Rice in Southeast Asia: Facing Risks and Vulnerabilities to Respond to Climate Change

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Rice is one of the most important staple foods for more than half of the world's population (IRRI, 2006) and influences the livelihoods and economies of several billion people. In 2010, approximately 154 million ha were harvested worldwide, of which 137 million ha (88% of the global rice harvested) were in Asia – of which 48 million ha (31% of the global rice harvested) were harvested in Southeast Asia alone (FAOSTAT, 2012) (Figure 1). The greatest levels of productivity are found for irrigated rice, which is the most intensified production system, where more than one crop is grown per year and yields are high – 12.5 tonnes/ha/year compared with 2.5 tonnes/ha/year for rainfed rice. Approximately 45% of the rice area in Southeast Asia is irrigated, with the largest areas being found in Indonesia, Viet Nam. Philippines and Thailand (Table 1) (Mutert and Fairhurst, 2002).

In Southeast Asia, where agriculture is a major source of livelihood, approximately 115 million ha of land are devoted to the production of rice, maize, oil palm, natural rubber and coconut (ADB, 2009). Rice has been feeding the region's population for well over 4 000 years and is the staple food of about 557 million people (Manzanilla *et al.*, 2011). In 2007, the average annual consumption per capita was about 197 kg (FAOSTAT, 2012) and provided 49% of the calories and 39% of the protein in the diet (FAOSTAT, 2012). Rice-growing methods have evolved through programmes such as farmer field schools [FFS], pioneered in Southeast Asia, that were successful in addressing pest management issues. They have advanced along with the accumulation of knowledge and technology

Table 1: Area (000 ha) under irrigated and rainfed lowland rice in Southeast Asia

Country	Irrigated	Rainfed
Cambodia	154	1 124
Indonesia	6 154	4 015
Lao PDR	40	319
Malaysia	445	152
Myanmar	1 124	4 166
Philippines	2 334	1 304
Thailand	2 075	6 792
Viet Nam	3 687	1 955

Source: IRRI Rice facts,2002 in Mutert and Fairhurst, 2002

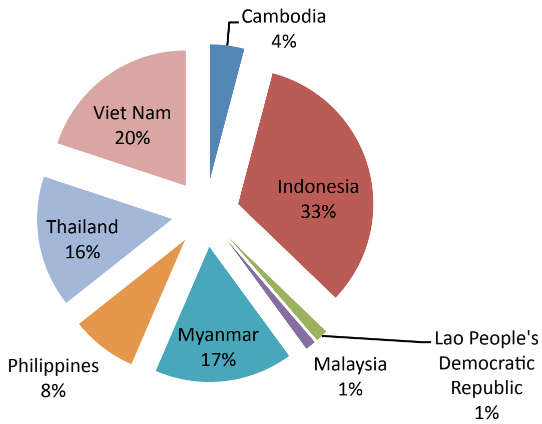

Figure 1. Production of rice paddy in 2010
(Source: FAOSTAT, 2012)

that the people of the region have acquired in the quest for progress. Such has been the role of rice in that quest that, throughout Southeast Asia today, rice is more than just food: it is the central subject of economic policy, a determinant of national objectives, and an important anchor in the maintenance of political stability.

OVERALL CHALLENGES

The IPCC 4th Assessment Report (IPPC, 2007) states that Southeast Asia is expected to be seriously affected by the adverse impacts of climate change. Since most of its economy relies on agriculture and natural resources as primary income, climate change has been and will continue to be a critical factor affecting productivity in the region (Figure 2). In the last five years, there has been an increase in the number of floods and periods of drought, and some of the most devastating cyclones, and water, soil and land resources are continuing to decline (the Philippines has lost about 50% of irrigated cropland, Indonesia has lost about 200 km^2/year and Thailand has lost approximately 32 km^2/year). In Indonesia, the Philippines, Thailand and Viet Nam, the annual mean temperatures are projected to rise by 4.8 °C by 2100, and the global mean sea level will increase by 70 cm during the same period (ADB, 2009). In Southeast Asia as a whole, small changes in the annual rainfall are foreseen to continue to 2040 (Cruz *et al.*, 2007) and there will be an increase in the occurrence of severe weather including heatwaves and precipitation events. Increases

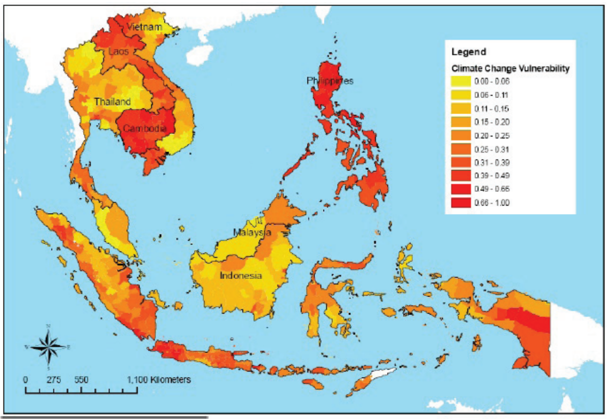

Figure 2. Climate change vulnerabilityin Southeast Asia
(Source: EEPSEA in Donnges, 2010)

Table 2: Critical temperatures for the development of the rice plant at different growth stages			
Growth stages	**Critical temperature (°C)**		
	Low	**High**	**Optimum**
Germination	16–19	45	18–40
Seedling emergence	12	35	25–30
Rooting	16	35	25–28
Leaf elongation	7–12	45	31
Tillering	9–16	33	25–31
Initiation of panicle primordial	15	-	-
Panicle differentiation	15–20	30	-
Anthesis	22	35–36	30–33
Ripening	12–18	>30	20–29
Source: FAO, 2005			

in tropical cyclone intensities by 10–20% are anticipated, and temperatures are projected to continue to increase by about 0.7–0.9 °C (Cruz *et al*., 2007). In the last few decades, sea levels have risen by 1–3 mm/year, marginally higher than the global average (ADB*,* 2009).

