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THE IMPACT OF GREENHOUSE EFFECTS ON RICE: A REVIEW

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Abstract

The sustainability of a natural system and the productivity of an agricultural system depend on healthy environmental conditions. The so-called greenhouse effect however is gradually changing the balance of world carbon and hydrological circulation. These changes have profound impacts on life systems including agricultural systems on earth. At the same time, many human activities including farming are also affecting environment: the composition of trace elements in atmosphere, and the interactions between inorganic and organic systems. Though many studies were designed to investigate the global change effects in the last decade, not all the studies can offer practical solutions in improving environmental qualities or the sustainability of agricultural systems. The problem is not necessarily due to the lack of scientific data, but in lack of methods that can integrate information generated from various disciplinarians. This report attempts to review some simulation and experimental results of climatic change impact on rice productions in Asia. Strategies and approaches to improve the sustainability of rice production systems in Asia countries are also briefly reviewed and discussed.

Introduction

World population is growing at an annual rate of 86 million and it is estimated that the world population will double by the middle of the next century. The single most threatening issue that mankind faces is: can humans produce adequate food to feed themselves given the limits of carrying capacity of the Earth? Worldwide records of food production in recent years send a sternly cautionary note. At least 20% of the world population is malnourished today, and the per capita grain production has been steadily declining in the past decade. At the same time, arable land is being seriously degraded, and the water and air seriously polluted: e.g. the life support system of Earth has been badly eroded. Evidence of the damage to the system is partly seen from the unstable weather patterns that we have witnessed in recent years: five of the most serious reductions of grain production that have occurred in the US in the last 50 years occurred in the last 10 years and were all caused by abnormal weather conditions. Indeed, previous studies showed that the variability of grain production and weather conditions have concurrently and significantly increased in recent years. Despite the urgency of the problem, little has been accomplished in the area of policy making which will allow preventative actions and remedies dealing with global environmental change and unstable

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food supply. This is partly, due to the lack of scientific information or an understanding of the phenomena, which are results from extremely complex interactions of natural systems and anthropogenic activities. In this report we will review the complex issue of global climate change and food production by focusing on rice. Specifically, we will examine the following issues: (1) the impact of greenhouse effect on rice production in Asia countries; (2) the impact of rice production systems on greenhouse gases; (3) strategies and approaches to improve the sustainability of rice production systems in Asia countries.

Global Climate and Trace Gas Changes. Anthropogenic activities affect the composition of atmospheric gases and the radiation balance on earth is widely recognized in the scientific community. The impact of greenhouse gases on global climate was repeatedly confirmed by an independent group of scientists, the Intergovernmental Panel on Climate Change (IPCC 1990, 1992). However, climatic parameters such as temperature are characterized by pronounced spatial variability and genuine dynamics in different time scales. The relatively short time span of available observations impedes an ultimate proof of an ongoing global warming, but indications to corroborate an anthropogenic impact on the global environment are compelling enough to urge against complacency (Wassmann et al, 1997).

The CO2 level in the atmosphere has increased by approximately 32% from the pre-industrial concentration of 270 ppm to a current concentration in the range of 335-360 ppm (IPCC 1990). As the world population increases and the demand for energy rises, increased burning of fossil fuels will continue to drive levels of atmospheric CO2 upward. The IPCC "business as usual" scenario predicts that atmospheric CO2 concentrations will rise to 530 ppm in 2050 and could potentially exceed 700 ppm by 2100 (IPCC 1990). This increase will significantly affect the physiological basis of plant production. The increasing UV-B exposure due to ozone depletion in the stratosphere poses a further threat of unknown dimension on the productivity of agricultural systems. The increase in CO2 concentration is the key process in the greenhouse effect, accounting for approximately 50% of the projected increase in mean surface temperature (IPCC 1990) . The imbalance of global sources and sinks in the atmospheric CO2 budget is primarily caused by combustion of fossil fuels . Net releases of CO2 by the agricultural sector are mainly related to land use changes, e.g., deforestation. Continuous cropping systems such as rice cultivation encompass high fluxes of CO_2, but input and output are balanced in sustainable production (Bronson et al. 1996a). However, changes in soil organic carbon (C) (caused by intensified use of fertilizers), have a large potential to sequester C from the atmosphere (Cassmann et al 1995), but the significance of this CO_2 sink is still unknown at present.

