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Simulated rice yields as affected by interannual climate variability and possible climate change in Java

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ABSTRACT: About 60% of the rice produced in Indonesia is grown in the fertile soils of the island of Java. Introduction of the high-yielding rice varieties and improvement of cultural technique have increased rice production, and self-sufficiency was attained in 1984. However, increasing population and decreasing land for rice cultivation could threaten the food supply in the country. Rice production is also threatened by interannual climate variability and possible climate change. To provide policymakers and planners with information to formulate a strategy to cope with interannual climate variability and the possible climate change, rice yields of 2 production areas on Java were simulated using the DSSAT (Decision Support System for Agrotechnology Transfer) rice growth simulation model. The crop model predicted lower rice yields for different management options, compared with experiment plots, but predicted yields similar to or slightly higher than the farmers' yield. In general, the predictions relate quite well. The GISS, GFDL, and UKMO climate models predicted higher rainfall, solar radiation, and temperature in both locations. In the higher rainfall and lower temperature of the West Java site, the climate change scenarios reduced rice grain yield in both the first and second crops. During normal years in the relatively warmer and dryer climate of the East Java site, there was no significant yield reduction due to climate change, except under the UKMO scenario in the second crop. Because high temperature and CO_2 concentration favor rice growth, development of more heat-tolerant varieties probably can compensate for the yield losses due to climate change in the future. Except for the GISS and GFDL climate scenarios in the first crop and the baseline climate scenario in the second crop in the West Java site, higher yield losses were predicted because of interannual climate variability. Since the dry spell threat is more imminent and frequent, to improve preparedness a short-term climate prediction for the tropical region is urgently needed.

KEY WORDS: Crop model · Climate model · El Niño · Climate change · Rice · Java · Indonesia

1. INTRODUCTION

As a staple food in Indonesia, rice is strategically important in the agricultural development and economy of the country. About 60% of rice produced in the country is grown in the fertile volcanic ash soils of the island of Java. The introduction of the high-yielding rice varieties and improvement in traditional techniques over the last several decades have boosted rice production. Except during recurring El Niño/Southern Oscillation (ENSO) episodes, which cause drought in Indonesia, rice production has steadily increased since 1969, from 12.8×10^6 to almost 31×10^6 t in 1993 (Binus Pangan 1994). Rice self-sufficiency was attained in 1984 when Indonesia produced 25.9×10^6 t and exported 11000 t of rice. However, the population increase (albeit at a reduced growth rate) and the recent prolonged droughts of 1991, 1994, and 1997, as well as the decreasing land available for rice cultivation, could threaten the food supply in the country. The effect of El Niño in 1991, 1994, and 1997 caused widespread crop failure that compelled Indonesia to import about 6×10^5 t of rice in 1991 and over 1×10^6 t in 1994. At least 2×10^6 t of rice have been imported because of the 1997 El Niño. It is estimated that about 2×10^4 ha of

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irrigated rice fields on Java are converted to industrial and residential uses every year.

Rice production in Indonesia is also threaten by a decrease in yield because of potential climate change. Long-term records indicate that the present atmospheric concentration of CO_2 and the global temperature have increased during the past 100 yr. Air temperature and air CO_2 concentration will directly affect plant growth through photosynthesis and respiration.

Higher CO_2 concentration in the atmosphere, to a certain extent, enhances photosynthesis. But plant growth is very sensitive to temperature. Often a difference of a few degrees leads to a noticeable change in growth rate. Higher air temperature by itself will increase rice plant respiration rate and reduce net photosynthesis, hence eventually reducing plant yield.

