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GENERAL ARTICLE

THE IMPACT OF CLIMATE CHANGE ON RICE VARIETY SELECTION IN THAILAND

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ABSTRACT

Rice is one of the main sources of food for the people of the world. Southeast Asia is one of the main rice growing areas, and Thailand is the world's fifth largest producer of this crop. Thailand is tied with Burma as the largest per capita rice producer: about 1/3 ton per person per year. Approximately one quarter of the land area of the Kingdom of Thailand is used for rice production, and this commodity constituted 12.6% of the GDP in 1988. Rice made up 8.6% of the 1988 exports from the country.

The above information supports the contention of this paper; that it is important both regionally and nationally for Thailand to adopt policies which would offset any negative trends imposed by possible climate changes on rice production.

Possible climate change scenarios from three Global Climate Models (GCMs) are illustrated, and one of these was selected for more detailed study as regards its potential impact on rice production. Four groups of factors are considered by our state-of-the-art rice plant process computer simulation model in estimating rice yield. These are: cultural practice, soils, climate, and genetics of the variety planted. The main focus of our study is on the genetic characteristics of crop yield; although, a portion of the cultural practice is of necessity considered along with the varietal aspects.

We have shown how the GCM climate change scenario can be used by the rice model to produce information concerning the effect on yield estimates of variations in the vector of input genetic coefficients. This methodology has been used to modify the genetic coefficients of the rice varieties currently grown at 7 selected locations across Thailand in order to obtain a set of "improved" varieties which would produce higher yields at these locations under a "new" climate. Such improved yields require changes in sowing dates and fertilizer application scheduling.

Finally these "representative" yield estimates are aggregated to area production values and then transformed into economic terms to illustrate possible baht/year impacts *at the national level of both climate change impacts and of the beneficial effects of planting our "improved" varieties under modified farm practice.*

Although our study is by no means comprehensive at this point, it is extensive enough to make the points that:

– a national policy which would direct rice breeders to consider possible climate change influences in their breeding programs would be cost beneficial,

– a national policy to encourage a cooperative effort between the agricultural extension service and the farming community which would highlight the variety selection/climate change/cultural practice interactive effects would be cost beneficial, and

– because of the geographical variability associated with the results we have obtained, a more extensive and comprehensive study of the type we present will be needed to produce quantitative information which can be used in strategic and tactical decision making at the national and regional levels.

INTRODUCTION

This paper is concerned with the impact of global warming on rice production in Thailand. Rice is Thailand's principal staple and the major agricultural export crop. About 18% of the agricultural export income of the year 1988 was earned from rice[1]. Forty percent of Thailand's total land area is devoted to growing crops (62% rice and 22% other field crops); approximately 70% of the population depends on agriculture. About 70% of the planted area is rainfed and single cropped during the wet season. Yields of the upland rice crop are low. In the lowlands, yields are usually much better, and often double that of the upland rice. The export of rice, maize, cassava and sugar cane is a significant source of foreign exchange.[2]

Although rice is grown in virtually every one of the 73 provinces in Thailand, the bulk of the productivity is in the Chao Phraya river basin surrounding, and north of Bangkok. Some half dozen major varieties have been identified by Huke[3] ranging from dryland in the Northeast region to deepwater in the southern portion of the Central region; the former subject to severe droughts, and the latter to extensive flood damage. Comprehensive studies, such as that reported by Janatwat *et al.*[4] for Northeastern Thailand, have related rice production problems to interactions between the variability of the atmospheric water delivery system and the ability of the soil to retain this water supply for later use by the crops.

The assessment of winners and losers in the context of global warming is still a controversial issue among scientists and policy-makers. No one can be certain of the answer. The amount of precipitation delivered on a given day to a given location could remain the same whether the precipitation itself were to be delivered by a rain-producing severe thunderstorm, or by a steady warm frontal rain falling over many hours. Precipitation in Thailand comes mainly from monsoonal troughs and tropical cyclones.

There has been a suggestion that the monsoon season has changed during the past decade, coming later to Thailand and producing less rainfall. The avarage rainfall of the past six years, for example, is 5% to 18% lower than the long-term avarage (greatest decrease in the northeastern region)[2].

