Global climate changes and rice food security

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Reducing hunger and poverty are the key United Nations Millenium Development Goals. This was the main reason for the UN declaration of the International Year of Rice 2004. In 2002, rice was the source of more than 500 calories per person per day for over 3 billion people (FAOSTAT). Furthermore, rice cultivation is the principal activity and source of income for more than 100 million households in developing countries in Asia, Africa and Latin America. The concerted and coordinated efforts to improve rice production through science, research and development in the 1970s and 1980s enabled global rice production to meet the demand of a growing population, created employment opportunities, increased the income of rice farmers, and enhanced access to rice of the poor populations living in urban centres across the world. The gains made during the Green Revolution, however, have begun to show diminishing returns in recent years. Since 2000, world rice production has been less than rice consumption and the deficit has been addressed by drawing on rice from buffer stocks. What is more, 852 million people continue to suffer from hunger and malnutrition (FAO, 2004).

The world population continues to grow steadily, while land and water resources are declining. Furuya and Koyama (2005) reported that high temperatures would cause a marked decrease in world rice production. Furthermore, studies have demonstrated that the production and distribution of (thus the supply of and access to) rice food in different parts of the world might be affected greatly by the global climate changes. Understanding the potential impact of climate change on rice-based production systems is important for the development of appropriate strategies to adapt to and mitigate the likely outcomes on long-term food security of interaction between rice production and climate change.

TABLE 1

World rice harvested area, 2004 [a]

	Harvested area (*ha*)
Inside tropical region (from Tropic of Cancer to Tropic of Capricorn)	114 794 445
Outside tropical region	38 224 740
World total	**153 019 185**

[a] It is estimated that about 1 119 450 ha in Brazil, 5 830 000 ha in Mainland China, 135 000 ha in Taiwan Province of China, 39 725 000 ha in India and 25 250 ha in Mexico were inside the tropical region.

Source: FAOSTAT (adapted).

BASIC FACTS ON RICE FOOD SECURITY AND GLOBAL CLIMATE CHANGE

Rice production systems make a vital contribution to the reduction of hunger and poverty. The basic facts presented herein on rice production, rice consumption and global climate changes provide a general appreciation of the dimensions of rice food security and global climate changes.

Rice production

The cultivation of rice extends from drylands to wetlands and from the banks of the Amur River at 53° north latitude to central Argentina at 40° south latitude. Rice is also grown in cool climates at altitudes of over 2 600 m above sea level in the mountains of Nepal, as well as in the hot deserts of Egypt. However, most of the annual rice production comes from tropical climate areas. In 2004, more than 75 percent of the global rice harvested area (about 114 million out of 153 million ha) came from the tropical region whose boundaries are formed by the Tropic of Cancer in the Northern Hemisphere and the Tropic of Capricorn in the Southern Hemisphere (Table 1). The tropical region includes: all Southeast Asian countries, Bangladesh, Sri Lanka, almost all the rice-growing states of India, almost all rice-growing countries in sub-Saharan African countries, and the majority of rice-growing areas in Latin America and the Caribbean.

TABLE 2

Food calories derived from rice of different people groups of the world population, 2002

Dependency on rice for calories	Position in relation to tropical region	Countries	Total population (thousands)
Very highly dependent (> 800 kcal/person/day)	Mostly to fully inside	Bangladesh, Cambodia, Guinea-Bissau, Guyana, India, Indonesia, Lao People's Democratic Republic, Madagascar, Myanmar, Nepal, Philippines, Sri Lanka, Thailand, Timor-Leste, Viet Nam	1 762 354
	Partially inside	China Mainland	1 272 403
	Outside	Republic of Korea	47 430
		Subtotal	**3 082 187**
Highly dependent (500–799 kcal/person/day)	Mostly to fully inside	Brunei, Comoros, Costa Rica, Côte d'Ivoire, Cuba, Guinea, Guyana, Liberia, Malaysia, Maldives, Mauritius, Senegal, Sierra Leone, Solomon Islands, Suriname, Vanuatu	86 394
	Partially inside	China Macao SAR	460
	Outside	Democratic People's Republic of Korea, Japan	150 019
		Subtotal	**236 873**
Moderately dependent (300–499 kcal/person/day)	Mostly to fully inside	Cape Verde, Colombia, Dominican Republic, Ecuador, Fiji, French Polynesia, Gabon, Gambia, Haiti, Kiralbati, Mali, Mauritania, Nicaragua, Panama, Peru, Sao Tome and Principe	128 230
	Partially inside	Brazil, China Hong Kong SAR, Taiwan Province of China	205 701
	Outside	Egypt, Iran (Islamic Republic of), Kuwait, Saudi Arabia, United Arab Emirates	167 477
		Subtotal	**501 408**
Less dependent (< 300 kcal/person/day)	All categories	Remaining countries	**2 404 510**
Total			**6 224 978**