Science and technology have generated a wealth of information, but the functional knowledge necessary to support decision-making is not accessible to those who need it most. To provide policy-makers and planners with information to formulate a strategy to cope with El Niño events and climate change, a clear picture of what is likely to happen in the future is necessary. For that purpose, climate change scenarios were produced using 3 general circulation models (GCMs). The response of food crops, including rice, to environmental effects now can be predicted using crop simulation models (IBSNAT 1993). Rice growth models simulate crop responses to changes in climate, soil, cultivars, and management. Thus, the climate scenarios were used as inputs to the rice crop model to predict the effect of a changing climate on the rice yield. This paper discusses the climate models used and their limitations, the rice simulation model and its validation, the results of the analysis, and possible adaptation options.

2. METHODS

2.1. Climate models. To incorporate all the important physical interactions, especially with atmospheric circulation, and to calculate the location of future climate change, fully 3-dimensional GCMs are necessary. These sophisticated models solve simultaneous equations for all the important climate variables in 3 dimensions. The atmosphere is broken up into a discrete grid of boxes placed side by side and stacked to cover the globe. The equations used to represent the physical and chemical processes involved are also simplifications of real-world processes (Robock 1989). When discussing climate change, it is sometimes convenient to refer to an equivalent doubling of CO_2, which refers to any combination of greenhouse gasses that has the same effect as doubling CO_2 alone.

Several climate modeling groups have conducted GCM experiments to calculate the equilibrium climate response to doubled CO_2. These include researchers at the NOAA's Geophysical Fluid Dynamics Laboratory (GFDL), NASA's Goddard Institute for Space Studies (GISS), and the United Kingdom Meteorological Office (UKMO). The results from the different experiments depend on the assumptions made, especially on the treatment of clouds and of oceans. The models predicted global temperature increases of 4.0 to 5.2°C and global precipitation increases of 7 to 16% (Benioff et al. 1996).

2.2. Study areas. Two main rice production areas in Java with different geographic conditions, Mojosari in East Java and Pusakanegara in West Java, were selected for this study. Pusakanegara is on lowlands at the northern coast of West Java at an elevation of 12 m above sea level, and Mojosari is further inland, on the flood plain of the Brantas River at an elevation of 30 m above sea level. In the last 5 yr, nearly 2×10^6 ha were cultivated in West Java, or 21% of the country's rice cultivation, and more than 1.5×10^6 ha were cultivated in East Java, or over 16% of the country's total (BPS 1994). To simulate the future weather of the areas, daily climate data—consisting of rainfall, minimum and maximum temperature, and solar radiation or day length from 1973 to 1992—were used as the baseline. At Pusakanegara, the mean annual rainfall during the stated period was 2031 mm, maximum and minimum single-day temperatures were 30.7 and 23.0°C, respectively, and the average monthly solar radiation was 18.3 MJ m^{-2}. At Mojosari, the mean annual rainfall was 1785 mm, maximum and minimum single-day temperatures were 32.9 and 22.0°C, respectively, and the monthly solar radiation was 20.4 MJ m^{-2}.

Although the weather in the tropics is warm all year round, rainy seasons alternate with dry seasons, and each season has its own distinct pattern of prevailing winds. The rainfall pattern is also affected by the El Niño phenomenon that is primarily centered in the Indo-Pacific basin, but has wider, nearly global impacts and implications. At least 4 dry years—1976, 1982, 1987, and 1991—in the baseline climate data probably are related to El Niño. The average annual rainfall during those years in Mojosari was 1074 mm, or only 60.2% of the 20 yr average. In Pusakanegara, it was 1025 mm, or 50.5% of the 20 yr average. The future climate in both areas was simulated based on doubling CO_2 level from pre-industrial time (prior to 1850) to 555 ppm using the GFDL, GISS, and UKMO climate models.

2.3. Crop growth simulation model. The CERES (Crop-Environment Resource Synthesis) family of crop models is used in the Decision Support System for Agrotechnology Transfer (DSSAT) to predict the performance of 6 grain crops (IBSNAT 1993). All 6 of these models are designed to use a minimum set of soil, weather, genetic, and management information. The models are daily incremented and require daily weather data consisting of maximum and minimum temperature, solar radiation, and rainfall. They calculate crop phasic and morphological development using temperature, day length, genetic characteristics, and vernalization where appropriate. Leaf expansion, growth, and plant population provide information for determining the amount of light intercepted, which is assumed to be proportional to biomass production. The biomass is partitioned into various growing organs in the plant using a priority system. A water and nitrogen balance submodel provides feedback that influences the development of the growth processes.

