Responses of the Irrigated Rice Ecosystem to Enhanced UV-B Radiation and Global Climate Change

Statement of the Problem

When this study was conceived there was a critical need for information on the ecological effects of UV-B radiation (from stratospheric O_3 depletion) and global climate change (increased atmospheric CO_2 concentration and air temperature) in tropical areas to support major international assessments on the environmental effects of ozone depletion (by the United Nations Environmental Programme), and climate change (by Intergovernmental Panel on Climate Change). Rice is a major food source for many of the world's people, especially in Asia, but also in Africa and South America (IRRI 1993). The irrigated rice agroecosytem, where fields are flooded for much of the growing season, is the most widely distributed rice system, with 55% of world's rice field area and 75% of the world's rice production (IRRI 1993). Thus any impacts on rice production from UV-B and climate change could have profound impacts on a key component of the world's food supply. In addition to enhancing rice production, flooding of irrigated rice fields results in anaerobic soil conditions conducive to the production of the greenhouse gas methane (Neue 1993). Therefore, understanding the underlying processes and management factors controlling the emission of methane from rice fields was important in terms of developing strategies for the potential mitigation of emissions of greenhouse gases to the atmosphere (Cole 1996).

Approach

To have the most impact and relevance to real field conditions, research on irrigated rice was conducted in tropical countries, in cooperation with local scientists. Thus, the rice research was conducted through a unique international partnership between the U.S. EPA and the International Rice Research Institute (IRRI) in Los Banos, the Philippines; with collaboration by other institutions and researchers in the United States, the Netherlands, Germany, Japan, China, Korea, India, Malaysia, and Sri Lanka (Olszyk and Ingram 1991). The research approach included field experiments, modeling activities and assessments which presented possible impacts of UV-B and climate change on a regional scale for eastern and southeastern Asia. The research was designed to consider responses of irrigated rice production from an ecosystem viewpoint, considering not only the direct effects of UV-B, CO_2 and temperature on the rice plant, but also indirect effects of these stressors on the insects, diseases of rice, and weed competition. The roles of CO_2 and temperature in methane production were also studied. The EPA/IRRI study was coordinated with other international global change research through the International Geosphere-Biosphere Programme (IGBP) of research on Global Change and Terrestrial Ecosystems (GCTE), Focus 3, Global Change Impact on Agriculture, Forestry and Soils.

Main Conclusions

This research provided critical data for international assessments on the impacts of UV-B radiation and climate change on rice and on options to mitigate those impacts not only on the rice crop, but on emissions of the greenhouse gas CH_4 from rice fields (Peng *et al.* 1995). The data were included in the extensive literature produced by the project including 3 books, 20 book chapters and over 75 peer-reviewed journal papers.

Key results indicated that rice yields likely will not be affected by increases in UV-B predicted from stratospheric ozone depletion under realistic tropical-field conditions based on extensive and intensive field experiments (Dai *et al.* 1997). Under greenhouse conditions, enhanced UV-B injury was associated with active oxygen metabolism in rice leaves (Dai *et al.* 1997), and could affect the susceptibility of rice to the important disease, rice blast (Finckh *et al.* 1995).

In contrast to enhanced UV-B, elevated CO_2 and temperature likely will have dramatic effects on irrigated rice production, not only by directly affecting the plant, but also through indirect effects on other aspects of the rice ecosystem (insects, diseases, and weed competition). Elevated CO_2 enhanced rice plant growth and grain yield provided that N fertilization was not limiting growth (Olszyk *et al.* 1999; Weerakoon *et al.* 1999; Ziska *et al.* 1998; Moya *et al.* 1998). In contrast, while elevated temperature enhanced plant growth, it decreased crop yield due to spikelet sterility. Combining elevated CO_2 and elevated temperature resulted also resulted in enhanced plant growth, but with spikelet sterility. Climate change also was predicted to affect rice productivity by altering disease occurrence (Luo *et al.* 1995) and insect infestations (Heong *et al.*1995).

Computer simulations and spatial analysis were used successfully to assess the potential impacts of climate change on rice productivity across south and Southeast Asia (sidebar). In the EPA/IRRI analysis, potential rice yield either decreased or increased depending on the global climate model, crop model, and site within a country. Overall, the analysis found an average 3.8% decrease in rice production across south and Southeast Asia with future increases in CO_2 and temperature compared to current conditions. Though relatively small, this predicted change would occur at a time when rice yields must increase substantially to keep in step with increases in human population in the area.

Unique field experiments indicated that the effects of elevated CO_2 and temperature on rice plants could increase methane emissions from rice fields, providing an important feedback to climate change from rice cultivation (Olszyk *et al.* 1999; Ziska *et al.* 1998). Elevated CO_2 or in combination with elevated temperature produced a large increase in methane emissions from rice fields compared to current conditions; primarily due to a large increase in belowground biomass (see sidebar). In contrast, elevated temperature alone tended to decrease methane emissions from rice fields. The magnitude of these changes in methane emissions from rice fields were not predicted by current plant growth simulation models (Olszyk *et al.* 1999).

In addition to demonstrating impacts of climate change on the irrigated rice systems, research indicated avenues to mitigate those impacts for this intensively managed agricultural system. The wide-range in variability among rice cultivars and plant types in terms of adverse effects from enhanced UV-B and elevated temperature, as well as beneficial effects from elevated CO_2, indicates the potential for plant breeding to maintain or enhance rice yields in the future (Moya *et al.* 1998; Dai *et al.* 1994). Similarly, methane emissions from rice fields varied considerably with rice cultivar, fertilizer amount and form, irrigation timing, and other factors, indicating the potential to reduce methane emissions from rice fields through altered management practices (Neue *et al.* 1995).