Climate Change and Rice Production System

Rice fields are main contributors for greenhouse gas, methane (CH_4), while nitrous oxide (N2O), another greenhouse gas, is emitted from virtually all cropping systems with high nitrogen (N) inputs (Rennenberg et al 1992). In spite of an increasing number of emission records, the estimates of the global emission of greenhouse gases are still tentative (Wassmann et al. 1996). One of the difficulties in quantifying the possible emissions from agriculture is that the cropping systems, particularly the land use for agricultural production, are dynamic. Below we will show the trends of rice production and land use in the world and in some pacific rim countries.

Trends of Global and Pacific Rim Countries' Rice Production

The world paddy rice production has been steadily increased over the last 36 years with an increasing rate about 10 million tons per year. The total paddy rice produced reached 563 million tons in 1998. The land used for rice production has also been increased over the same period of time, from 116 million hectares in 1961 to over 150 million hectares in 1998, almost 1 million hectares increase per year (Fig. 1). Since the world population is projected to double in the next 50 years, particularly in the Asia and Africa countries, these trends are highly likely to continue into the 21st century. A major contributor of world rice production is China. In 1998, China produced 193 million tons or 35% of the world paddy rice, which represents an impressive 345% increase in the last 36 years (Fig. 2). Though US only produced about 4% of the amount rice produced by China, US has increased its rice production also by 3.4 fold in 36 years (Fig. 3). The difference between China and the US is that for the last 36 years, while US has doubled its rice production area to 13 million hectares in 1998, China has decreased its rice land by 4 million hectares from 1976. Japan, a major rice producer and consumer, illustrates a different trend. Japan has reduced paddy rice production by 150,000 tons and rice area by 40,000 hectares a year since 1961 (Fig. 4). South Korea has maintained a relatively stable production system for the last 36 years and had a similar production level as that of the US in 1998 (Fig. 5). These trends are important because they illustrate a potential shift of rice producing and consuming centers in the pacific rim region. It is likely, China will not meet all its rice demands in 21st century because of its land scarcity. On the other hand, US, Thailand and Australia may increase their production for exports.

The projected increase in CO_2 concentration will significantly affect the physiological basis of plant production. However, the beneficial effect of enhanced CO_2 levels on plant growth may be outweighed by concomitant changes in other environmental factors (Rosenzweig and Perry 1994, Barry and Geng, 1995ab). Global increases in CO_2 along with other bio- and anthropogenic trace gases such as CH_4 and N_2O will trap outgoing thermal radiation leading to enhanced temperatures at the earth's surface. Therefore, special emphasis has to be given to synergistic effects of CO_2 and temperature on crop growth, weed competition, and water demand (Wassmann et al, 1997). These impacts on rice are discussed below.

Climate Change Impacts on Rice Growth and Production

Between 1991-1995, IRRI, under a contract of US EPA, examined the impact of climate change on rice cultivation as well as the specific contribution of rice fields to the global budget of greenhouse gases (Neue et al 1995). These studies include different approaches at various levels including the physiological base of rice plants and the microbial community, the element cycling in rice ecosystems, and the regional and global trends in rice yields under a changing climate. These studies have generated the most comprehensive experimental data sets on the influence of global climate change on rice production, which are summarized in Wassmann et al (1996). In this section, whenever IRRI's results are mentioned, they are taken from Wassmann's report.