Rice production systems of the region have over recent years become increasingly threatened by the effects of climate change (Masutomi *et al.,* 2009), as a large portion of the rice-growing areas are located in especially vulnerable regions. A number of countries have, in fact, begun to see a gradual stagnation in production levels brought about by major production constraints for rice in Southeast Asia (Annex 1). Changes in temperature regimes greatly influence not only the growth duration, but also the growth pattern and the productivity of rice crops. The critical temperatures for the development of the rice plant at different growth phases are shown in Table 2. A decrease of 10% in rice yield has been found to be associated with every 1 °C increase in temperature (ADB, 2009), while Peng *et al.* (2004) reported that the yield of dry-season rice crops in the Philippines decreased by as much as 15% for each 1 °C increase in the growing season mean temperature.

These temperature and aggravating climate change effects may cause a decline in the world rice production (Furuya and Koyama, 2005; Li and Wassmann, 2011), and have already proven to have negative effects on agricultural production and the socio-economic conditions of farmers. For example, in Indonesia, the total damaged area and production losses because of flooding were estimated to be 268 823 ha and 1 344 million tonnes, respectively. With an average yield of 5.0 tonnes/ha, Indonesia experienced an economic loss of about USD 353.7 million/year affecting 4.4 million farm households (Wassmann *et al.,* 2011).

Predictions show that there will be a further decrease of 3.8% in rice yields in Southeast Asia due to future climates, which will include increasing CO_2 fertilization, water scarcity and increased temperatures (Murdiyarso, 2000). By 2100, Indonesia, the Philippines, Thailand and Viet Nam are projected to experience a potential fall of about 50% in rice yield, assuming no adaptation and no technical improvement. The rice yield decline would range from 34% in Indonesia to 75% in the Philippines (ADB, 2009) (Figure 3).

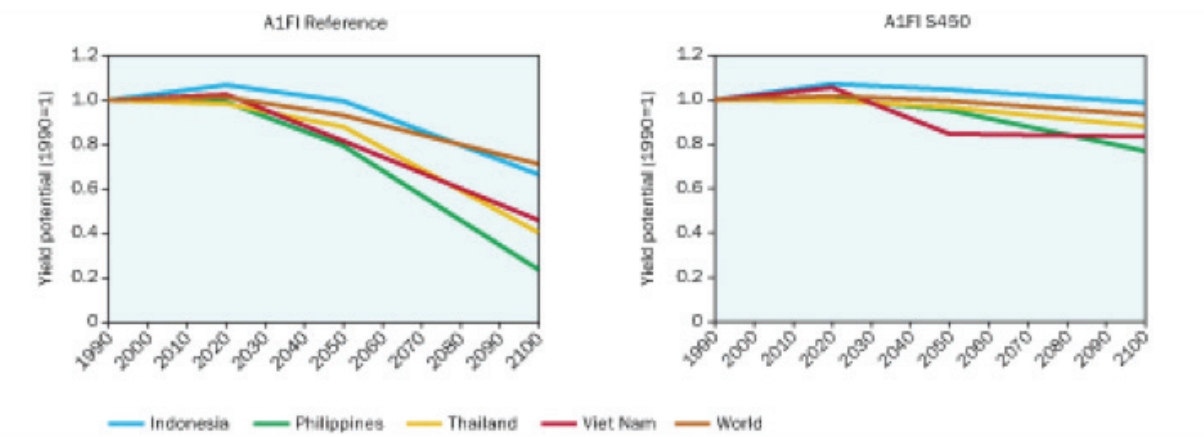

Figure 3. Rice yield potential in Indonesia, the Philippines, Thailand, Viet Nam and the world
(Source: ADB, 2009)

THREATS TO RICE PRODUCTION

Drought:

Current rice production systems rely on an ample water supply and thus are more vulnerable to drought stress. Drought is the most important limiting factor for rice production and is becoming an increasingly severe problem. Since early November 2009, rainfall has been consistently below the long-term average in Southeast Asia, particularly causing drought in Cambodia, Lao PDR, Myanmar, Thailand and Viet Nam. It is estimated that 50% of the world's rice production is affected to a greater or lesser extent by drought (Bouman *et al.,* 2005).

Drought stress is severely damaging during reproductive stages of the rice crop, especially during flowering, although drought in other stages can also lead to significant yield reductions (Liu *et al.,* 2006). Drought is the most serious constraint to rice production since most of the farmers' popular rice varieties are susceptible to drought stress (Serraj *et al.,* 2009).

Average yield reduction in rainfed, drought-prone areas has been found to range from 17% to 40% in severe drought years, leading to huge production losses and chronic food scarcity (Greenbio, 2011). In 1997/1998, droughts caused massive crop failures, water shortages and forest fires in various parts of Indonesia, Lao PDR and the Philippines. More recently, in 2010, the level of the Mekong River (that flows through Cambodia, Lao PDR, Myanmar, Thailand and Viet Nam, covering some 4 350 km and affecting the livelihoods of more than 60 million people living along the riversides) reached its lowest water levels in 20 years. In the Philippines, El Niño-induced climate variability regularly results in: (a) late onset of the rainy season; (b) early termination of the rainy season; (c) weak monsoon events characterized by isolated heavy rainfall events of short duration; and (d) weak tropical cyclone activity characterized by less intense cyclones (Lansigan, de los Santos and Coladilla, 2000). In 2009, the Philippines suffered from an El Niño-induced drought, drying up watercourses and irrigation systems in some of the most productive rice areas in Luzon, leaving parched and cracked paddies in its wake as it extended into the following year. By mid-February 2010, the Philippine Department of Agriculture had announced that rice production in the country decreased by some 3.31% from the levels realized in 2008 (a loss of approximately 494 700 tonnes from 2009 to 2010 [FAOSTAT, 2012]).