Elevated UV-B Radiation from Stratospheric O3 Depletion not expected to affect Rice Yields

With depletion of the stratospheric O_3 layer, ground-level UV-B levels are expected to increase. The effect of potential increases in UV-B under realistic field conditions was determined in rice fields at the International Rice Research Institute at Los Baños, the Philippines. Over five growing seasons, both wet (cloudy, rainy) and dry (more sunlight, dry) two widely grown (yet potentially UV-B susceptible) rice cultivars IR 72 and IR 74 exposed to current and enhanced UV-B radiation. There was no significant UV-B effect on rice yield for either cultivar in any season. Across all seasons and both cultivars the average yield was the same at 608 g m^{-2} for both control and enhanced UV-B rice plants. Source: Dai *et al.* 1997.

Increased Atmospheric CO2 and Air Temperature Affects Rice Yields and Methane Emissions from Rice Fields

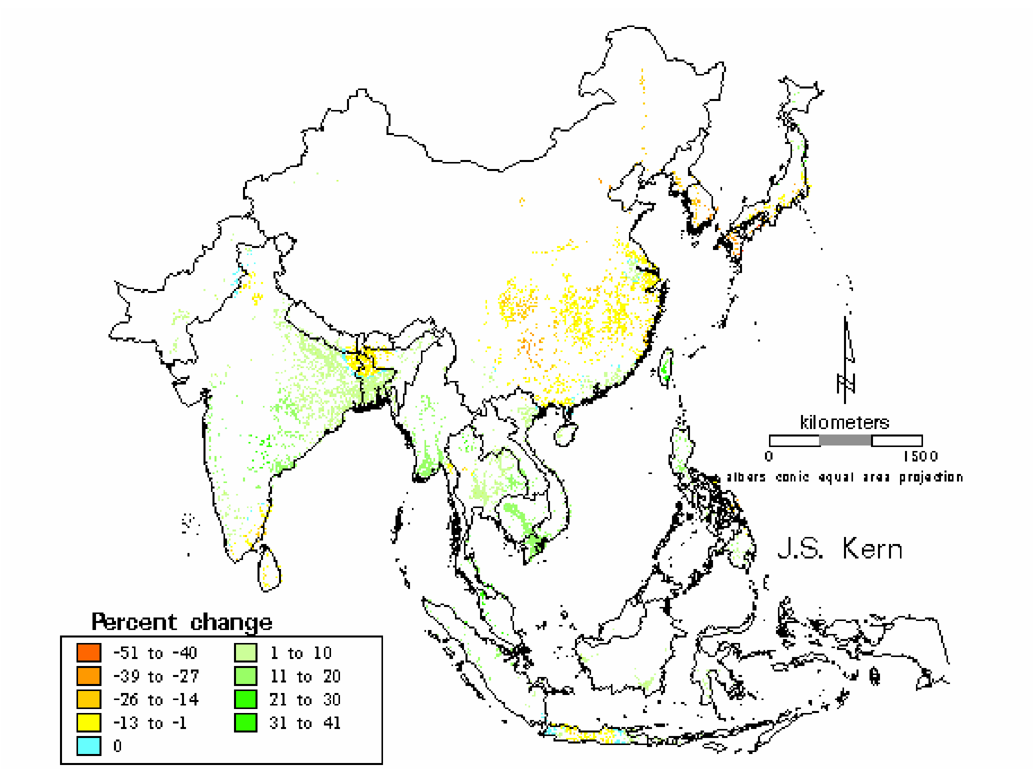
The effects of increased atmospheric CO_2 and consequent predicted increases in air temperature were studied for rice -- the world's most important crop for direct human consumption. Both rice yield and methane emissions, a greenhouse gas produced in rice soils, were measured for rice plants grown in open-top chambers under realistic tropical field conditions at the International Rice Research Institute in the Philippines. Yield and methane emissions were determined for the widely grown rice cultivar, IR 72, grown for two wet and two dry seasons under current ambient CO_2 and temperature conditions (ACAT) and under three future climate scenarios of elevated CO_2 and ambient temperature (ECAT), ambient CO_2 and, elevated CO_2 and elevated temperature (ECET). By itself, elevated CO_2 increased rice yields, as shown for many other crops grown under conditions of optimum N fertilization and water. However, elevated temperature tended to decrease rice yields and thus the increase in rice yield with elevated CO_2 alone was negated when temperature also elevated. Emissions of methane were increased when rice plants were exposed to elevated CO_2 either with or without elevated temperature, which was associated with an increase in root biomass; while elevated temperature alone tended to decrease methane emissions. Source: Olszyk, *et al.* 1999; Moya *et al.* 1998; Ziska *et al.* 1998.

Scenario[a]	Parameter	1994 Wet	1995 Dry	1995 Wet[b]	1996 Dry
ACAT	Grain Yield (g m^{-2})	366	683	----	874
ECAT	Change Grain Yield (%)	**+29**	**+24**	**----**	**+15**
ACET	Change Grain Yield (%)	-26	-16	----	-13
ECET	Change Grain Yield (%)	-14	+9	----	-6
ACAT	Methane (mg m^{-2} d^{-1})	----	----	142	260
ECAT	Change in Methane (%)	----	----	**+60**	**+48**
ACET	Change in Methane (%)	----	----	----	-54
ECET	Change in Methane (%)	----	----	----	**+45**

[a] Experimental values in bold are significantly different from ambient CO_2 and ambient temperature at $p<0.05$.
[b] Rice yield severely decreased due to typhoon prior to crop maturity.