Source: FAOSTAT (adapted).

Rice consumption

In terms of food energy derived from rice in 2002 (when the most recent data are available), Table 2 shows that: 3.08 billion people out of the whole world population (6.22 billion) belonged to group A, i.e. very high dependence on rice for food calories (> 800 kcal/person/day); followed by 236.8 million people in group B, highly dependent (500–799 kcal/person/day); 501.4 million people in group C, moderately dependent (300–499 kcal/person/day); and the remaining 2.4 billion people in group D, less dependent (< 300 kcal/person/day). Rice is considered a staple food for the 3.31 billion people in groups A and B in 2002 (Table 2).

Of groups A and B, about 1.84 billion people lived inside and 1.27 billion people partially inside the tropical region, while only 197 million people lived outside. Of the 501 million people who were moderately dependent on rice for food calories, 128 million lived inside and 205 million partially inside the tropical region, with only 167 million outside. In summary, in 2002, rice clearly had a vital role in the food security of people living in the tropical region. Data in Table 2 also indicate that the majority of people who depended on rice for food lived in low-income and developing countries.

Global climate changes

Attention to global climate changes resulting from human activities and their potential impact took a momentous step on 16 February 2005 when the Kyoto Protocol entered into force. Enormous quantities of greenhouse gases are released into the atmosphere through mining and combustion of fossil fuels, deforestation, maintenance of livestock herds and even rice production. The emission of methane and nitrous oxide gases from lowland rice cultivation and the deforestation entailed in upland rice production under slash-and-burn shifting cultivation are considered contributors to global climate changes.

The accumulation of greenhouse gases in the atmosphere has warmed the planet and caused changes in the global climate. In 2001 the UN-sponsored Intergovernmental Panel on Climate Change (IPCC) reported that worldwide temperatures have increased by more than 0.6°C in the past century and it also estimated that by 2100, average temperatures will increase by between 1.4° and 5.8°C. IPCC also reported that sea levels have risen by between 10 and 20 cm and snow and ice covers have fallen almost worldwide, while the precipitation patterns characterizing land areas of the Northern Hemisphere have progressively changed. In the same report, IPCC estimated that sea levels would rise by an average 0.09 to 0.88 m between 1990 and 2100.

POTENTIAL IMPACTS OF GLOBAL CLIMATE CHANGES ON RICE PRODUCTION AND DISTRIBUTION

The food security of more than half the world population depends on the ability of the world to supply and distribute rice. Rice supply depends on global rice production, while its distribution depends on the distance from production sites to consumers' residences as well as on transportation systems and facilities. Studies suggest that the temperature increases, rising seas and changes in rainfall patterns and distribution expected as a result of global climate change could lead to substantial modifications in land and water resources for rice production as well as in the productivity of rice crops grown in different parts of the world.

Effect on land and water resources for rice production

In 1992, it was reported that Zimbabwe's core agricultural zone would be reduced by 67 percent with a 2°C temperature increase (Downing, 2002). A later report also suggested that the greatest temperature increase could be expected in agricultural land in low latitude tropical regions (Rosenzweig and Iglesias, 1994). Darwin *et al.* (2005) estimated that the amount of land classified as "land class 6" – i.e. the primary land class for rice, tropical maize, sugarcane and rubber in tropical areas – would decline by between 18.4 and 51 percent during the next century due to global warming. On the other hand, it is possible that the land and water resources for rice production in areas outside the tropical region increase with global climate changes (Darwin *et al.*, 2005). Likewise, enormous areas of coastal Florida, much of Louisiana, the Nile Delta and Bangladesh will become uninhabitable once sea levels have risen by as much as 88 cm (Klutger and Lemonick, 2001).