Case Study: Viet Nam

Viet Nam is one of the centres of origin of rice cultivation. Rice occupies 74% if Viet Nam's 5.7 million ha of arable land (IRRI, 2008). Rice production is dominated by small, irrigated farms based around the Mekong River Delta in the south (52%) and the Red River Delta in the north (18%). In commercial farming in Viet Nam, both seasonal and semi-permanent adoption of climate-resilient rice varieties is practised (Snidvongs, 2006). The use of short cycle rice varieties allows farmers to produce two cycles of rainfed rice within the seven months of rainy seasons in the Mekong River Delta.

Climate change is increasing sea water levels, brought about by higher global temperatures, which will have significant negative consequences (up to 16% of the area would be impacted by a 5 m sea level rise) (Dasgupta et al., 2007). Estimates state that sea levels are expected to rise up to 33 cm by 2050 (IFPRI, 2010a). This is placing huge stress on the populations that live along the lowlying delta.

FAO-IAEA has collaborated with agricultural research institutes in Viet Nam to develop high-yielding rice varieties with good levels of tolerance to salinity such as VND 95-20 and VND 99-3 for planting in saline-affected soils in the Mekong River Delta (FAO, undated).

Salinity:

Rice is considered to be moderately sensitive to salinity (IRRI, 1997). The symptoms of salt injury in rice are stunted growth, rolling of leaves, white tips, drying of older leaves and grain sterility. Soil salinity limits the rice plant's growth and development, resulting in yield losses of more than 50% (Zeng and Shanon, 2000). Sensitivity of rice to salinity stress varies with the growth stage. Though salinity affects all stages of the growth and development of the rice plant, when the rice is at the young seedling stage it becomes even more sensitive to salinity (Shereen *et al.,* 2005; Deepa Sankar, Saleh and Selvaraj, 2011). Existing guidelines (Maas and Grattan, 1999; Hanson, Grattan and Fulton, 1999) indicate that rice yields are reduced by 12% for every unit (dS/m[1]).

In the humid regions of Southeast Asia there are many hectares that are technically appropriate for rice production but are left uncultivated or are grown with very low yields because of salinity and problem soils. Low water levels in Viet Nam's Mekong River Delta, the country's rice bowl, have resulted in an inward flow of salt water, increasing the salinity in the river water and endangering rice paddies. In addition, in the rainfed rice fields of northeastern Thailand, salinity affects about 3 million ha, representing 17% of the surface area (Clermont-Dauphin *et al.,* 2010).

The full extent of the effects of increased soil salinity on agriculture can be seen in the Thai Khorat Plateau, where

[1] Unit of measurement for salinity- dS/m= deciSiemens per metre

an underground salt source has been brought to the surface by rising groundwater levels. Crop growth throughout the Khorat Plateau diminished and the destruction of plants hastened soil erosion. The eroded soil sliding into nearby streams and waterways affected water quality and constricted the flow of irrigation canals (ACIAR, 1992).

Rising sea levels:

Experts predict that the sea levels will rise by about one metre by the end of the twenty-first century as a result of global warming (IPCC, 2001). Higher sea levels impede gravitational river discharges and accelerate tides further inland. More than 50% of Viet Nam's rice production (Minh and Kawaguchi, 2002) is grown in the Mekong Delta, with another 17% in the Red River Delta (IRRI, 2008). As heat is trapped it accumulates in the earth's atmosphere, meaning that water from melting glaciers and polar ice caps will gradually swell the banks of the Mekong and Red Rivers. This will in time affect the entire hydrology of myriad watercourses, including changes in sediment discharge and shoreline gradients – the very dynamics that form the core of all rice production in Viet Nam.

In combination with heavy monsoon rainfall, rising sea levels create serious waterlogging and prolonged stagnant floods in major rice-growing, lowlying mega-deltas in Southeast Asia, for example in the Mekong Delta and Red River Delta in Viet Nam and the Irrawaddy in Myanmar. Rising sea levels may deteriorate rice production in the deltas since only a few low-yielding rice varieties have evolved to withstand such conditions (Wassman *et al.,* 2009), which means that under extreme sea level cases, countries such as Viet Nam find themselves having to alter their trade from exporters to importers (Chen, McCarl and Chang, 2012) to maintain food security.

Submergence:

Along with rising sea levels, more frequent and intense tropical storms brought about by the shifting of La Nina will undoubtedly cause uncontrolled flooding throughout Southeast Asia. The region's coastlines are likewise fringed with rice production systems that receive heavy monsoon rainfall, often coinciding with strong sea disturbances and high tides. With the combined high rainfall and high tides, rice crops in coastal areas experience submergence with moderately saline water during early crop growth (Wassman *et al.,* 2009).

Submergence is increasingly becoming a major production constraint affecting about 15–20 million ha of rice fields in South and Southeast Asia and causing a loss of up to USD 1 billion every year. During 2004, Thailand suffered from a tsunami that affected 58 550 people in six provinces. However, in 2010, flooding affected 8 663 221 in 51 provinces, causing economic damage of 32–54 billion baht according to the Department of Disaster Prevention and Mitigation, Ministry of Interior. It saw a reduction in production quantity, from 32 116 100 tonnes in 2009 to 31 597 200 tonnes in 2010, a loss of 518 900 tonnes in only one year. While rice thrives in wet conditions, it cannot survive when submerged under water for long time periods. Stagnant flooding affects rice crops at any stage of growth although submergence intolerance at the vegetative stage is the most common problem (Mackill *et al.,* 2010).