Changes in Rice Grain Yield across East and South Asia with Elevated CO_2 and Elevated Temperature

Potential effects of climate change (elevated CO_2 and elevated temperature) on irrigated rice production across south and East Asia were estimated based on computer simulations and spatial analysis. Climate change scenarios from the General Fluid Dynamcis Laboratory (GFDL), Goddard Institute of Space Studies (GISS), and United Kingdom Meteorological Office (UKMO) General Circulation Models (GCMs,) were used, assuming a doubling of current atmospheric CO_2. The outputs from those models were used with site-specific weather data and two plant process-based rice crop simulation models, ORYZA1 and SIMRIW to predict potential rice yield under current and future climate conditions at sits across Asia. The changes in rice yield with climate change were assessed using a Geographic Information System (GIS). An example of the pattern of these changes in yield from current climate conditions based on the UKMO GCM and ORYZA1 model is shown below. In this simulation, global climate change produced increases in potential yield (green colors) for much of India and southeast Asia, and decreases in yield (yellow to orange colors) in most of China, Japan and Korea; with an average 5.6% reduction in yield across all of Asia (Source: Matthews, Horie *et al.* 1995).



Percent change in rice yield using UKMO climate compared to current climate.

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Ziska, L.H., T. Moya, O.S. Namuco, R. Levine, R. Wassman, and D. Olszyk. 1998. Elevated carbon dioxide stimulates methane emission in tropical paddy rice. Global Change Biology 4:657-665.

Annotated Bibliography of WED Research

Bachelet, Dominique. 1993. Climate change impacts on net primary production in China. International Symposium of Climate Change, Natural Disasters, and Agricultural Strategies.

Several studies have estimated the potential effects of greenhouse gas-induced climate change on various systems using outputs of general circulation models (GCMs). The purpose of this study was to generate comparable estimates of potential impacts on net primary production using the GCM climate scenarios in a very simple net primary production model. We also wanted to identify the most likely limiting factor that would follow a change in global climate.

Bachelet, D., P.W. Barnes, D. Brown and M. Brown. 1991. Latitudinal and seasonal variation in calculated ultraviolet-B irradiance for rice-growing regions of Asia. Photochemistry and Photobiology 54:411-422.

Ultraviolet-B (UV-B, 280-320 nm) irradiance was calculated for more than 1200 sites in Asia to characterize the spatial and temporal variation in the present UV-B climate for rice-growing regions. The analytical model of Green *et al.* (Photochem. Photobiol. 31:59-65, 1980) was used to compute UV-B irradiance for clear skies using satellite-observed ozone column thickness and local elevation data. Ground-based observations of cloud cover were then used to approximate the average effect of cloud cover on UV-B irradiance using the approach of Johnson *et al.* (Photochem. Photobiol. 23:179-188, 1976). Over the geographic range of rice cultivation, the maximum daily effective UVB irradiance (UV-B_{BE}), when weighted according to a general plant action spectrum, was found to vary approx. 2.5-fold under both clear and cloudy sky conditions. Under clear skies, the timing of maximum solar UV-B_{BE} changed with latitude and varied from February-March near the equator to July-August at temperate locations. Cloud cover was found to alter the season of maximum UV-B_{BE} in many tropical regions, due to the pronounced monsoonal climate, but had little effect on UV-B seasonality at higher latitudes. Under a climate resulting from a doubling of atmospheric carbon dioxide, estimated UV-B using predicted cloud cover was found to change by up to 17% from present conditions in Thailand. Both latitudinal and seasonal variation in solar UV-B radiation may be important aspects of the UV-B climate for rice as cultivars differ in sensitivity to UV-B and are grown under diverse conditions and locations.

Bachelet, Dominique, Douglas Brown, Margi Böhm and Periann Russell. 1992. Climate change in Thailand and its potential impact on rice yield. Climatic Change 21:347-366.

In Thailand, the world's largest rice exporter, rice constitutes a major export on which the economy of the whole country depends. Climate change could affect rice growth and development and thus jeopardize Thailand's wealth. Current climatic conditions in Thailand are compared to predictions from four general circulation models (GCMs). Temperature predictions correlate well with the observed values. Predictions of monthly rainfall correlate poorly. Virtually all models agree that significant increases in temperature (from 1 to 7 °C) will occur in the region including Thailand following a doubling in atmospheric carbon dioxide (CO_2) concentration. The regional seasonality and extent of the rise in temperature varies with each model. Predictions of changes in rainfall vary widely between models. Global warming should in principle allow a northward expansion of rice-growing areas and a lengthening of the growing season now constrained by low temperatures. The expected increase in water-use efficiency due to enhanced CO_2 might decrease the water deficit vulnerability of dryland rice areas and could make it possible to slightly expand them.

Bachelet, Dominique and Cheryl A. Gay. 1993. The impacts of climate change on rice yield: a comparison of four model performances. Ecological Modelling 65:71-93.