The CERES-rice model has the same features and characteristics as those described for the other CERES models. It differs from them, however, in that it can also simulate the establishment of a rice crop from dry sowing, pre-germinated seeding to transplanting, and provision has been made within the model to calculate the effect of transplanting shock on crop duration. The water balance also simulates crop water uptake under intermittent flooding and drying, as well as fully upland conditions, where the soil is never flooded. In addition, the nitrogen (N) submodel of the CERES-rice model simulates transformations of N in the plant in both upland and lowland conditions. The model simulates the effects of N deficiency on photosynthesis, leaf area development, tillering, senescence, and remobilization of N during grain filling.

In simulating rice growth, rainfed conditions were applied by using weather data from both normal and dry years. The baseline climate data as well as the climate scenarios from the GISS, GFDL, and UKMO models were utilized in the DSSAT rice growth model. Rice cultivars used in running the model were IR 36 for the Mojosari area and IR 42 for the Pusakanegara area. A standard management practice in the rice intensification program in Java was also selected — namely, transplanting rice seedlings 18 d after germination; 2 seedlings per hill at 20 by 20 cm spacing; 2 applications of urea fertilizer at a rate of 58 kg N ha^{-1} both before planting and 30 d after planting incorporated into the soil at a depth of 5 cm. The simulation began at the time of transplantation. Full irrigation with no water stress was applied to simulate years with normal rainfall by using weather data for the rainy season in normal years. The rice simulation model has several water management options, including fully irrigated with no water stress and rainfed, which depends fully on rainfall. By using the weather data from normal years during the rainy season, the condition of no water stress can be assured. Two times of planting were also applied. In the Mojosari area, the first crop started in early October at the beginning of the rainy season, and the second started soon after harvesting the first rice crop in February. In the Pusakanegara area, the first crop started in late November and the second in early April.

The baseline climate data of 1976, 1982, 1987, and 1991 and the corresponding years in the transient climate scenario, which are years when El Niño events occurred, show very little rainfall. The weather data of those year were utilized to simulate the rice performance for dry years in current and future climate. In dry years, water in many of the upstream reservoirs is far less than normal. In competition with human and animal uses, agriculture, particularly rice cultivation, is given the least opportunity to utilize the limited water. In dry years, many farmers opt for secondary crops (such as corn, peanut, or cassava) that require less water.

3. LIMITATIONS

GCMs do a reasonable job in simulating global values of surface air temperature and precipitation, but do poorly at the regional scale (Grotch 1988). Computer speed and size constraints limit the size of the grid boxes to very large areas horizontally but only 1 to 5 km vertically. The details of coastlines and topography are not resolved. For a country comprising more than 13 000 islands in the tropics, the CGMs are not yet suitable for simulating future climate. Attempts to increase the resolution for the CSIRO9 model only enable it to simulate data at points 200 km apart (Whetton 1994). In Java, this grid covers an area that has several distinct rainfall patterns.

Global sensitivity of climate to greenhouse gases is expressed as the change in the global temperature when the equivalent CO_2 concentration in the atmosphere is doubled and reaches a new equilibrium climate; this change is estimated by the IPCC (1990) to be in the range between 1.5 and 4.5°C. There is a factor of 3 difference in these values; the difference between the last glacial period and the present is 5°C.