Submergence is also causing increasing negative effects for rainfed rice areas, specifically in areas where resource-

Case Study: Philippines

Rice is the staple food for about 89% of the population of the Philippines and is the source of income and employment for about 12 million farmers and family members (FAO, 2007a). Though it is predominately produced on small landholdings that average 1.7 ha (Estudillo and Otsyka, 2006), it is planted on about 4 704 million ha and in 2005 it produced 14 603 million metric tons, which was valued at 155.6681 million Philippine pesos (about USD 3.5 million).

The Philippines is a centre of diversity of rice. Extensive traditional varieties exist, consisting of farmers' varieties adapted to varied agro-ecological zones (e.g. lowland irrigated paddy, lowland rainfed, upland, saline, and cool elevated areas [Estudillo and Otsyka, 2006]). There are, to date, a total of over 5 500 collected and documented traditional varieties of rice in the country.

However, with the increase in climate change events, farmers are finding it more difficult to maintain rice production levels. They can no longer depend on the seasonal rainfall to irrigate their paddy fields. Therefore, farmers have to pump groundwater onto the field (about 5 000 litres are needed for 1 kg of rice); however, this is having financial implications for the farmers. They now need to buy diesel in order to run the pump (per hour a farmer in the Philippines will use about 8 litres of diesel; on average to fill a paddy field the pump is used for 2–4 hours).

Farmers in the Philippines are adopting new strategies in order to try and combat these issues. They have implemented alternate wetting and drying technologies, developed by IRRI, which improved the use of irrigation water and increased productivity. This reduced the methane emissions by almost 50% compared with the production of rice under continuous flooding. The farmers were able to increase their income while decreasing greenhouse gas (GHG) emissions on the whole (IFPRI, 2009).

poor farmers rely on the annual rain precipitation for their crops. More than 100 million people in South and Southeast Asia depend on these systems for their livelihood (Manzanilla *et al.,* 2011).

The destruction caused by recent typhoons in Southeast Asia clearly demonstrates just how vulnerable the region's rice systems are to typhoons and floods. In late 2011, a string of typhoons tore across Southeast Asia, causing floods that destroyed around 12.5% of Thailand's rice farmland, along with 12% in Cambodia, 6% in the Philippines, 7.5% in Lao PDR, and 0.4% in Vietnam. By year-end, the floods had pared Thailand's rough-rice production by around six million tonnes while the Philippines lost some 600 000 tonnes of milled rice to the floods and strong winds brought on by the typhoons (GIEWS, 2012).

Socio-economic factors:

Climate change presents an additional burden on the world's agricultural and natural resources, which are already coping with the growing food demand driven by population growth and higher income in developing countries (Wassmann *et al.,* 2011). This is reflected in the escalating volumes of rice imported by nations that regularly experience production deficits. Indonesia, Malaysia and the Philippines have begun to develop an untenable dependence on imported rice to ensure sufficient national stocks. In the 1990s, rice importation for these three countries increased by around 1.5 million tonnes over the annual average registered during the previous decade. By 2000, rice imports undertaken by Indonesia, Malaysia and the Philippines had risen to some 6.5 million tonnes (Mutert and Fairhurst, 2002). In 2010, the Philippines alone had to import 2.45 million tonnes of rice to address domestic requirements (IRRI, 2010).

Global imports constitute less than 10% of all rice consumption, which partly explains why international rice prices have always been more volatile than other prices and much more volatile than domestic rice prices (IFPRI, 2010b). Most rice produced by farmers across the globe is consumed domestically, and the marketable surplus is therefore small. Moreover, the rice export market is highly concentrated, with the top five exporting nations – Thailand, India, Viet Nam, the United States of America and China – accounting for 83% of the rice traded in global markets (FAO, 2002a). Because of this, any change in production among exporting countries weighs heavily on available global supplies, as demonstrated by the crisis in 2007/2008.

This growing need to import rice is not only due to the effects of climate change. Small-scale farmers (family farmers) are finding it hard to buy the best seeds, as well as appropriate resources to irrigate and fertilize their land adequately, owing to the increase in prices. Moreover, these small-scale farmers, who are often in charge of rainfed rice production, are the most vulnerable – as in the case of Cambodia, where 80% of the farmers grow rice, of which 60% of the rice is for family subsistence. In addition, coupled with the increase in urbanization and industrialization, the need to increase food supply (as population increases by 2% annually[2] [ADB, 2009] the demand for rice within Southeast Asia is projected to increase by 11% by 2015 [IRRI, 2006]) is becoming progressively more important.

Urbanization is another issue. The areas that are under the most productive and fertile irrigated rice lands are located in areas of high population density (Mutert and Fairhurst, 2002). In the Philippines, for example, much of the land is mountainous and made up of small islands, therefore unsuitable for rice production. With the increase in population and a need for more urban areas, the area available for paddies is decreasing. Some 50% of irrigated cropland in the Philippines has already been lost to urban development. In Thailand, losses are estimated at 32 km^2 of farmland to the urban sprawl annually, while in Java, Indonesia, farmers lose some 200 km^2 of cropland a year to industry and human settlements (Sundquist, 2007). With the continued increase in urbanization, the loss of agricultural lands, especially paddy lands, is predicted to increase rapidly in the next few years.

RESPONSES

Adaptation:

Rice production has always been impacted by different stresses, including environmental – and has looked for ways to manage these. Climate change adaptation requires more than simply maintaining the current level of performance from the rice production sector, but rather developing a set of responses that allow the sector to improve performance under the changing conditions climate change implies.

Adaptation to climate change in rice production systems is complex and must involve a range of environmental, social and economic factors. It must also involve creative financial and technological factors such as better understanding and application of indigenous knowledge and coping strategies.