Increasing concentrations of carbon dioxide (CO_2) and other greenhouse gases are expected to modify the climate of the earth in the next 50-100 years. Mechanisms of plant response to these changes need to be incorporated in models that predict crop yield estimates to obtain an understanding of the potential consequences of such changes. This is particularly important in Asia where demographic forecasts indicate that rice supplies worldwide will need to increase by 1.6% annually to the year 2000 to match population growth estimates. The objectives of this paper are (1) to review the major hypotheses and/or experimental results regarding rice sensitivity to climate change and (2) to evaluate the suitability of existing rice models for assessing the impact of global climate change on rice production. A review of four physiologically-based rice models (RICEMOD, CERESRice, MACROS, RICESYS) illustrates their potential to predict rice responses to elevated CO_2 and increased temperature. RICEMOD does not respond to increases in CO_2 nor to large increases in temperature. Both MACROS and CERES (wetland rice) responses to temperature and CO_2 agree with recent experimental data. RICESYS is an ecosystem model which predicts herbivory and inter-species competition between rice and weeds but does not respond to CO_2. Its response to increasing temperature also agrees with experimental data.

Bachelet, Dominique, Andrew Herstrom and Doug Brown. 1993. Rice production and climate change: design and development of a GIS database to complement simulation models. Landscape Ecology 8:77-91.

A cooperative project between the International Rice Research Institute in Los Baños, Philippines, and the U.S. EPA Environmental Research Laboratory in Corvallis, Oregon, was initiated to estimate how rice yield in Asia might be affected by future climate change and enhanced UV-B irradiance following stratospheric ozone depletion. A radiative transfer model was used to estimate daily UV-B irradiance levels using remotely sensed ozone and cloud cover data for 1274 meteorological stations. A rice yield model using daily climatic data and cultivar-specific coefficients was used to predict changes in yield under given climate change scenarios. This paper gives an overview of the data required to run these two models and describes how a geographical information system (GIS) was used as a data pre- or postprocessor. Problems in finding reliable datasets such as cloud cover data needed for the UV-B radiation model and radiation data needed for the rice yield model are discussed. Issues of spatial and temporal scales are also addressed. Using simulation models at large spatial scales helped identify weaknesses of GIS data overlay and interpolation capabilities. Even though we focused our efforts on paddy rice, the database is not intended to be system specific and could also be used to analyze the response of other natural systems to climatic change.

Bachelet, Dominique, Jeffrey Kern and Michael Tölg. 1995. Balancing the rice carbon budget in China using spatially-distributed data. Ecological Modelling 79:167-177.

Rice paddies are a source of food for over half of the world population and also the source of a very potent greenhouse gas, methane. We used the FAO soil map of the world to produce a high-resolution rice location map. Using published GIS-linked climate-based and yield-based empirical models, we calculated the net primary production (NPP) of rice fields in China. Values varied between $136 \cdot 10^{12}$ g C using climate drivers from digital maps to $222 \cdot 10^{12}$ g C using published grain production figures for 1988. We assumed that either 5% of NPP or 30% of the organic matter added to the soil during rice cultivation was transformed into methane, adding up to a total emission of 7 to $16 \cdot 10^{12}$ g C. We also gathered published data on fertilizer inputs and management practices and, using linear regression techniques, calculated the correlation between methane emission and carbon inputs to obtain a total emission value of $10 \cdot 10^{12}$ g C. Using the results for NPP ($135\text{-}222 \cdot 10^{12}$ g C). methane emission ($7\text{-}16 \cdot 10^{12}$ g C) and published grain production figures, we balanced the carbon budget of rice paddies estimating soil respiration at $51 \cdot 10^{12}$ g C for all Chinese rice fields or 159 g C m^{-2} y^{-1} for an average Chinese rice field, a number which agrees with published values for similar systems. This result confirmed our assumption that rice soils in

China, where rice cultivation has occurred for several thousand years, were neither losing nor accruing carbon. However, any changes in the hydrology of these soils may transform them into significant carbon sources. Using the Food and Agricultural Organization (FAO) digital map of the soils of the world, we estimated soil carbon content for the rice-growing regions of China and quantified the potential carbon losses that would occur if these soils were drained.

Bachelet, D. and J.L. Mailander. 1992. Rice field inventory using AVHRR data. 13th Asian Conference on Remote Sensing, October 7-11, 1992, Ulaanbaatar, Mongolia.

Time series Normalized Difference Vegetation Index (NDVI) data, computed from Advanced Very High Resolution Radiometer (AVHRR) data, were used in a pilot study to locate areas of rice cultivation in the Unftod States of America (USA). The large size of rice fields and the relative phenological homogeneity of the rice growing regions in the US make them ideal sites for a pilot study. NDVI dynamics were examined using 16 km global area coverage satellite data from 1988. Unsupervised classification was used to distinguish rice fields from other vegetation cover types. The technique was used for California where the contrast between irrigated and natural vegetation is the most pronounced and later applied to Louisiana, Arkansas and Texas. Identical methods were used to classify the vegetation in China where the field size is much smaller and the cropping season more extended. The rice NDVI dynamics was most obvious where only one crop is grown and the growing season is limited by low winter temperatures. Areas where several crops are grown each year were more difficult to identffy. To effectively assess rice locations, the seasonal fluctuations of the crop, which are only partially dependent on seasonal precipitation because of irrigation, must be isolated from characteristics associated with natural vegetation and other irrigated crops.

Bachelet, D. and H.U. Neue. 1991. Methane sources and sinks. Working Group Report, NATO Workshop on The Atmospheric Methane Cycle, Mt. Hood, Oregon, October 6-11, 1991.