Another source of uncertainty is the spatial pattern of changes in temperature, precipitation, and solar radiation for a given global warming. Pittock (1994) found a greater measure of agreement in the more recent, improved GCMs, and there is some confidence that at the subcontinent scale the spatial patterns are correct; however, there is still little agreement for Java, particularly in precipitation. In addition, the effect of natural variability due to other causes, such as volcanic eruption, change in deep ocean circulation, and solar variability, is still not understood. The selection of El Niño years in the future climate for crop growth simulation probably is not quite correct, and therefore may not be typical of the past. El Niño events seem to have been more frequent in the last decade.

Although the models do not exactly reproduce the current climate, the differences between their simulations of current and future climates may still provide an estimate of potential future changes. In addition, the models produce a data set of all the variables needed for impact assessment that are physically consistent. The actual model projections are useful in providing scenarios for impact assessment. As model projections become more accurate, the scenarios they generate should become more relevant for assessment.

4. RESULTS AND DISCUSSION

4.1. Climate change scenarios

The changes from current climate (1973 to 1992) as simulated by the 3 GCMs are presented in Table 1. All the climate variables as simulated by the 3 CGMs increase from the current condition when atmospheric CO_2 doubles. A higher increase in solar radiation and temperature is produced by the GISS model, but a higher increase in rainfall is produced by the UKMO model. The smallest increase is in solar radiation for the Mojosari area as simulated by the UKMO model (an increase of 0.2 MJ m^{-2}, or 1.3%), and the highest is in rainfall for Pusakanegara as simulated by the UKMO model (an increase of 1681 mm, or 82.8%).

The highest increase in rainfall occurs during the peak of the rainy season from December to February. The high increase in rainfall during these months produced by the UKMO model causes a decrease in solar radiation both in normal and dry years in Pusakanegara and during dry years in Mojosari. No significant change in the rainfall during the dry season is produced by the 3 models.

Table 1. Increase in rainfall, temperature, and solar radiation in Pusakanegara and Mojosari, Java, at the 2 × CO_2 concentrations simulated by the GCMs

Scenario	Pusakanegara	Mojosari
GISS		
Annual rainfall (mm)	423 (20.8%)	354 (19.8%)
Maximum temperature (°C)	3.9	3.9
Minimum temperature (°C)	3.9	3.8
Solar radiation (MJ m^{-2})	0.7 (3.5%)	0.6 (3.3%)
GFDL		
Annual rainfall (mm)	506 (24.9%)	265 (14.9%)
Maximum temperature (°C)	2.3	2.3
Minimum temperature (°C)	2.3	2.3
Solar radiation (MJ m^{-2})	0.3 (2.2%)	0.3 (1.5%)
UKMO		
Annual rainfall (mm)	1681 (82.8%)	1130 (63.3%)
Maximum temperature (°C)	2.9	3.0
Minimum temperature (°C)	3.0	2.9
Solar radiation (MJ m^{-2})	0.6 (3.3%)	0.2 (1.3%)

In both locations, minimum and maximum temperatures increase by more than 2°C as simulated by the GFDL and UKMO models and more than 3°C when simulated by the GISS model. This increase is more than twice that in the scenario produced by the CSIRO9 model. The warming was thought to be smallest in island and coastal areas and greater inland (Whetton 1994). Data from several places in Java indicated only a small rise in minimum temperature, but no clear indication of the increase in maximum temperature in the last 100 yr (Karyoto pers. comm. 1994). Higher temperatures may decrease solar radiation as a result of increased clouds, particularly in a maritime archipelago like Indonesia.

4.2. Crop model validation

For validation purposes, the model outputs were tested against field experiment results from various sites in Indonesia. The rice field experiments were conducted at Sitiung in West Sumatra, Cianjur and Sukamandi in West Java, and Ngawi in East Java during 1981–1982 and 1991–1992. The experiment in Sumatra tested the response of several rice cultivars to soil management practices on an acid soil, while the experiments in Java tested the source, rate, and methods of nitrogen fertilizer application on IR 36 and IR 42 rice cultivars. These 2 cultivars were the main rice cultivated in the areas because of their relatively high yield and resistance to brown plant hopper in that period. As these new hopper-resistant rices were introduced, a new population of brown plant hopper developed to feed upon them. When IR 42 became susceptible to brown plant hopper in late 1980s, particularly in West Java, a new variety, Cisadane, was introduced. At present, 6 rice cultivars—IR 36, 42, 46, and 64, Cisadane, and Krueng Aceh—account for 70 to 80% of Indonesia's rice production (Fox 1994).