However, rice production is a complex "biological factory". Farmers work in a system of great unreliability. Heavy rainfalls, droughts and temperature rises are already affecting the production and quality of products. A complicated interaction exists between the many parameters of production. This means that the effect of "controlled actions" depends on factors that are more or less out of the control of the individual farmer. Nevertheless, farmers have developed routines and strategies to cope with uncertainties and continuously create more resistant and

[2] Compared with the 1.4% global annual increase (ADB, 2009).

Example of an adaptation solution: Terrace system
The terrace system is a typical product of the ponding technique that allows cultivation even on steep slopes. This technique is useful not only in the prevention of soil erosion and landslides but also for its capacity for flood control.

In the Ifugao rice terraces in the Philippines water management and conservation are being carried out through the use of micro-watersheds in highland areas. The permanent presence of water on rice fields furthermore generates water percolation and groundwater recharge, which are often beneficial for other water uses. This provides the farmers with constant water (from the forest clad mountain tops and creating stone terraces and ponds), therefore allowing them to adapt to the climatic variations. One major advantage of water ponding in rice cultivation is that it prevents weed development, thereby avoiding the use of herbicides or reducing the amount of labour required (FAO, 2004b)

resilient production systems. Examples include improved water management and irrigation, constraining or moving the growing period, or changing the crop rotation.

There are a range of options that can be used to adapt to the effects of climate change. These include:

- **Selection of appropriate planting date.** The planting date can have a dramatic effect on the development and yield of the crop. As temperature varies, the aims would be to try and select the right date for crop establishment in order to allow for the reproductive and grain filling phases of rice to take place during the months with a lower temperature (FAO, 2004a).
- Use of **traditional varieties** with high resilience and **breeding of new varieties** with higher temperature tolerance, resistance to salinity, drought and floods. A report conducted by the Australian Centre for International Agricultural Research has demonstrated that the average annual value is equivalent to USD127/ha (in 2009 values) across the average rice area in southern Viet Nam of over 4.2 million ha/year since 1985. This is significantly higher than the average value per hectare for the Philippines (USD52/ha) and Indonesia (USD76/ha) (Brennan and Malabayabas, 2011). In addition, **hybrid rice**, where two varieties are crossed, for example a high-yielding variety that is not salt-tolerant with some land races that are salt-tolerant (IRRI-bred variety, labelled as IR63307-4B-4-3), can be used to increase yields (up to 30% more yield can be generated using a commercial hybrid rice compared with a high-yielding inbred rice variety). In addition, appropriate infrastructure needs to be in place and research needs to be undertaken into **hydroponic seed production technologies**, **aerobic rice varieties** and **rainwater harvesting** for production systems situated in upland and rainfed areas.
- **Site-specific nutrient management (SSNM):** This approach enables rice farmers to tailor nutrient management to the specific conditions of their fields, and provides a framework for nutrient best management practices for rice. It is a sophisticated knowledge system focused on double and triple rice monocropping (FAO, 2011). A study conducted in the Mekong Delta showed that by using SSNM an increase in grain yield of about 0.5 tonnes/ha was obtained (Hach and Tan, 2007).
- **Altering farm management practices**: In Cambodia, for example, some farmers have split their rice plots into two using different management approaches to address uncertainty in rainfall. Half of the rice plot uses conventional wet-paddy rice techniques (that can survive the heavy rains) and the other half uses a drought-resistant, less water-intensive cultivation technique called "system of rice intensification" (Resurreccion, Sajor and Fajber. 2008).
- **System of Rice Intensification (SRI):** Compared with common rice production practices, SRI has numerous benefits as it is an example of options available to farmers and nations to promote community-led agricultural growth, while managing soil and water resources more

Example of an adaptation solution: Symbiotic technology
Recent research shows that using fungal endophytes (fungi that live within a rice plant without causing it harm) reduces water consumption by 20–30% and significantly increases the growth and development of seedlings in the absence of stress. The findings indicate that fungal endophytes enhance the stress tolerance in rice plants via symbiosis with Class 2 endophytes, and suggest that symbiotic technology may be useful to combat the impacts of climate change (Redman *et al.,* 2011).

Example of an adaptation solution: Scuba Rice
IRRI, funded by DFID, has identified a waterproofing gene called Sub1A in support of building crop resilience to climate change (DFID, 2011). This gene allows rice to survive while being completely submerged for two weeks. It survives by extending its leaves and stems above the water's surface to escape drowning.

Scuba rice has already been disseminated across ten Asian countries (Cambodia, Indonesia, Lao PDR, Myanmar, the Philippines, Thailand, Viet Nam, Nepal, Bangladesh and India). In Bangladesh, it produced high yields and minimized crop loss due to floods (95% of scuba plants recovered after flooding compared with just 12% for a traditional variety).

sustainably and even enhancing their future productivity (Africare, Oxfam America, WWF-ICRISAT Project, 2010). Successful applications of SRI have shown that farmers are able to increase their paddy yields by 50–100% while using fewer inputs, in particular water (farmers were able to reduce their water requirements by about 25–50%) (Uphoff, 2007). The average increase in income from SRI in eight countries (Bangladesh, Cambodia, China, India, Indonesia, Nepal, Sri Lanka and Viet Nam) has been shown to be around 68%, with yield increases of 17–105% and decreases in water requirement between 24% and 50% (Africare, Oxfam America, WWF-ICRISAT Project, 2010). With the increased impacts of climate change, increasing variability of rainfall, and the growing competition for water and land, SRI offers a new opportunity for increasing the production value per drop of water and for reducing agricultural water demand (The World Bank, 2008). As rice cultivated under SRI grows with stronger stalks and longer roots, it is more resistant to episodes of drought, waterlogging, storm and typhoons.