Methane (CH_4) concentrations in the atmosphere have increased from about 0.75 to 1.7 ppmv since preindustrial times (Steele et al. 1987, Khalil and Rasmussen 1990). Lelleveld and Crutzen (1992) attribute the current annual rate of increase of about 0.8% year^{-1} to increases In industrial and agricultural emissions since some key natural sources (e.g. wetlands and marshes) have been reduced due to development pressure decreasing their area in various parts of the world. We have tried, in this chapter, to concisely summarize the discussions that took place at Timberline, October 8-10, 1991, to quantity the size of the global “Methane Sources and Sinks” that may contribute to the atmospheric increase. Several “specialty” groups emerged during the workshop and it is their conclusions that are presented here. Each paragraph is also the focus of an individual chapter and of usually several manuscripts that were submitted to Chemosphere. We have tried to cite these documents in the relevant sections and we refer the reader to these sources for detailed explanations of each source and sink.

Bachelet, Dominique, John Van Sickle and Cheryl A. Gay. 1992. The impacts of climate change on rice yield: evaluation of the efficacy of different modeling approaches. *In* International Symposium on Systems Approaches for Agricultural Development.

Increasing concentrations of carbon dioxide (CO_2) and other greenhouse gases are expected to modify the climate of the earth in the next 50-100 years. Mechanisms of plant response to these changes need to be incorporated in models that predict crop yield to obtain an understanding of the potential consequences of such changes. The objectives of this paper are (1) to review climate change predictions and their reliability, (2) to review the major hypotheses and/or experimental results regarding rice sensitivity to climate change and (3) to evaluate the suitability of existing rice models for assessing the impact of global climate change on rice production in the rice-growing areas of Asia. A review of physiologically-based rice models (CERES-Rice, MACROS, RICESYS) illustrates their potential to predict possible rice responses to elevated CO_2 and increased temperature. Both MACROS and CERES (wetland rice) responses to temperature and CO_2 agrees with recent experimental data from Baker et al.. (1990c). RICESYS is an ecosystem model which predicts herbivory and inter-species competition between rice and weeds but does not include CO_2 effects. Its response to increasing temperature also agrees with experimental findings. Models using empirical relationships between climate and yield have been used to predict country-scale changes following climate change. Their simplicity is an asset for continental-scale assessments but the climatic effects are often overshadowed by stronger technological or political effects. In conclusion, each modeling approach has its value. Researchers should choose or build the most appropriate model for their projects' objectives.

Barnes, Paul W., Herman Gucinski and David Turner. 1989. Ecosystem responses to increases in solar Ultraviolet-B radiation. For presentation at the 82nd Annual Meeting and Exhibition, Anaheim, California, June 25-30, 1989.

Initial concern over a possible link between release between anthropogenic release of chlorofluorocarbons (CFCs) and stratospheric ozone depletion came in the early 1970's. There is now convincing evidence that CFCs and other substances are indeed contributing to ozone depletion. Ozone depletion has been found over the region of the South Pole as well as over mid-latitudes in the northern hemispheres. The recent detection of chlorine in the atmosphere above the arctic has increased concern over possible ozone depletion for this region as well. Stratospheric ozone depletion to therefore an issue of global importance.

Barnes, Paul W., Sharon Maggard, Steven R. Holman and Benito S. Vergara. 1993. Intraspecific variation in sensitivity to UV-B radiation in rice. Crop Science 33:1041-1046.

Twenty-two cultivars of rice (*Oryza saliva* L.) from diverse origins were grown under greenhouse conditions and exposed to ultraviolet-B radiation (UV-B; 280-320 nm) simulating a 5% reduction in stratospheric ozone in spring for the Philippines (14° N lat.) to evaluate growth and morphological responses to UV-B. In comparison to controls that received no UV-B, plants exposed to UV-B exhibited significantly reduced dry matter production (total plant and shoot), shoot height, leaf blade length and total leaf area, increased number of tillers, and greater weight fractions in leaf blades and roots. For most cultivars, the relative effects of UV-B on shoot morphology were greater than the effects on biomass production. The direction of the UV-B effects were generally similar for all cultivars, however, there were significant differences among cultivars in the magnitude of the UV-induced changes. Upland cultivars (IRAT104 and OS4) and two lowland cultivars commonly planted in the USA (Star Bonnet and Lemont) were found to be least affected by the UV-B, whereas modern, high yielding, lowland cultivars developed in the Philippines (IR52, IR35546-17-33, and IR58) were found to be among the most sensitive to UV-B. Our results indicate that in rice, as in other grasses, shoot morphology may be more responsive to solar UV-B change than plant productivity. Intraspecific variation in morphological responses to UV-B could contribute to difference among cultivars in susceptibility to UV-B-induced changes in competitive balance between rice and associated weeds of the rice agroecosystem.

Dai, Qiujie, Shaobing Peng, Arlene Q. Chavez, Ma. Lourdes L. Miranda, Benito S. Vergara and David M. Olszyk. 1997. Supplemental Ultraviolet-B Radiation Does Not Reduce Growth or Grain Yield in Rice. Reprinted from Agronomy Journal 89:793-799.