The DSSAT rice crop model slightly under-predicted lowland rice yields of the experimental plots, but its predictions were almost equal to or a little higher than farmers' yields. It seems that in all locations except Sukamandi, the model under-predicted the grain weight by almost 1 mg. Nevertheless, the simulation outputs and experimental plot yields are closely related, with a coefficient of determination value of 87% (Fig. 1). Intensive rice cultivation in the East Java area at the farm level with 250 kg urea fertilizer ha^{-1} during that period produced 5115 kg of rice, compared with 5789 kg rice in the simulation result. In the West Java area, farmers produced 4101 kg compared with 4426 kg as simulated in the Sukamandi area, and 3974 kg compared with 4683 kg as simulated in the Cianjur area (BPS 1981). The small experiment plots are certainly better managed than the larger fields of the farmers.

4.3. Simulated rice yields

The rice yield as simulated by the DSSAT rice growth model at Mojosari produced 7319 and 10 823 kg ha^{-1} of rice, respectively, for the first and second crop during normal years, but only produced 6051 and 4531 kg ha^{-1} during dry years. In the Pusakanegara area, the rice yields were 7543 and 5976 kg ha^{-1}, respectively, for the first and second crop during normal years. During dry years, the rice grain yield substantially decreased to 6471 kg ha^{-1} for the first crop but slightly increased to 6348 kg ha^{-1} for the second crop (Fig. 2). Except for the GFDL climate scenario in the first crop and the baseline climate in the second crop in the Pusakanegara area, the biomass production during the dry years in both locations was significantly reduced relative to normal years (Table 2).

Cell enlargement is extremely sensitive to desiccation and can be affected by the normal changes in plant water status that follow changes in evaporative demand during the day. Although photosynthetic activity of the leaves is considered less sensitive to drought, any inhibition in the rate during grain filling has an important effect on agronomic yield. The flowering process requires a specialized set of events that may be controlled to an extent by photosynthate supply and cell enlargement. Floral development, flowering, pollination, and fertilization represent the stages of crop development most sensitive to drought inhibition (Boyer & McPherson 1976).

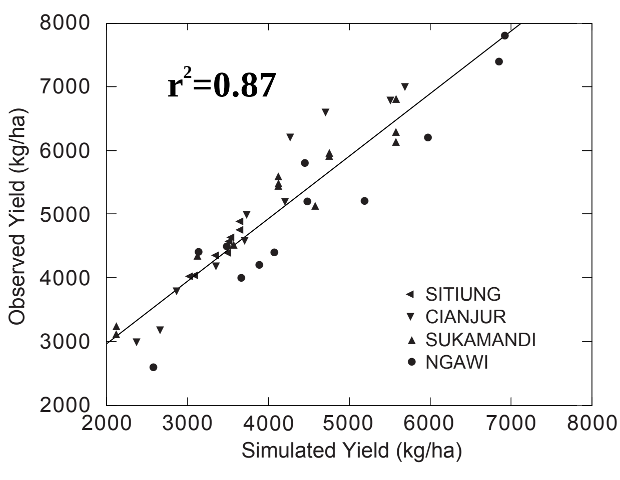

Fig. 1. Observed and simulated rice yields at 4 locations in Java and Sumatra

Table 2. Simulated rice biomass (kg ha^{-1}) as affected by possible climate change and interannual climate variability. Note: for Mojosari, the first crop started in early October and second in early February; for Pusakanegara, the first crop started in late November and the second in early April