- **Rotations** with different crops that have their most drought-sensitive phase in different phases of the growing season may prove a valuable adaptation to limited water resources. For example, in countries that have a high rice yield, the rice is planted in rotation with other crops, such as wheat. This practice is often overlooked, but integrated with other options it may provide rewarding results. In the Philippines, in recent years, fish or ducks have been raised with rice, as well as legumes such as mungbean (*Vigna radiata*), groundnut (*Arachis hypogaea*) and soybean (*Glycine max*) after two rice croppings (FAO, 2007a).
- **Rice and integrated pest management (IPM)**: Flooded rice agro-ecosystems have evolved under human management for more than 5 000 years – or more than 50 000 generations of plant feeders (herbivores). When the ecosystem is not disrupted, these insects are part of a complex food web (Figure 4) that converts sunlight and soil organic matter into energy that supports many species of insects and spiders in every rice field: in soil, under and on top of water, and on or around plants including rice.

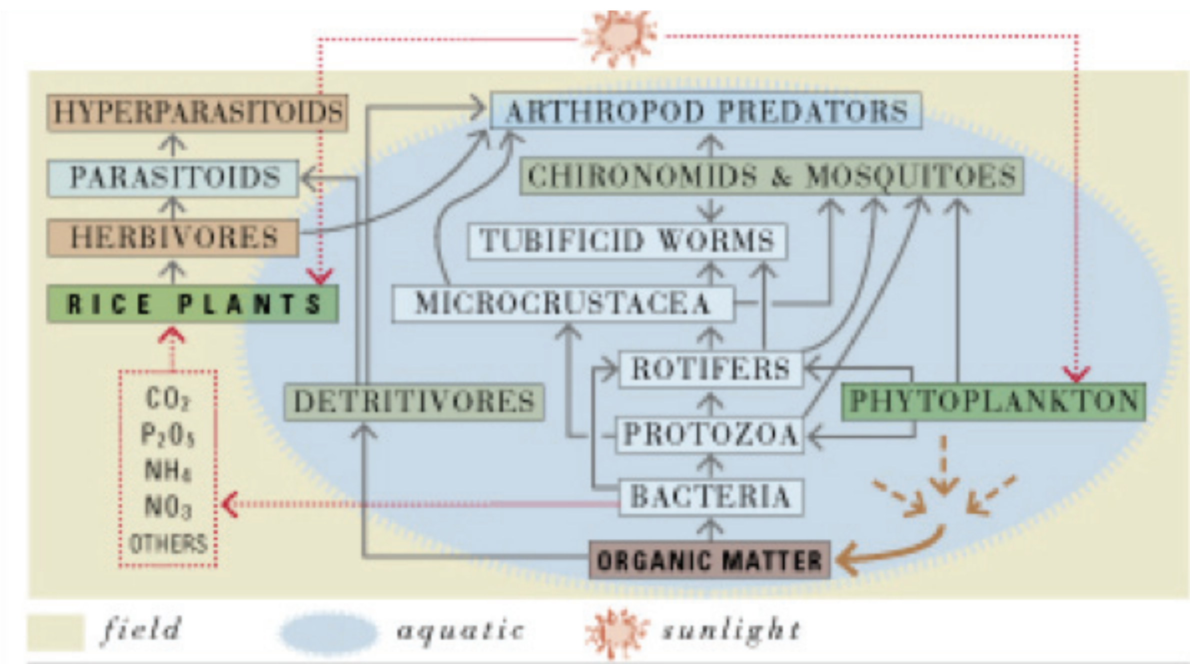

Figure 4. Food webs in a rice field
(Source: FAO, 2009)

These food webs fulfil the ecosystem function of naturally occurring biological pest control in annual crop systems such as rice. Their capability of keeping the system in balance varies as the predators multiply or leave to other fields in their search for larger populations of food (pests). Making the rice field ecosystem healthier means enhancing this ecosystem function by protecting the role of natural enemies to feed on pests. If the balance is broken by improper use of pesticides, the pests may prevail on natural enemies causing outbreaks (Allara *et al.,* 2012).

Mitigation:

Rice production, especially from flooded rice soils, is a large source of atmospheric methane, therefore a large contributor to global warming (FAO, 2004a). According to the IPCC, estimates of the global emission rate from paddy fields are 60 Tg/year; in South and East Asia the CH_4 emissions were a total of 82% (Smith *et al.,* 2007). Under anaerobic conditions of submerged soils of flooded rice fields, the methane that is produced predominately escapes from the soil into the atmosphere via gas spaces that are found in the rice roots and stems, and the remainder of the methane bubbles up from the soil and/or disperses slowly through the soil and overlying flood water (Figure 5).

In the same way that the efforts to ensure the ability of Southeast Asia's rice production systems to adapt are made more difficult by climate change, programmes that mitigate the impact of rice production on the natural resource base must be both broad and detailed. Mitigation systems must be developed that offer inputs that will provide farmers with affordable access to necessary technologies and technical assistance.

- **Flood irrigation** is often an inexpensive method depending on the access to the water resources. If the fields are completely even then it is possible to practise a reasonable irrigation, but this is not always the case. Hence, there is a high risk of loss of water and nutrients to the subsoil and groundwater. Furthermore, flooding techniques involve a high risk of CH_4 emissions. This is particularly evident in rice production, where the warm and waterlogged rice fields provide an optimal environment for CH_4 production. Rice production is responsible for 50 to 1 000 million tonnes CH_4/year and is probably the largest of the human-induced sources of this GHG (FAO, 2007b). Research has shown that it is possible to reduce CH_4 emissions from rice production. In 2006, Jondee *et al.* discussed how, in Thailand, they changed the breeding programme for drought-prone rainfed lowland rice in order to increase tolerance. In addition, a study conducted in China, indicated that water management by flooding with mid-season drainage and frequent waterlogging without the use of organic amendments is an effective option for mitigating the combined climatic impacts from CH_4 and N_2O in paddy rice production (Zou *et al.,* 2005).