Negative effects of enhanced UV-B radiation have been demonstrated in plants, but impacts under realistic field conditions remain uncertain. Adverse impacts to major crops, such as rice (*Orvza saliva* L.), that are grown in areas with currently high ambient levels of UV-B, could have consequences for food security. To address the response of rice to UV-B, we conducted an intensive and extensive series of field experiments from 1992 to 1995 documenting the effects of supplemental UV-B (simulating approximately 20% ozone depletion for the Philippines), using irrigated rice cultivars under tropical conditions. This multiseason study indicated that supplemental UV-B had no significant effects on rice grain yield (including the yield components spikelet filling percentage, and 1000-grain weight) or growth parameters (plant height or panicles per square meter). The absence of UV-B effects was consistent across seasonal environment (four dry and three wet seasons), cultivar, and type of exposure system. Thus, rice yields are not likely to be affected by increases in UV-B under realistic field conditions.

Dai, Qiujie, Bin Yan, Shaobai Huang, Xiaozhong Liu, Shaobing Peng, M. Lourdes L. Miranda, Arlene Q. Chavez, Benito S. Vergara and David M. Olszyk. 1997. Response of oxidative stress defense systems in rice (*Oryza sativa*) leaves with supplemental UV-B radiation. Physiologia Plantarum 101:301-308.

The impact of elevated ultraviolet-B radiation (UV-B, 280-320 nm) on membrane systems and lipid peroxidation, and possible involvement of active oxygen radicals was investigated in leaves of two UV-B susceptible rice cultivars (*Oryza sativa* L. cvs IR74 and Dular). Rice seedlings were grown in a greenhouse for 10 days and then treated with biologically effective UV-B (UV-B_{BE}) radiation for 28 days. Oxidative stress effects were evaluated by measuring superoxide anion ($O_2^{\cdot}$ -) generation rate, hydrogen peroxide (H_2O_2) content. malondialdehyde (MDA) concentration and relative electrolyte conductivity (EC) for IR74 and Dular at 0 (control). 6 or 13 kJ m^{-2} day^{-1} UV-B_{BE}. Significant increases in these parameters were found in rice plants grown at 13 vs 0 kJ m^{-2} dav^{-1} UV-B_{BE} after 28 days; indicating that disruption of membrane systems may be an eventual reason for UV-B-induced injury in rice plants. There was a positive correlation between $O_2^{\cdot}$ - generation and increases in EC or MDA in leaves. Activities of enzymatic and nonenzymatic free radical scavengers were measured for IR74 after 7, 14. 21 and 28 days of exposure to 13 or 0 UV-B_{BE} to evaluate dynamics of these responses over time. Activities of catalase and superoxide dismutase , (but not ascorbate peroxidase) and concentrations of ascorbic acid and glutathione were enhanced by 13 vs 0 UV-B_{BE} after 14 days of UV-B exposure. Further exposure to 28 days of OV-B was associated with a decline in enzyme activities and ascorbic acid, but not glutathione. It is suggested that UV-B-induced injury may be associated with disturbance of active oxygen metabolism through the destruction and alteration of both enzymatic and nonenzymatic defense systems in rice.

Dai, Qiujie, Victoria P. Coronel, Benito S. Vergara, Paul W. Barnes and Arlene T. Quintos. 1992. Ultraviolet-B radiation effects on growth and physiology of four rice cultivars. Crop Science 32:1269-1274.

Enhanced ultraviolet-B (UV-B, 280-320 nm) radiation, such as could be caused by stratospheric O_3 depletion, has been demonstrated to profoundly affect plants. This study was conducted to determine the effects of UV-B on four high-yielding, lowland rice (*Oryza saliva* L.) cultivars (IR30, IR45, IR64, and IR74), and to evaluate morphological and physiological parameters for identifying sensitive and less-sensitive genotypes in future screenings. Ultraviolet-B radiation was supplied by UV-B-emitting fluorescent lamps in the phytotron. Plant height, leaf area, dry weight, net assimilation rate (NAR), and relative growth rate (RGR) were significantly influenced by 4-wk UV-B treatment in some cultivars. Based on the relative change in total biomass production between UV-B-irradiated and control plants, cultivar IR74 was the most sensitive and cultivar IR64 the least sensitive. Biomass production, however, did not proportionally decrease with plant height under UV-B treatment. Changes in plant height and leaf area induced by UV-B can alter the rice plant canopy structure. Differential varietal response was found in shoot dry weight, leaf area, specific leaf weight (SLW, NAR, and RGR. These parameters can be used as selection criteria for rice cultivars less sensitive to UV-B. Most physiological and biochemical parameters evaluated, including root-oxidizing activity, soluble protein, nucleic acid, ion leakage, stomatal aperture, and flavonoid and chlorophyll contents, were affected by 2 wk of UV-B treatment and gave differential cultivar responses. The distinct responses and relative ease in measurement of stomatal opening and ion leakage make these parameters suitable indices in selecting rice cultivars less sensitive to UV-B after 2 wk of UV-B treatment.

Dai, Qiujie, Shaobing Peng, Arlene Q. Chavez and Benito S. Vergara. 1994. Intraspecific responses of 188 rice cultivars to enhanced UVB radiation. Environmental and Experimental Botany 34:433-442.