Effect on the productivity of rice crops

Temperature increase

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 3.

TABLE 3
Critical temperatures for the development of 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 primordia	15	-	-
Panicle differentiation	15–20	30	-
Anthesis	22	35–36	30–33
Ripening	12–18	> 30	20–29

Source: Yoshida, 1978.

TABLE 4
Symptoms of heat stress in rice

Growth stage	Symptoms
Vegetative	White leaf tip, chlorotic bands and blotches, white bands and specks, reduced tillering, reduced height
Reproductive anthesis	Reduce spikelet number, sterility
Ripening	Reduced grain-filling

Source: Yoshida, 1981 (adapted).

Extreme temperatures – whether low or high – cause injury to the rice plant. In tropical regions, high temperatures are a constraint to rice production. Table 4 outlines the various possible injuries to rice crops caused by extremely high temperatures. The most damaging effect is on grain sterility; just 1 or 2 hours of high temperature at anthesis (about 9 days before heading and at heading) result in a large percentage of grain sterility.

Studies on rice productivity under global warming also suggest that the productivity of rice and other tropical crops will decrease as global temperature increases. Mohandrass *et al.* (1995), using the Hadley-coupled model, predicted a yield decrease of 14.5 percent for summer rice crops across nine experiment stations in India in 2005. Peng *et al.* (2004) reported that the yield of dry-season rice crops in the Philippines decreased by as much as 15 percent for each 1°C increase in the growing season mean temperature. Similarly, Mohamed *et al.* (2002a and b) estimated that by 2005, climate change in Niger could lower yields of millet by 13 percent, groundnut by between 11 and 25 percent and cowpea by 30 percent. Chipanshi, Chandra and Tototo (2003) reported that in

Bostwana, climate change could bring about yield decreases of 10 to 36 percent in maize and 10 to 30 percent in sorghum.

Temperature increases in subtropical and temperate climate areas may have a positive or negative effect on rice crops, depending on the location. For example, temperature increase would improve the crop establishment of rice in Mediterranean areas, where cool weather usually causes poor crop establishment (Ferrero and Nguyen, 2004). On the other hand, a similar temperature increase would reduce the beneficial effects on grain production of the low night temperature in northern Japan (16°–21°C) (Matsushima and Tsunoda, 1958).

Rising seas

Large areas in the low-lying deltas of the Ganges, the Mekong, the Nile, the Yangtze, the Yellow and other major river systems that are home to major rice-growing regions have been affected by tidal waves. For example, it was reported that there were about 650 000 ha of saline soils (eutric fluvisols) along the coastal belt in the Mekong River Delta and 350 000 ha in the Red River Delta of Viet Nam (FAO, 1988). Most eutric fluvisols have moderate to high inherent fertility, but a saline phase in these soils limits their potential for wetland rice production (Dent, 1980).

Enterprising farmers worldwide have improved tidal-affected lands for rice production. They have also used flooded rice systems to reclaim land to produce other crops for their food and incomes. Yields of rice planted in tidal-affected lands, however, are normally lower than in lowlands that are not influenced by tidal waves. This is due to the salinity in the soil (tidal waves contaminate water and soil with the salt in the seawater). In flooded soils, salt displaces K^+, NH_4^+, Fe^{2+}, Mn^{2+}, Ca^{2+} and Mg^{2+} from exchange sites. Most rice varieties are severely injured in submerged soil culture at an electrical conductivity (ECe) of 8–10 mmho/cm at 25°C (Ponnamperuma and Bandyopadhya, 1980). The symptoms of salt injury in rice are stunted growth, rolling of leaves, white tips, drying of older leaves and grain sterility. The rising seas expected under global climate changes would definitely increase the size of land areas that are influenced by tidal waves in the low-lying deltas of the major river systems. In the Mekong Delta of Viet Nam, for example, the effect of the ocean tides could sometimes be observed as far as 200 km from the sea (Nguyen, 1987).