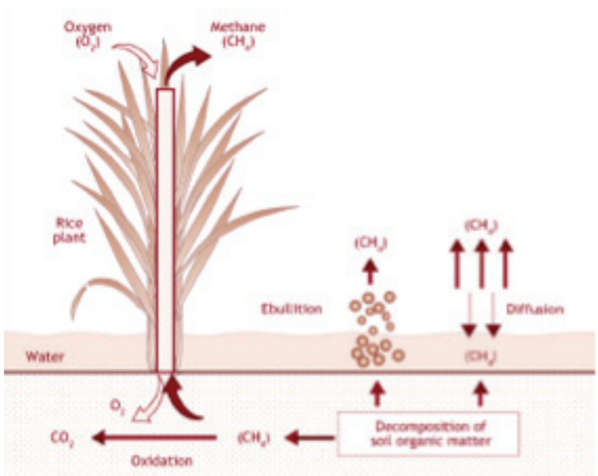

Figure 5. Dispersion of methane
(Source: Maclean *et al.*, 2002)

- **Intermittent irrigation or alternating dry-wet irrigation** could reduce emissions from rice-fields, while the transfer and adoption of a rice integrated crop management approach (e.g. the Australian RiceCheck) would increase the efficiency of nitrogen fertilizer in rice production, thus reducing N_2O (FAO, 2007c). Performing mid-season drainage and intermittent irrigation reduces the methane levels by about 50%.
- **Zero- or no-tillage and soil conservation** generate higher yields, reduce production costs and lessen erosion and land degradation. In addition, they improve environmental quality as they emit less GHG (therefore reducing the air pollution) through decreasing the use of diesel fuel and non-burning of rice residues (Adhikari *et al.,* 2007).
- **Rice residues:** On average after the rice is harvested and dehusked, rice straw and rice husk remain and are commonly re-incorporated into the soil or burned, which causes CH_4 and soot to be released into the atmosphere. Charring – or partly burning – rice residues and adding the obtained black carbon or "bio-char" to paddy fields instead of incorporating untreated harvest residues may reduce field CH4 by about 80% (IRRI, no date).
- **Urea deep placement (UDP):** Deep placement of fertilizer has been recognized as a method to increase fertilizer use efficiency. It involves the placement of 1–3 g of urea granules at a soil depth of about 7–10 cm shortly after the paddy is transplanted. UDP doubles the percentage of nitrogen that is absorbed by the plant, reduces nitrogen that is lost in the air and to surface water runoff (as most of it remains in the soil close to the plant roots where it is better absorbed) and has produced an average yield increase of 18% in farmers'

fields (FAO, 2011). The UDP technology increased paddy yield by 900–1 100kg/ha (depending on the cropping season), and reduced urea use by 78–150 kg urea/ha. The net return to farmers of using UDP versus broadcasting urea averages about USD 188/ha (IFDC, 2004–2005; Roy and Groot, 2009).

- **Leaf colour charts:** This is a four-panel leaf colour chart (LCC), developed for rice cultivation in Asia, that corresponds to actual colours of rice leaves (Figure 6). The LCC consists of plastic panels, each with distinctly different shades of green – ranging from yellowish-green to dark green. The LCCs can be used by farmers in the field to determine how much nitrogen fertilizer is needed for efficient use, and to maximize rice yields (Witt *et al.,* 2005). It can be used for real-time N management and synchronizing N application with crop demand to reduce GHG emissions.

Coping with change:

FFS is a form of adult education, which evolved from the concept that farmers learn optimally from field observation and experimentation. Unlike traditional approaches, it brings together concepts and methods that aim to help farmers produce crops more efficiently. Developed to help farmers tailor their IPM practices to diverse and dynamic ecological conditions (FAO, 2004c), it is an example of how farmers can adapt to and mitigate climate change through the ability to select, adapt and apply knowledge-intensive methods that are productive, profitable and sustainable.

FFS enables groups of farmers, through a participatory platform, to improve decision-making and stimulate local innovation by learning-by-doing. It has a strong emphasis on the development of human resources that brings about tremendous changes. It is a vehicle for knowledge and skill generation and has a proven track record of farmer empowerment at community level in Southeast Asia. Farmers increase their control over technologies, markets, relevant agricultural policies and their agro-ecosystems (FAO, 2002b).

Since the 1990s, FFS in the Philippines, through the IPM national programme (KASAKALIKASAN), introduced sustainable agricultural strategies that increased yields (Table 3) and provided positive profit to small subsistence farmers. In Indonesia, the FFS programme allowed farmers to considerably reduce the levels of insecticide and pesticides uses (Figure 7). In Cambodia, where use of hazardous class Ia and Ib insecticides is high, training enabled farmers to reduce pesticide volume in rice by 64% and to select relatively less hazardous compounds. FFS farmers were better aware of pesticide-related health risks than non-FFS farmers (FAO, 2004c). The FFS approach has also been used in Thailand, where a decrease of 60% in the use of insecticides and moluscicides in rice was shown in the season after training, and an increase in knowledge about pests and natural enemies.