Phytotron studies were conducted to determine the intraspecific variation in sensitivity of rice (*Oryza sativa* L.) to enhanced UVB and to test the hypothesis that rice cultivars originating from regions with higher ambient UVB radiation are more tolerant to enhanced UVB. Out of the 188 rice cultivars (from various rice growing regions and ecosystems) tested, 143 had significantly reduced plant height, 52 had smaller leaf area, 61 had lower plant dry weight and 41 had less tiller number under elevated UVB radiation (13.0 kJ m^{-2} day^{-1}) for 3 weeks. Six cultivars showed significant positive growth response to enhanced UVB radiation, although the mechanism is not clear at present. These six cultivars were from the summer rice crop of Bangladesh and from high elevation rice areas where prevailing UVB radiation is most likely to be greater. However, there was no correlation between the dry matter changes under enhanced UVB and the ambient UVB level at the origin of the cultivar across the 188 cultivars tested. Therefore, cultivars originating from regions with higher ambient UVB are not necessarily more tolerant to enhanced UVB radiation.

Matthews, R.B., M.J. Kropff and D. Bachelet. 1994. Climate change and rice production in Asia.

Rice is the second most important crop in the world after wheat, with about 522 million tonnes being produced from about 148 million hectares in 1990. The largest production of rice is from Asia, which produces about 94 per cent of the total world production. In this region, rice is the main item of the diet and provides an average of 35 per cent of the total calorific intake compared to only 2 per cent in the U.S. Rapid population growth is already placing increasing pressure on the rice-growing resources in the region, not only from the increased demand from a higher number of people to feed, but also from the encroachment of residential areas into rice growing areas. The effects of climate change only add to an already complex problem, even more so as rice cultivation itself has a significant effect on global warming through the emission of the greenhouse gas, methane from decaying plant material in the water-logged paddy fields. There is clearly an urgent need to evaluate the interaction between climate change and rice production in this region to provide a basis for decisions by policy make, agriculturalists, and environmentalists alike.

Moya, T. B., O. S. Namuco, L. H. Ziska, and D. Olszyk. 1998. Growth dynamics and genotypic variation in tropical field-grown paddy rice (*Oryza sativa* L.) with increasing carbon dioxide and temperature. Global Change Biology 4:645-656.

Increasing atmospheric concentrations of trace pollutants, especially carbon dioxide (CO_2) are expected by many leading scientists to result in increases in air temperature and associated changes in the global climate. Increasing CO_2 and temperature directly affect vegetation with potentially important impacts on critical world food crops. The EPA, in collaboration with the International Rice Research Institute in Los Baños, the Philippines, conducted a long-term study on the effects of increased CO_2 and temperature on tropical field-grown paddy rice, the most important food crop for a large portion of the world's population. Over four growing seasons, two wet and two dry, increased CO_2 alone increased grain yield. In contrast, increased temperature alone decreased grain yield. The combination of increased CO_2 and temperature resulted in a yield slightly less than with current ambient conditions. Comparison of the CO_2 and temperature results for several rice cultivars indicated differences in response which may be useful for adaptation of rice to a future climate. These results are vital for international assessments of the impacts of global change on the earth's resources.

Olszyk, D. M., H. G. S. Centano, L. H. Ziska, J. Kern, and R. Matthews. 1999. Global climate change, rice productivity and methane emissions: Comparison of simulated and experimental results. Agriculture and Forestry Meteorology 97:87-101.

Irrigated rice production in Asia is a major source of food for a large portion of the world's population, as well as a major anthropogenic source for the greenhouse gas methane. Potential impacts of global change (elevated CO_2 and/or temperature) can be predicted with simulation models, but experiments are necessary to determine whether these effects occur in the field. We compared key experimental results (grain yield, biomass, methane emissions) from experiments at the International Rice Research

Institute at Los Baños, the Philippines; with simulation model predictions based on the climate data from those experiments. Comparisons covered three typical growing seasons, two dry (DS) and one wet (WS), with added data from an additional WS where growth was affected by a typhoon. Under current climate conditions (ambient CO_2 and temperature), potential yield from the ORYZA1 process model was the essentially the same as experimental grain yield in one DS, but 35% greater than experimental yield in the other seasons. Potential above ground biomass from ORYZA1 was close (-3 to +9%) to experimental above ground biomass in each season. The model generally predicted the increases in yield and above ground biomass found experimentally with elevated CO_2 alone, and small decreases to increases in yield and biomass with elevated temperature alone; but generally overestimated the magnitude of the changes. With both elevated CO_2 and elevated temperature, the model predicted a large increase in yield (+27%), compared with a slight decrease in yield (-4%) found in the experiments, across one WS and two DS. Model simulations of methane emissions with current climate corresponded to experimental results assuming 1.5% of the model total above and below ground biomass was emitted as methane. Model simulations of methane emissions with climate change scenarios generally agreed in direction but differed substantially in magnitude from the experimental results, as total plant biomass was not a good indicator of experimental methane emissions. This study demonstrated the usefulness of both experiments and models, and suggested ways of improving the models to predicting impacts of climate change on rice, such as by considering root biomass to predict methane emissions.

Olszyk, David, Quijie Dai, Paul Teng, Hei Leung, Yong Luo and Shaobing Peng. 1996. UV-B effects on crops: response of the irrigated rice ecosystem. Journal of Plant Physiology 148:26-34.