Location/climate	Standard	GISS	GFDL	UKMO
Mojosari				
Normal years				
First crop	15826	16120	15082	12042
Second crop	11161	11223	9918	10707
ENSO years				
First crop	10799	12269	14228	7899
Second crop	9852	5964	6953	6064
Pusakanegara				
Normal years				
First crop	10898	8727	9994	8318
Second crop	10323	10114	10079	12042
ENSO years				
First crop	9941	9090	10273	7352
Second crop	10984	7239	9137	8438

More than any other food crop, rice has a critical requirement for high and regular water availability. The water required is totally lost through evapotranspiration, seepage, and percolation since very little is actually retained by the plant (Lawson & Alluri 1980). In lowland rice systems, the seepage and percolation losses are minimized because of the bunds that maintain the water levels in the flooded rice system and because of the development of the plough pan at about 50 cm depth. High temperatures and solar radiation increase evapotranspiration and the requirement for water, but favor growth and yield.

Except for the GISS climate scenario in the first crop in the Mojosari area, a significant decrease in grain yields was simulated by using the GISS, GFDL, and UKMO models in normal years at both locations. Except for the current climate in the second crop in the Pusakanegara area, the grain yields are significantly lower during dry years (Fig. 2). In the second crop in the Mojosari area, the rice yield in normal years is significantly higher, compared with the first crop, except for the UKMO climate scenario. On the other hand, for the Pusakanegara area the rice yields are higher in the first crop except for the GISS and UKMO climate scenarios. The rice yields obtained using all the climate scenarios are generally reduced during El Niño years.

Within the optimal temperature range from 15–18 to 30–33°C, higher temperatures in general favor the vegetative growth and development of rice plants. However, root growth has an optimal temperature around 25°C, and lower temperatures are favorable to raising strong seedlings (Nishiyama 1976). In the climate scenarios using the GISS, GFDL, and UKMO models, the temperature increases by 3.9, 2.3, and