Estimates of the impact of climate change on rice yields differ depending on the model and the scenario used. Leemans and Solomon (1993) predicted a 11% increase using simple crop models. Rosenzweig and Parry (1993) used the more sophisticated IBSNAT model and found that rice yields would reduce by 2- 4%. These losses were mainly come from countries at low latitudes while the crop yields in mid- and high latitudes were predicted to increase. Matthews et al (1995) coupled the ORYZA and SIMRIW models to different climate change scenarios and obtained an overall impact on rice production in Asia ranging from +6.5% to -12.6%. The average of these estimates suggests that rice production in Asia may decline by 3.8% (Matthews et al 1995). However, the negative impact of high temperature may be avoidable by using improved varieties. The level of adaptation required (e.g., for spikelet fertility) is within the genotypic variation currently available in environments with hot climates (Matthews et al 1995). Rice cultivars exhibit a range of adaptation to changing global CO_2 and temperature. Of the 22 species of the genus Oryza, commonly called the wild relatives of rice, that were examined by IRRI several species were found to possess photosynthetic characteristics superior to modern cultivars of rice in adaptability to climate change. The mechanisms of how rice plants optimize their vegetative and reproductive growth under high CO_2 and temperature conditions need further studies.

Rice Field Emssions

There are generally 4 rice ecosystems. These are irrigated rice, rainfed rice, deep water and upland rice ecosystems. Irrigated rice comprises approximately 51% of the global rice land and is characterized by a full control of the water regime. The other rice systems, rainfed rice, deep water rice and upland rice ocupy respectively 27%, 10% and 11% of the global rice land.

Due to prevailing anaerobic conditions during flooding, CH_4 emission rates from irrigated rice gradually increase during the first half of the growing season and remain high during the ripening stage. Due to the absence of irrigation facilities, water regime in this system fluctuates and depends on seasonal precipitation and local topographic conditions. As a result, methane emission also fluctuates according to the rainfall patterns of this system. Long submergence and growing periods naturally favor CH_4 emission in the deepwater rice system. However, a large proportion of deepwater rice is found in coastal areas where CH_4 generation is inhibited by saline conditions. The other rice ecosystem, upland rice is not associated with flooding and is therefore negligible in terms of potential CH_4 emission.

Basically, methane is generated in the anaerobic layers of rice soils. The organic material converted to CH_4 is derived mainly from decomposed soil organic matters such as plant-borne material, and applied organic manure (Neue 1993). Methane production requires a redox potential of less than -200 mV which is commonly found in rice soils usually 2 wk after flooding (Neue 1993). However, the upper micro layer (< 1cm) and parts of the rhizosphere are generally aerobic, facilitating microbial CH_4 oxidation. In previous field studies, the CH_4 production rates exceeded the actual amount of CH_4 released from the field by a factor of 2-4 (Holzapfel-Pschorn et al 1985), indicating intensive consumption of CH_4 occurred in the field. Since methanotrophic bacteria can also oxidize ammonia, CH_4 oxidation is, therefore, closely linked to the N cycle (Conrad and Rothfuss 1991), which produces a complex and interacting relationships among mineral and nutrient cycling processes. The CH_4 produced in the flooded rice soil can be transferred to the atmosphere by different routs. In the early stage of the vegetation period, the efflux of CH_4 from rice fields is in the first half mainly attributed to the emergence of gas bubbles (Wassmann et al. 1996a). Diffusive transport of CH_4 through the water column was shown to be minor in rice fields, while the transfer of CH_4 through the rice plants gradually gains with plant growth and becomes dominant pathway within the mature plant stages (Wassmann et al 1996a).

The impacts of various factors on CH_4 emissions from irrigated rice fields are shown in Wassmann (1996) and is copied here in Table 1. These observations were obtained at the IRRI research station and at seven sites in five major rice-growing countries in Asia (Wassmann et al 1995).