Increasing ultraviolet-B (UV-B) radiation resulting from depletion of the stratospheric ozone layer could have damaging effects on crops. This paper reviews recent findings on direct effects of UV-B on rice growth and yield as well as indirect effects via impacts on other organisms in the rice (*Oryza sativa*) agroecosystem. The findings are based on research by scientists at the International Rice Research Institute (IRRI) in Los Baños, the Philippines, and their collaborators in China and the United States; with comparison to research by scientists in other countries. Current results indicate that while enhanced UV-B directly impacts many aspects of rice growth, physiology, and biochemistry under controlled phytotron conditions; in general rice growth and yield are not affected under natural field conditions. The difference in response may be related both to the levels of UV-B exposure used in phytotron vs. field studies and the lower ratio of UV-A to UV-B in the phyrotron compared to field. In terms of indirect effects on rice blast disease, enhanced UV-B affected both the fungus itself (*Pyricularia grisea*) and the susceptibility of the rice plant to the fungus. Based on these data, simulation models estimated potential impacts of higher UV-B levels on blast severity and rice yield in different countries of southeast and east Asia. Ultimately, results from rice studies can be used to identify strategies to minimize any negative effects of UV-B on rice productivity.

Olszyk, D., C. Wise and W.M. Weerakoon. 1993. Effects of CO_2 and temperature on five rice cultivars. J. Agr. Met. 48:787-790.

To obtain information for more detailed studies of how rice responds to climate change plants of three high tillering (IR30, IR52, IR74) and two low tillering cultivars (Azuceña and IRAT 104) were grown under controlled environment conditions for 28 days. To detect CO_2 responses, plants were grown at 400 µL L^{-1} (ambient) or 700 µL L^{-1} CO_2, at 31/26°C and a 13 hr photoperiod. To detect temperature responses, plants were grown at 28/22, 31/25, or 34/28°C light/dark temperatures, ambient CO_2, and a 13 hr photoperiod. Across all rice cultivars, a 300 µL L^{-1} increase in CO_2 stimulated root growth more than shoot growth ($p<0.05$), i.e. a 12 to 54% increase in root weight, 4 to 49% increase in total dry weight, and 10 to 32% increase in root/shoot ratio; but neither leaf nor stem weight and leaf or tiller number was affected by CO_2. In contrast, increasing temperature by 6°C for 28/22°C stimulated shoot but inhibited root growth, resulting in an increase ($p<0.05$) (38 to 69%) in leaf number but a significant decrease (32 to 48%) in root/shoot ratio and nonsignificant changes for other parameters. Cultivars responded similarly to CO_2 or temperature; there were no significant CO_2 x cultivar or temperature x cultivar interactions. However, rice cultivars responded differently to the same environment; IRAT 104 plants tended to have lower dry weights and tiller numbers than the IR cultivars with Azuceña as intermediate. Azuceña had lower root/shoot ratios than the other cultivars.

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Neue, Heinz-Ulrich, Lewis H. Ziska, Robin B. Matthews, Qiujie Dai. 1995. Reducing global warming - the role of rice. GeoJournal 35:351-362.

Activities to provide energy for an expanding population are increasingly disrupting and changing the concentration of atmospheric gases that increase global temperature. Increased CO_2 and temperature have a clear effect on growth and production of rice as they are key factors in photosynthesis. Rice yields could be increased with increased levels of CO_2, however, the rise Of CO_2 may be accompanied by an increase in global temperature. The effect of doubling CO_2 levels on rice production was predicted using rice crop models. They showed different effects of climate change in different countries. A simulation of the Southeast Asian region indicated that a doubling Of CO_2 increases yield, whereas an increase in temperature decreases yield.

Enhanced UV-B radiation resulting for stratographic ozone depletion has been demonstrated to significantly reduce plant height, leaf area and dry weight of two rice cultivars under glasshouse conditions. Data are still insufficient, however, for conclusive results on the effect of UV-B radiation on rice growth under field conditions.

Rice production itself has a significant effect on global warming and atmospheric chemistry through methane emission from flooded ricefields. Water regime, soil properties and the rice plant are major factors controlling the flux of methane in ricefields. Global and regional estimates of methane emission rates are still highly uncertain and tentative. Integration of mechanistic modeling of methane fluxes with geographic information systems of factors controlling these processes are required to improve estimates and predictions.

Weerakoon, Weerakoon M., David M. Olszyk and Dale N. Moss. 1999. Effects of nitrogen nutrition on responses of rice seedlings to carbon dioxide. Agriculture, Ecosystems and Environment 72:1-8.

Global atmospheric CO_2 concentration is increasing, likely increasing the productivity of crops as higher CO_2 enhances plant photosynthesis. Responsiveness to nitrogen supply is an essential trait of modern rice cultivars, and may play a role in the response of rice cultivars to higher CO_2. To determine the relationship between these two important production variables on young rice plants, seedlings of *Oryza sativa* L. 'IR72' and 'KDML 105' were exposed for 28 days after sowing to higher CO_2 levels of 373, 545, 723 and 895 µmol mol^{-1} and 3 levels of nitrogen fertility. There were large increases in leaf higher CO_2 assimilation and biomass production whereas leaf nitrogen concentration dropped sharply as higher CO_2 increased from 373 to 545 µmol mol^{-1}, with little additional effect from higher levels of higher CO_2. Root and shoot biomass, and tiller number per plant increased with increasing nitrogen supply and with increasing atmospheric higher CO_2 concentration. The biomass response to higher

CO_2, was slight at low N supply, but became dramatically greater as the N supply increased. Mean root/shoot ratio increased slightly as atmospheric higher CO_2 concentration increased, but decreased sharply as nitrogen fertility rate increased. These results suggest that careful attention to nitrogen fertilization will be necessary for rice-farming to get the full benefit of any future increases in atmospheric higher CO_2.