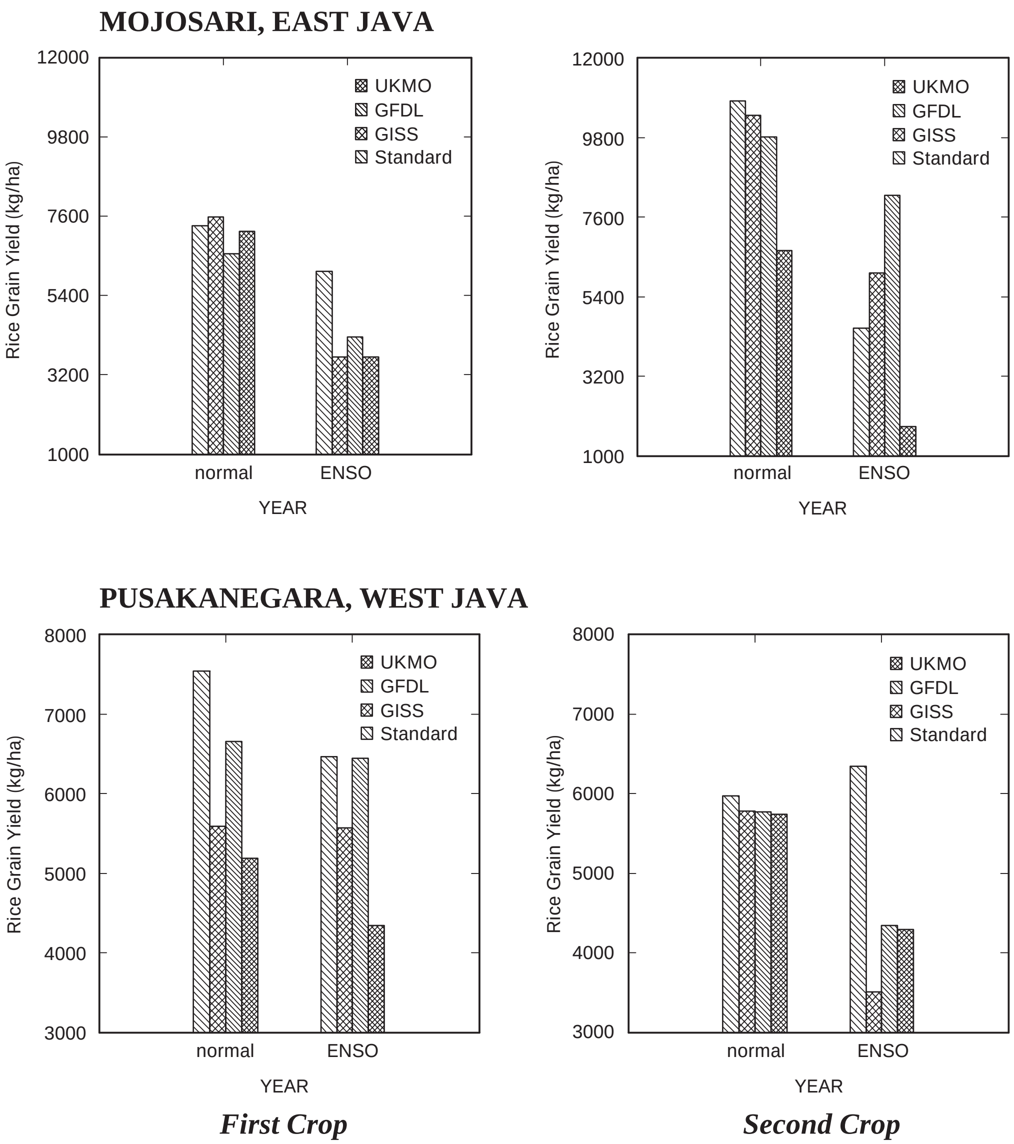

Fig. 2. Predicted rice yield as affected by interannual climate variability and climate change in the Mojosari and Pusakanegara areas

3.0°C, respectively. Except with the GISS model, the temperature for the Pusakanegara area is well within the optimal temperature for rice plants; but for the Mojosari area, the maximum temperature exceeds the optimal temperature. The higher temperature is probably unfavorable for reproductive growth. Panicle differentiation occurs favorably in a temperature range from approximately 18 to 30°C. Above 30°C, it delays or is inhibited under some conditions (Adachi & Inouye 1972). The critical temperature for seed ripening is in the range from 12 to 18°C (Sinitsyna & Chan 1972). Higher air temperatures averaging approximately 30°C are not favorable for ripening (Osada et al. 1973).

The number of spikelets plays an important role in determining the grain yield of rice plants through its effect on the total sink size. Analyzing rice yields from 200 farm fields ranging from cool to warm regions in Japan, Munakata (1976) concluded that spikelet production has a clear optimum at 20 to 23°C and rises again at 27 to 28°C. The complex temperature response may be explained by analyzing the competing biological reaction in plants. Tsunoda (1964) observed that the number of tillers had an inverse proportion to stem elongation (plant height), and the optimum temperature for stem elongation was about 25 to 30°C. These results suggest that inhibition of stem elongation at low and high temperature brought about the increase of tillers, resulting in the temperature curve with 2 optima for the number of panicles and spikelets. It seem likely that the temperature curve with 2 optima is attributable to the increase in ammonification of soil by high temperatures, as well as to the inhibition of stem elongation at low and high temperatures (Munakata 1976). High temperature also increased sterility as a result of smaller pollens and non-dehiscence of anthers (Sato et al. 1973).

In the simulation results for the Mojosari area, reproductive yields decreased in the higher temperatures of the climate scenarios of GISS, GFDL, and UKMO models, particularly in the second crop. Further reduction of yield was obtained in the dry years. In the Pusakanegara area, the simulation results indicate yield reduction because of climate change, particularly in the first crop. Both the vegetative and reproductive rice yields in both locations using all the climate scenarios are generally lower during dry years. When rice was planted as a second crop early in April, the baseline climate produced higher yield during dry years compared to normal years.

