation domain areas in China for aerobic rice (at a 60% probability level of finding the similar socioeconomic and climatic conditions to the pilot sites) is 12.4 million ha, which similar to the 13 million ha estimated by the CAU and cited above. However, when the probability level is increased to 70%, the ED estimate falls to 5.1 million ha. This lower estimate (5.1 million ha) is used in the analysis.

Even though the results from the ED analysis are preliminary, they provide starting point in terms determining adoption levels. Again it would be unreasonable to expect that there would be 100% adoption rate across the whole ED. A more plausible estimate is based recent trends in adoption, the improved performance of the newer aerobic rice varieties and commitment to further research on developing drought tolerant rice varieties, and the increasing water scarcity problem. As aerobic rice has been grown in Funan County for 10 years, information from the household surveys undertaken in Funan County provides an indication of level adoption and recent changes in adoption (Ding et al 2008). While the percentage of total land area used for aerobic rice production in Funan was only around 4% in 2007, it still represents a doubling of the adoption rate from 2% in 2005. Moreover, at the village level, the area sown to aerobic rice was 20% in 2007, an increase of eight percentage points since 2005. The number of farmers growing aerobic rice also increased rapidly from 52% in 2005 to 73% in 2007. As stated above, the rapid increase in interest in, and adoption of, aerobic rice was also evident from the key informant interviews (Table 4.2). Hence, it would be quite plausible to assume that the maximum adoption level could reach at least 40% of ED estimate by 2015. Applying this assumption to the current regional-level adoption figures provided in Table 4.4 provides figures for the maximum level of adoption of aerobic rice for North China (383,890 ha), the North China Plain (503,270 ha) and South China (1,152,840ha), totalling just over two million ha (Table 4.6).

Table 4.6 Assumed future adoption of all aerobic rice and CAU aerobic rice varieties

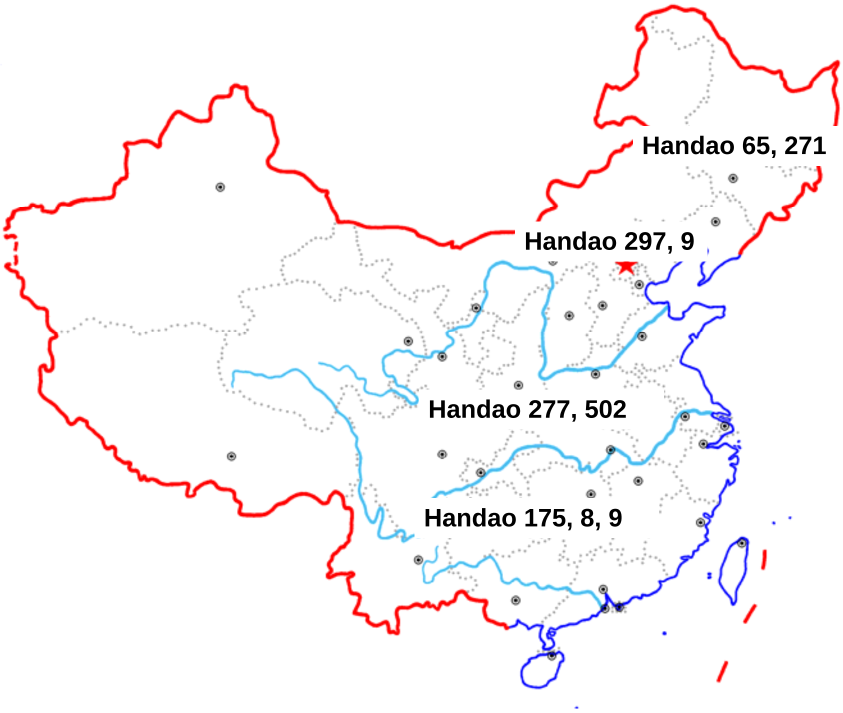
Areas	Assumed Future Level of Adoption	CAU varieties	
	ha	%	ha
North China	383,890	15.0	57,583
North China Plain	503,270	15.0	75,491
South China	1,152,840	15.0	172,926
Total	**2,040,000**	**15.0**	**306,000**

Now the adoption rate of aerobic rice has been subjectively estimated, the next step is to obtain a plausible estimate of how much of this is due to adoption of CAU varieties. Figure 4.2 shows where CAU varieties have been released. Figure 4.2 was constructed by Professor Huaqi Wang from the CAU. It depicts those areas where the variety was officially released by either state or provincial government authorities. For example, Handao 65 was released by the state government in 2003 and can be disseminated to farmers in only in North-East China; Handao 175 was released by Guizhou provincial government in 2006 and can be disseminated only in the South-West China; Handao 9 was released by both the State Government of North China in 2003 and by Guizhou provincial government for dissemination in the South-West in 2006.