Changes in the pattern of precipitation

At present, about 40 percent of the total rice area is classified as rainfed (lowland or upland), while about 3.5 million ha of rice-land are still being classified as deep-water or flood-prone (Maclean *et al.*, 2002). Variability in the amount and distribution of rainfall is the most important factor limiting yield of rainfed rice. Variability in the onset of the rainy season leads to variation in the start of the planting season in rainfed rice. Moreover, in freely drained upland, moisture stress severely damages or even kills rice plant in an area that receives as much as 200 mm of precipitation in 1 day and then receives no rainfall for the next 20 days. Complete crop failure usually occurs when severe drought stress takes place during the reproductive stages.

Flood is the most important constraint to rice production in low-lying areas. Most rice varieties for rainfed lowland, irrigated and deep-water ecosystems can stand complete submergence for at least 6 days before 50 percent of them die. However, the mortality rate becomes 100 percent when submergence lasts 14 days. Floods also cause indirect damage to rice production through the destruction of property and farmers' production means, as well as of infrastructures supporting rice production (e.g. dams, dikes and roads). The changes in the pattern of rainfall distribution may lead to a more frequent occurrence of intense flood and drought in different parts of the world (Depledge, 2002).

Effects on rice distribution and access to rice

Studies on the impact of global climate changes on land and water resources for rice production and on the productivity of rice crops point towards a possible decrease in rice production in the tropical region, contrasted with a possible increase in areas outside the tropical region. As the majority of people who are highly dependent on rice for food live in the tropical region (Table 2), such a shift in rice production areas would create difficulty in the distribution of and access to rice. Furthermore, the expected increase in the intensity and frequency of floods and storms caused by the changes in rainfall and its distribution pattern (Depledge, 2002) would have negative effects on the transport and distribution of rice to consumers. In summary, the analysis suggests that there will be serious implications for world food security if no effort is made to adapt rice production to climate changes. The effort to reduce the emission of greenhouse gases and deforestation from rice production would also be beneficial to sustainable rice production in the long run.

TECHNICAL OPTIONS FOR ADAPTATION AND MITIGATION

Adaptation involves adjustments to decrease the vulnerability of rice production to climate changes, while mitigation focuses on reducing the emission of greenhouse gases from rice production and minimizing deforestation resulting from upland rice cultivation under slash-and-burn shifting cultivation. There are a range of technological options that are presently available or which can potentially be developed in the near future for enhancing the rice production systems' ability to adapt to and mitigate the effects of global climate changes.

Technical options for adaptation

Selection of appropriate planting date

Given that germination and emergence of rice seedlings are more likely to be limited by low than by high temperatures, any temperature increase under global climate changes would not significantly affect the selection of the appropriate date for establishing the rice crop in tropical regions. As temperature varies from month to month, it is possible to select the right date for crop establishment in such a way that the reproductive and grain filling phases of rice fall into those months with a relatively low temperature. This would minimize the negative effect of temperature increase on rice yield as reported by Peng *et al*. (2004). Efforts to collect and disseminate the information on month-to-month variation in temperature regimes in major rice-producing tropical areas, therefore, are essential for helping rice production to adapt to climate changes.

Selection and development of appropriate rice varieties

Rice varieties have different abilities to tolerate high temperature, salinity, drought and floods. For example, BKN6624-46-2 is more tolerant to high-temperature-induced sterility than N22 (Yoshida, 1981). Rice varieties with a high level of salinity tolerance have been utilized to expedite the recovery of rice production in areas recently damaged by the *tsunami*. The selection of appropriate rice varieties is, therefore, another technical option for adaptation to global climate changes.

Also, the development of rice varieties that have not only high-yielding potential, but also a good degree of tolerance to high temperature, salinity, drought and flood, would be very helpful under the environment of global warming. Efforts to increase the trehalose biosynthesis in rice by introducing *ots A* and *ots B* genes from *Escherichia coli* have resulted in transgenic rice with a higher level of tolerance to drought and salinity (Garg *et al*., 2002). Similarly, FR13A (one of the submergence-tolerant donors) has been used to develop improved rice cultivars with submergence tolerance (MacKill *et al*., 1993).