Higher CO_2 concentration will increase photosynthesis. From a CO_2 enrichment experiment, Yoshida (1976) found that the optimum concentration for growth and yield of rice lies between 1500 and 2000 ppm CO_2. These values are far higher than the atmospheric CO_2 concentration assumed for the models used here. However, the yield increase caused by increasing CO_2 concentration cannot compensate for the yield reduction due to increasing temperature.

Caution has to be taken because the yield reduction due to climate change as simulated by the climate and crop models is probably a little exaggerated. At least 2 reasons need to be considered. First, the temperature increase seemed to be higher than predicted by other models and the change observed in the past. Second, the rice growth model under-predicted the experimental yields. The yield decline in El Niño years is far greater than the threat of yield decrease by possible climate change. An El Niño event also seems more imminent because it has become more frequent in recent years. During the El Niño of 1991 and 1994, more than 8×10^5 and 5×10^5 ha of rice fields were affected by drought, respectively. The droughts caused crop failure in about 400 000 ha, mostly in Java (Dirjen 1995). However, in rice cultivation on a bunded field, there is always standing water after the rain for a certain time, although it probably is lost through evaporation later. Such conditions are not similar to rainfed conditions, in which all the rainfall either percolates through the soil profile or is lost through runoff.

Simulating rice growth in dry years using rainfed conditions does not represent real conditions in the field. Farmers, learning from past experiences, usually plant rice after sufficient rainfall.

During a prolonged dry season, rice planting does not always start in November, as it does in normal years. Delaying planting time until sufficient water is available, or supplemention of irrigation water, will greatly improve rice growth and increase the yield.

Higher rainfall and its variability probably enable farmers to grow more upland rice, but the already intensive land utilization in Java and low yield of upland rice, as well as competition with other crops with more market value, hinder much of the implementation. Currently, intensive upland rice cultivation is promoted outside Java as an inter-crop in tree plantations before the establishment of the full canopy of the tree plants. However, higher rainfall in over-utilized upstream areas of Java also induces more erosion, causes siltation of dams and harbors, raises river beds, and causes flood during the heavy rainfall of the rainy season.

To overcome the problems in securing food supply for the country, several actions have been taken, including a better near real-time analysis of climate to improve preparedness, using early rice varieties and *gogo rancah* — that is, planting early at the end of dry season in upland conditions, more efficient water uses with intermittent flooding, and improvement of rural irrigation systems. Improvement of cultural techniques in many parts of the outer islands can contribute substantially to the country's rice production. Currently, the yield levels in these places are about 50 to 60 % of those in Java. In the long run, expansion of rice cultivation particularly to the under-utilized swampy areas of the outer islands, as well as food diversification, seems to be inevitable.

5. CONCLUSIONS

Climate models at the current stage still poorly predict climate change at the regional scale, particularly for an island system like Indonesia. The GISS, GFDL, and UKMO climate models predict higher temperature increases in both study areas compared with what is predicted by the CSIRO9 model. Observed data in the archipelago of Indonesia indicated only a slight increase in minimum temperature and no significant increase in maximum temperature.

The DSSAT crop model predicted lowland rice yields quite well for different management options, with a coefficient of determination value of 87 %. Experimental data with standard management practices over a sufficient span of time are limited, thus restraining the model validation for the changing climate.

The rice crop model generally predicted yield reduction in both East Java and West Java because of possible climate change in the future. However, an insignificant reduction was simulated when the rice crop was planted at the proper time. Because high temperature and CO_2 concentration favor rice growth, development of more tolerant varieties probably can compensate for the yield losses due to climate change. Higher yield losses are predicted because of interannual climate variability. Since the dry spell threat is more imminent and frequent, to improve preparedness a short-term climate prediction for the tropical region is urgently needed.

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