Table 4.3, the CAU contribution is estimated to be around 15% overall in 2008. Unfortunately data are not available at a regional level so the 'national; figure of 15% is combined with the total aerobic rice area to calculate the total area sown to CAU varieties in China (306,000 ha) and for each of the regions (Table 4.6.).

In sum, estimating the maximum level of adoption of CAU varieties requires a significant amount of subjective and largely qualitative information. Because of this, a largely conservative approach was used to determine possible future adoption. Hence, the maximum adoption rate should be seen as a lower bound of the potential adoption rate.

Figure 4.2 Distribution of new varieties of Handao from CAU in farmer areas in China: 2007



Source: Prof Wang, CAU, 2008 pers. comm.

Philippines

In the Philippines, the areas deemed to be potentially suited to aerobic rice technologies were rainfed areas where the rain pattern is sufficient for rice production during the wet season (May-November) and irrigated areas where water scarcity is either a physical or economic problem dry season (January-May). However, as stated above, (Section 4.3), there was little adoption of aerobic rice varieties by early 2008, largely because more trail evaluations are required before aerobic rice technologies can be confidently transferred to farmers. Nevertheless, the ED analysis suggests that around 241,970 ha could be suited to aerobic rice production based on a 70% probability of similarity to the pilot sites (Rubiano and Soto 2008).

5 Benefits

5.1 Capacity impact

In addition to contributing to the development of technical outputs within the project, human capacity building can directly benefit both the newly trained individuals and the organisation that they work for. The benefit to the individuals is the most direct link between capacity building and impact. The main benefits to trainees include improvements in confidence, competence, promotion and higher income. Gordon and Chadwick (2007, p. 30) state that as a rule of thumb, 'a worker's lifetime income is higher, on average, by around 10% for each additional year spent in formal education.' Hence applying this 'rule-of-thumb' to the 22 students, and nearly 1600 short-course trainees, the rewards for the trained individual over their working life would be significant.

At the organisational level, the efficiency of CAU was enhanced through the researchers' capacity-induced changes in practice and behaviour. This is reflected in increased effectiveness in the provision of technical outputs (identification of the high-yielding potential of a number of aerobic rice varieties – Handao 502, 297, 277 - and the packaging of relatively simple crop management recommendations) and in innovations in the type of services and in the delivery process (farmer participatory research, and farmer demonstrations and training). The recognition of the capacity of CAU to undertake multi-disciplinary research on aerobic rice efficiently and effectively enhanced the reputation of the CAU influenced in the policy arena as evidenced by increased international and national funding (subsection 3.3). As a general rule of thumb, workers tend to keep around half of the productivity improvement from training, the other half being captured by the institution (see Gordon and Chadwick 2007).

A similar story is true in the case of the Philippines. Researchers and irrigation managers from national institutes who have been involved in the project activities and/or training on aerobic rice became proactive agents of the technology. One case in point is the initiative of BASC to make their college the Aerobic Rice Centre of the Philippines. They received a US$25,000 (PhP1,000,000) grant from Japan, through the Philippine National Economic Development Authority, to start the aerobic rice seed production business (Barclay 2008).

The ultimate beneficiaries, apart from the individuals who receive financial and intrinsic benefits from the training, are the final users of the outputs of the research and extension organisations. This is because the community-level impact of investing in capacity building arises from the technical outputs developed within the project or follow-on research and/or through the improvements at the organisational level that flow from use of the enhanced capacity. In general, while organisational benefits can be large relative to the investment in training, they are small compared with the returns to the innovations produced if there is significant adoption of these innovations by the final users.

In the case of the STAR project, because the capacity building activities were an integral and on-going component of the research, these activities directly contributed to the realisation of other output targets within the life of the project, such as the identification on high yielding aerobic rice varieties and crop/water management techniques. Moreover, given the strength of the capacity built during the STAR project, the skills and knowledge gained by the researchers is likely to be used the beyond the STAR project to generate further research deliverables. Areas for further research mentioned by the CAU aerobic rice researchers include varietal improvement (increased diversity and drought and disease resistance, and yield and quality enhancement), improved crop management (in the areas of irrigation and fertiliser application, weed control and yield decline due in mono-cropped systems) and up-scaling and out-scaling strategies. Because the capacity built is combined with other inputs to produce the adoptive outputs that ultimately lead to the higher-order outcomes and impacts, the impact at the farm- and community-level is covered in the following section.