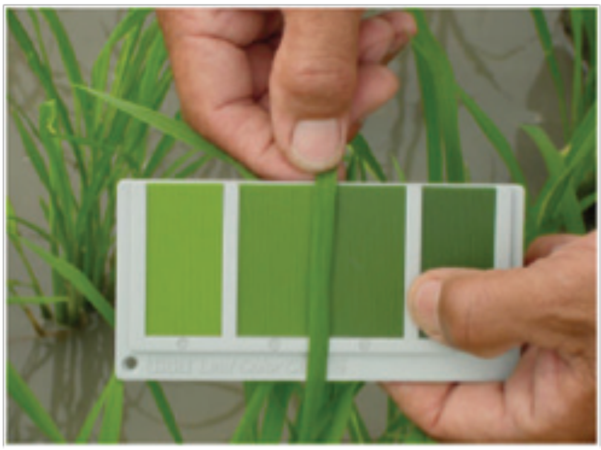

Figure 6. Leaf colour chart

Table 3: Yield per hectare of rice, before and after FFS

	Yield (kg)	
	Before FFS	After FFS
Wet Season	3 903	4 451
Dry Season	4 010	4 435
Source: FAO, 2005		

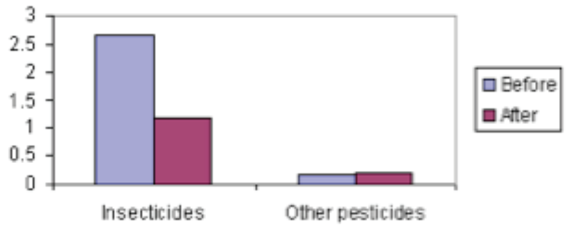

Figure 7. Mean pesticide applications per field, before and after training
(Source: FAO, 2004c)

The success of IPM FFSs has opened up a new approach to the development of sustainable, small-scale agricultural systems that can adapt to various kinds of changes including climate change. This will enhance agricultural productivity and resilience in the face of new climatic stresses.

CONCLUSIONS

Rice production in Southeast Asia is highly vulnerable to climate change. As described in this paper, rice production simultaneously contributes to global climate change and is affected by it. However, there is a wide range of adaptation measures already being applied, and many examples of the potential that rice production has in contributing to the reduction of GHG emissions globally. In Southeast Asia this issue is of particular relevance owing to the importance of rice to the national food security, economy and livelihoods, and also because of the intensity of the impacts of climate change in the region. Adaptation and mitigation in rice production systems both have important roles to play. Farmers will need to have access to a genetically diverse range of improved crop varieties that are resilient to climate change and suited to a variety of ecosystem and farming practices. Adaptation will allow farmers to cope with climatic events, while mitigation practices will contribute to global reduction of GHG emissions from rice production.

Planning, policy and farm practices must be based on actual knowledge of systems that are already in place, but with emphasis on new adjustments to make them function with much greater efficiency in the future. Improved knowledge and technology concerning efficient use of inputs and research on stress-tolerant species need to be developed to allow farmers to increase the value of both the primary product of their enterprise as well as its by-products. Quality farmer education plays an important role in addressing sustainable livelihoods and in meeting the need to provide food for all, raising rural incomes, reducing poverty and sustainably managing the environment and natural resources (such as through FFS).

An increased focus on traditional knowledge that includes the integration of research into adaptive capacity within farming systems is also needed in order to create resilience to the changing climate. In each country attention must be given to means of involving every relevant institution – public and private – in the process of reducing GHG emissions, renewing soil and water resources, and repairing the ecosystem.

Appropriate agricultural management practices are critical at the field level. However, a supportive policy, planning and institutional environment is also essential. Therefore, policy support to rice research and development to introduce and transfer appropriate and efficient technologies are vital to better understand the role of rice cultivation in climate change. In addition, it enables farmers to improve their production practices while adapting to the severe challenges to their food security posed by climate change. Increased support is also needed for the collection, conservation and utilization of plant genetic resources, as well as a need for funding to revitalize public plant breeding programmes even as the links between formal and farmer-saved seed systems are strengthened through appropriate policies, and efforts are undertaken to encourage the establishment of local seed enterprises. More work should be done to better understand the role of introducing other grain crops, legumes and pastures into the rotations and evaluating the benefits and trade-off of changing from monoculture of rice (at species and variety level) to more diverse systems that use biodiversity to improve adaptation, mitigation and food security. The achievement of climate resilience in Southeast Asia's rice production systems will depend on suitable policies that will govern the regulation of the seed sector in order to guarantee farmers' access to quality seeds (including the affordability and availability of a wide range of varietal material).

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Annex 1: Main production constraints for rice in Southeast Asia

CONSTRAINT	CAMBODIA	INDONESIA	LAO PDR	MALAYSIA	MYANMAR	PHILIPPINES	THAILAND	VIET NAM
Low soil fertility			Sand soils			50% problem soils	>75% rice lands	
Soil acidity							Acid sulphate soils	Acid sulphate soils
Salinity				Sea water intrusion	Sea water intrusion		NE and S coast	Coastal areas
Drought				Rainfed rice systems	Rainfed rice systems			
Flooding	Low lying areas		Mekong River			Typhoons	In RLLR	Rainfed areas
Low temperatures							Upland in North, Irrigated in North and NE	North Viet Nam
Pests and diseases	Stemborer, gall midge	BPH, stemborer, BLB, blast, RTV		BPH, stemborer, blast, GLV, RTV		RTV. BLB, blast, GLH, stemborer	BLB, blast, BPH, stemborer	BPH, stemborer, leaf rolle, blast, BLB, brown spot
Weeds				Direct seeded rice		Direct seeded rice	Direct seeded rice	Direct seeded rice
Land fragmentation			Small farm size					Small farm size
Land security	Land mines							
Rural poverty								
Labor scarcity		In agriculture production areas						
High input costs	Fertilizers		Fertilizers		Fertilizers	Fertilizers	Fertilizers	Fertilizers
Input scarcity	Infrastructure, credit, seed, fertilizers, agrochemicals	Lack of quality fertilizers	Infrastructure, credit, seed, fertilizers, agrochemicals		Infrastructure, credit, seed, fertilizers, agrochemicals			Infrastructure, credit, seed, fertilizers, agrochemicals
Rice price policy			Low price	Low price		Price policy		
Ineffective extension								
Land loss		Urban sprawl	Erosion					
Others		New technology required	Preference for glutinous rice		Limited market opportunity			

Source: Mutert and Fairhurst, as modified after IRRI Rice Facts, 2002