Optimization of high CO_2 concentration for higher yield

The high CO_2 concentration present in the atmosphere under global warming could be harnessed to increase the productivity of the rice crop. The grain yield of IR8, for example, was significantly increased with carbon dioxide enrichment before and after heading (Table 5). C4 plants, such as maize and sorghum, are more productive than C3 rice and wheat, because C4 plants are 30 to 35 percent more efficient in photosynthesis, especially when the level of CO_2 concentration in the atmosphere is high. Ku *et al*. (1999) and Matsuoka *et al*. (2001) introduced cloned genes from maize to regulate the production of enzymes responsible for C4 synthesis to alter the photosynthesis of rice from C3 to C4 pathway.

Technical options for mitigation

Reducing the emission of greenhouse gas

The emission of methane from flooded rice soils has been identified as a contributor to global warming. Water regime, organic matter management, temperature and soil properties, as well as rice plants, are the major factors determining the production and flux of methane (CH_4) in rice fields. Results of studies during the 1990s,

TABLE 5
Effect of carbon dioxide enrichment on grain yield of IR8

Treatment	Yield (*tonnes/ha*)
Dry season	
Control	9.0 a
CO_2 enrichment before heading	11.6 b
CO_2 enrichment after heading	10.9 b
Wet season	
Control	5.7 a
CO_2 enrichment before heading	7.7 b
CO_2 enrichment after heading	6.9 b

Note: Two means followed by the same letter are not significantly different at the 5 percent level.
Source: Yoshida, 1981.

however, showed that methane emission from rice fields is actually much lower than originally thought, accounting for only about 10 percent of total global methane emissions (Maclean *et al.*, 2002). Varietal differences could be used to lessen methane emission in rice production. Also, intermittent irrigation or alternating dry-wet irrigation could reduce emissions from rice-fields, while the transfer and adoption of a Rice Integrated Crop Management (RICM) approach (e.g. the Australian RiceCheck) would increase the efficiency of nitrogen fertilizer in rice production, thus reducing nitrous oxide emissions (Nguyen, 2002). In addition, the initial results obtained from rice-wheat systems in China and India demonstrate that the fossil fuels used in land preparation operations in rice-based systems could be substantially minimized with conservation agriculture practices such as minimum and reduced tillage (T. Friedrich, personal communication, 2005).

Similarly, the planting of high-yielding rice (e.g. hybrid rice and super rice) would permit sustainable rice production, while reducing the area actually planted to rice and consequently the emission of methane. As a result of the widespread adoption of hybrid rice (about 50 percent of total rice area), Chinese rice production increased sustainably from 128 million tonnes in 1975 to 191 million tonnes in 1990, while over the same period the rice harvested area was reduced from 36 to 33 million ha (Nguyen, 2004).

Minimizing deforestation resulting from upland rice cultivation

Upland rice cultivation, especially in sub-Saharan Africa, is done under slash-and-burn shifting cultivation. Under this system the vegetation in a forest land area is cleared and burnt and the area is then cultivated to upland rice for 1 to 2 years before the farmers move to new areas. Farmers return to a previously cleared area only several years later to repeat the same process of cutting and burning of the cover vegetation. Upland rice production in sub-Saharan Africa is a major cause of deforestation and desertification. However, tropical sub-Saharan Africa has a total of 24 million ha of wetlands which are suitable for rice production (Andriesse, 1986). The development of wetland rice in sub-Saharan Africa would markedly reduce the deforestation which currently results from upland rice cultivation.

CONCLUSIONS

Rice is the staple food crop of the world population. The world population continues to grow steadily, while land and water resources are on the decline. Studies suggest that temperature increase, rising seas and changes in patterns of rainfall and its distribution under global climate changes might lead to substantial modifications in land and water resources for rice production as well as the productivity of rice crops grown in different parts of the world. The emission of methane and nitrous oxide gases from lowland rice production and the deforestation in upland rice production under slash-and-burn shifting cultivation are contributors to global climate changes.

The sustainable increase of rice production for food security will require efforts to enhance the capacity of rice production systems to adapt to global climate change as well as to mitigate the effects of rice production on global warming. Technical options for adaptation and mitigation are available and could be further improved. Policy support to rice research and development to develop and transfer appropriate and efficient technologies, however, will be vital for the realization of such measures for sustainable rice production.

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