5.2 Farm-level impacts

In general, farm-level impacts for crops stem from a change in yield and/or in the cost of producing those crops. In the case of aerobic rice, there is an added complexity that stems from the fact that aerobic rice may be grown in different locations for fundamentally different reasons. For example, it may be grown in some irrigated areas in response to the increased irrigation costs rather than because water is physically scarce. In this case, aerobic rice could replace lowland rice varieties as a cost-saving measure even though there is some yield loss. Information from key informant interviews held Tarlac in the Philippines suggests that farmers, who are currently using pump irrigation to continuously flood their lowland rice crop in the dry season, could save between US$340 and US$410 in irrigation costs if they adopt aerobic rice technologies. Therefore, for as long as the yield sacrifice is less than 1 t/ha, the farmers would be better off. Lower irrigation costs were also cited by farmers in Fentai County (Anhui Province) in China as an important benefit.

Farmers may also replace either lowland rice or other summer crops with aerobic rice in areas where labour is in short supply and hence becoming relatively expensive at critical times in the crop calendar – such as at planting and harvesting. This is particularly true in some poorer areas of China because of labour out-migration. Indeed, as stated above, one of the main benefits of growing aerobic rice cited by farmers in Funan county (Anhui Province) in China (Table 4.2), was that it required less labour that either lowland rice or some other summer crops. This concurs with the household survey data presented by Ding et al (2008), which found labour costs for aerobic rice are US$28/ha and US$104/ha less than they are for lowland rice and maize, respectively.

Another major reason for choosing to grow aerobic rice in areas where other summer crops, such as maize and soybean, are traditionally grown is to mitigate flood-induced crop losses (see Funan County in Table 4.2). Similarly, even without the occurrence of water logging, farmers may grow aerobic rice as a summer crop rather than alternatives because aerobic rice may have a higher profit margin. The information in the key informant interviews suggests that farmers are substituting aerobic rice for maize and soybeans because of its higher profit margin. Conversely, the relative profitability of aerobic rice was not reflected in the results of gross margins analysis undertaken by Ding et al 2008. an average yield figure of 3.7 t/ha, which is around 2 t/ha below the yield data collected in the key informant interviews undertaken in October 2008. It should be noted however that 3.7 t/ha was an average over three years (2004, 2005 and 2006) across three counties (Fengtai, Yingshang and Funan) and is relatively low because average yield for 2006 was 2.9 t/ha due to crop failure in Yingshang County. However in Funan County, the average yield for the three years was 4.96 t/ha, which is more in line with expected yields. In situations where aerobic rice yields are around 5 t/ha, all else being held equal, the gross margin for aerobic rice is up to US$300/ha higher than for maize.

Conclusions and Areas for Further Research

6.1 Conclusions

Aerobic rice technologies have been developed for production systems that are characterised by physical and/or economic water scarcity, such as those areas visited in the Philippines. Here aerobic rice is seen as a potentially viable alternative to lowland rice. Aerobic rice systems are also suited to areas where summer crops are traditionally grown but where both frequent drought and flooding occurs such as in the provinces visited in the North China Plain. In these area farmers are starting to accept that aerobic rice can be grown in the same way as other non-rice summer crops such as maize and soybean.

The main inhibitor to adoption of aerobic rice systems in the past was the inability of some farmers to control weeds. However, with the development, and increased awareness, of post-emergent herbicides, weeds are no longer seen as a major constraint. Low yields were another significant inhibitor to adoption, but the development of new aerobic rice varieties and optimal management techniques, has meant that yields of 6 t/ha or higher are now being achieved in farmer fields. The main enablers to adoption of aerobic rice by farmers include reduced labour and water requirements and the fact that aerobic rice is both relatively drought and flood tolerant.

The cultivation of aerobic rice is found to be economically feasible and comparable to popular upland crops like maize and soybean. As shown in the analysis, when aerobic rice yields of 5 t/ha or more are achieved, the gross margin of aerobic rice higher than that of maize and soybean. Moreover, in irrigated systems where water is either physically or economically scarce, aerobic rice could be a profitable alternative to lowland rice.

6.2 Areas for Further Research

The two main areas for further research are assessing the market-level impact and dealing with the related issues of the correct counterfactual and attribution. These require further information on crop substitution possibilities, and potential yield and input and management changes, for the different domains were aerobic rice may be adopted, as well as a more detailed understanding of the contribution of the STAR project to the spread of aerobic rice.

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