1. Natural factors influencing methane emissions: The magnitude and pattern of CH_4 emission are affected by soil and climatic conditions. Methane production, a biological process, depends on the soil organic C content and soil quality, texture, Eh/pH buffer capacity, Fe content, sulfate content, and salinity (Neue and Roger 1994). Methane production is optimum in flooded rice fields under the conditions that a redox potential below -200 mV, a pH between 6 and 8, and a temperature above 10^oC. However, soil properties also affect CH_4 oxidation and transfer of CH_4 to the atmosphere, resulting in a complex web of interrelations among factors and processes. Methane fluxes are modulated by diurnal patterns of temperature and are thus, relatively uniform across sites in similar climates (Buendia et al 1996).
2. Agricultural practices: Water management and fertilizer application greatly influence the magnitude of greenhouse gas emissions in rice fields (Wassmann et al 1993a). Continuous flooding favors CH_4 emission while temporary dry conditions suppress its generation. Dry periods within the first half of the season impede CH_4 production and enhance CH_4 oxidation, resulting in low CH_4 emission rates even after the field is flooded again. The incorporation of organic material enhances CH_4 emission rates. The impact of organic fertilizers is limited to the first half of the vegetation period, while the emission rates during the second half are relatively uniform at a given rice field

irrespective of fertilizer treatment. Addition of urea fertilizer generally enhances CH_4 emission while sulfate-containing fertilizers depress emissions.

3. Interaction of methane and nitrous oxide emissions: Nitrous oxide is generated in rice soils by two microbial processes, i.e. denitrification and nitrification (Rennenberg et al 1992). Denitrification is an anaerobic process while nitrification is aerobic. Denitrification is the last step in the N cycle, returning oxidized N to molecular form. Nitrification comprises several biochemical pathways of oxidizing ammonium to nitrate. The intensity of these two processes in wetland rice fields highly depends on the available N and moisture regime in the soil (Bronson and Singh 1995). In general, farmers avoid application of nitrate to wetland rice because of N losses involved in denitrification. Drying of the soil stimulates nitrification and also entails losses of N. In both cases, N escapes from the soil in the form of N_2O emissions. The pattern of N_2O fluxes shows a pronounced antagonism to CH_4 fluxes (Bronson et al 1996b). Long periods of flooding facilitate high CH_4 emissions, while the microbial N conversion and thus, N_2O emission, is low. The N turnover and N_2O emissions are accelerated by dry periods, which, on the other hand reduce CH_4 emissions.

Strategies and Approaches to Mitigate Rice Field Emissions

The IRRI and other national studies in rice producing countries have generate invaluable information on global climate change impact on rice production as well as the potential mitigation methods of reducing rice field emissions on CH_4. So far only very crude estimates are available on CH_4 emissions from rice fields, which accounts about anywhere 4-20% of the global CH_4 emission (GEIA 1993). This wide range estimation reflects the nature of the problem, i.e., the inability to quantify the extreme complex interactions between natural and anthropogenic factors that would result in CH_4 emission and the non-uniformity in field study and sampling techniques (Neue and Boonjawat 1996).

Similar problems occur in the assessment of the N_2O emissions from rice fields. Nitrous oxide is mainly released in spikes lasting only for a few days, which makes detection of these emissions very difficult. Methane and N_2O emissions are usually negatively correlated in rice fields. For instance, replacing organic manure with mineral fertilizer reduces the amount of CH_4 emitted but could increase emission of CO_2 in the field and that involved in fertilizer production. Therefore, the mitigation options should focus on management rather than on replacement of organic amendments in rice cultivation. Wassmann et al (1993b) suggested that fermentation of organic manure in biogas generators before incorporation into the soil would reduce CH_4 emissions by approximately 30 %.

The potential of improving rice cultivars to reduce CH_4 emission is currently studied in IRRI. However, the reduction of CH_4 and N_2O represent losses of energy and nutrients that are available to plant growth and therefore result in yield reduction . The development of sound strategies to reduce greenhouse gas emissions from rice fields must simultaneously consider natural factors as well as field and resource management alternatives.

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Table 1: Major factors influencing methane emission rates in irrigated rice system (* = weak, ** = moderate, *** = high) and the possible mechanisms. (Taken from R. Wassmann, T. Moya, and R. S. Lantin, 1996)

Factor	Significance	Possible Mechanism
Soil	**	Indigenous methanogenic material Chemical inhibition of methane production Texture with high porosity
Climate	*	High and evenly distributed precipitation Low temperature Hazardous events
Water management	**	Long duration of flooding Continuous flooding in early season Continuous flooding in late season Strong leaching
Organic Amendments	***	Removal of plant residues High doses of manure Replacement of fresh manure by biogas residues High organic inputs from floodwater
Nutrient and Crop nagement	*	Use of sulfate fertilizers High N inputs Dense spacing of rice plants Frequent soil disturbance
Rice Cultivar	**	Strong root exudation High oxidation power High diffusion resistance for methane transport Short vegetation period

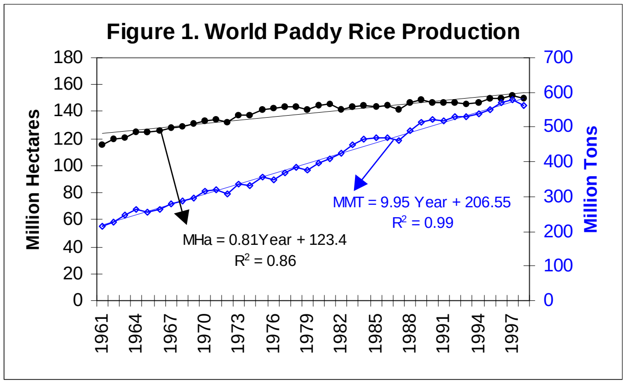
Figure 1. World Paddy Rice Production
Million Hectares
Million Tons
MMT = 9.95 Year + 206.55
R2 = 0.99
MHa = 0.81Year + 123.4
R2 = 0.86
0
20
40
60
80
100
120
140
160
180
0
100
200
300
400
500
600
700
1961
1964
1967
1970
1973
1976
1979
1982
1985
1988
1991
1994
1997

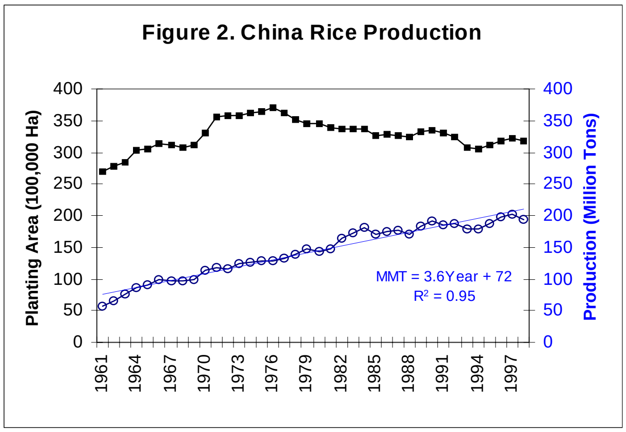
Figure 2. China Rice Production
Planting Area (100,000 Ha)
Production (Million Tons)
MMT = 3.6Year + 72
R2 = 0.95
0
50
100
150
200
250
300
350
400
1961
1964
1967
1970
1973
1976
1979
1982
1985
1988
1991
1994
1997

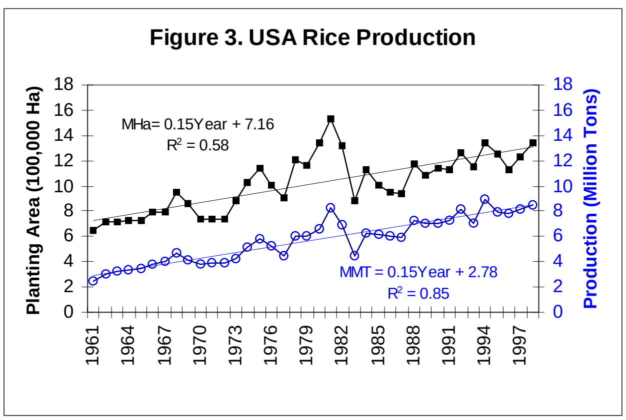
Figure 3. USA Rice Production
Planting Area (100,000 Ha)
Production (Million Tons)
MHa= 0.15Year + 7.16
R2 = 0.58
MMT = 0.15Year + 2.78
R2 = 0.85
0
2
4
6
8
10
12
14
16
18
1961
1964
1967
1970
1973
1976
1979
1982
1985
1988
1991
1994
1997

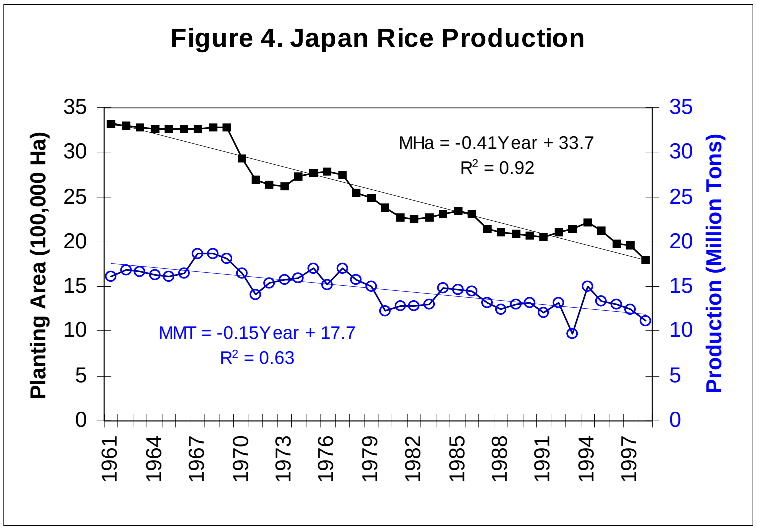
Figure 4. Japan Rice Production
MHa = -0.41Year + 33.7
R^2 = 0.92
MMT = -0.15Year + 17.7
R^2 = 0.63
Planting Area (100,000 Ha)
Production (Million Tons)
35
30
25
20
15
10
5
0
1961
1964
1967
1970
1973
1976
1979
1982
1985
1988
1991
1994
1997

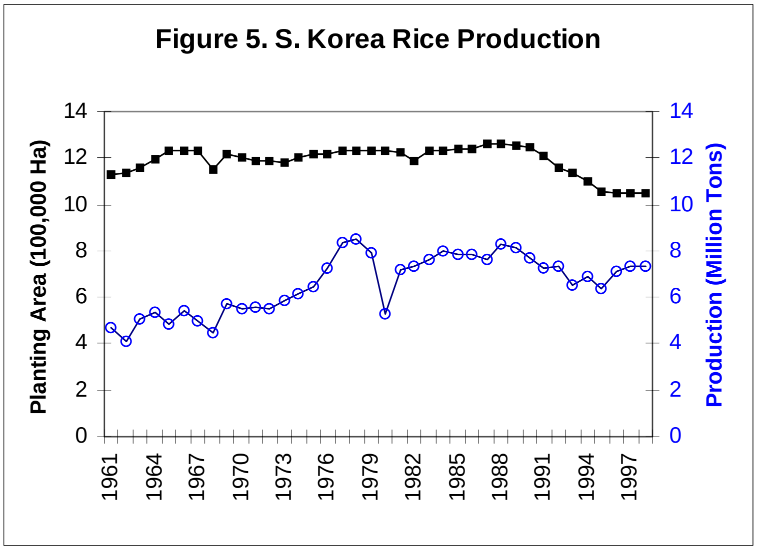
Figure 5. S. Korea Rice Production
Planting Area (100,000 Ha)
Production (Million Tons)
14
12
10
8
6
4
2
0
1961
1964
1967
1970
1973
1976
1979
1982
1985
1988
1991
1994
1997