Rainfed farming is a high risk enterprise, particularly in the monsoon type of climate where usually heavy rains are received for periods varying from 3 to 8 months followed by extended dry periods of 4 to 9 months. In many areas there is a high degree of interannual variability not only of the amount of rainfall but of the timing of the rainy season. Frequently, there are long spells of dry periods within the rainy season, which, if they occur at the critical stages of growth of a crop, may result in reduced yields or even in a complete loss of the crop. In 1987 Thailand experienced one of the worst droughts in many years, with about 960,000 hectares of crop land adversely affected. Rice production decreased by about 8.2% from the previous season.[2]

Solar radiation, temperature, and precipitation are three climate variables which affect the growth and development of the rice plant. When these features of the climate change, then, for a given soil, cultural practice, and varietal genetics, the yield (both grain and straw) of the rice will change.

Plants require solar radiation for their photosynthesis process and are sensitive to relationships between radiation intensities at specific wavelengths. Their phenology also reacts to daylength.

In Thailand the southwest monsoon with its extensive cloudy periods decreases available solar radiation during the major rice season, thereby decreasing yields; whereas the northeast monsoon provides cloud-free sunny weather during the second rice season, thereby making possible higher rice yields (given irrigation). In the lowlands, flooding frequently reduces yields and acts as a disinducement for the use of fertilizer and other cash inputs, the risk of drought and an early end to the rainy season are the main disincentives on the flood-free terrace lands. Fortunately, when floods reduce production in the lowlands, the better rains usually mean a higher yield on the terraces.

The principal question for the present study is: what would be the response of the policy planners on the aspects of changes in food production which would result from changes in the climate, so that Thailand will have enough food for both local consumption and world export. The answer could be made up of some or all of the following elements:

– alternate crops and alternate cropping practices,

– investment in new irrigation canal systems,

– investment in new reservoirs,

– encouragement of farmers to modify their tillage practice, fertilizer use, irrigation methods and other farming techniques,

– recommendation to the rice breeder to breed new varieties which will improve the yields for the climate change scenarios.

This paper will focus on the last element as input to policy exercises conducted at national or regional levels. To accomplish this objective, all information needed for model input was collected from 7 sites selected from all 4 regions of Thailand: Northern, North-Eastern, Central and Southern. Ninety-two percent of rice exports come from Asia. It would be beneficial to Thailand to prepare rice varieties that would improve yields for such specified climate changes, while some of the other Asian rice exporting countries may not be ready for such changes.

Both the BASE climatological data (raw data from the Thailand Meteorology Department) and the GISS (Goddard Institute for Space Studies) climate change data have been used as input to the state-of-the-art plant process, CERES-RICE (Version 2) developed by Godwin and Singh[5] of the IFDC (Internation Fertilizer Development Center) for the simulation of both lowland and upland rice growth and development. This model makes explicit use of precipitation, temperature, and solar radiation on a daily basis in estimating changes in biomass and phenological development of the crop.

The genetics are represented by an 8-vector of coefficients which control the length of the phenological stages, photosensitivity and growth properties.

The plant process computer simulation model is used to examine potential impacts of changes in ambient weather conditions, and of changes in varietal characteristics of the plant, on rice yield under specific soil and cultural practice factors. Different types of climate, soil and the cultural practice of the farmer require different rice varieties to obtain optimal yield. Consequently, to optimize the yield the farmer should use that variety whose genetic characteristics can make the best use of the other three factors mentioned above on his farm.

Rice Climate

GCMs (global climate models) have found an increasing use in climate impact analysis studies[6-8] Output from the models being used in this study has been obtained from NCAR (National Center for Atmospheric Research) for the Southeast Asia region. The generating models comprise: GISS (Goddard Institute for Space Studies), GFDL (Geophysical Fluid Dynamics Laboratory), and the OSU (Oregon State University).

The amounts of CO_2 used in the control (1×) GCM model runs for each model were as follows:

GISS 315 ppm,
GFDL 300 ppm, and
OSU 326 ppm.

The amount of CO_2 in the atmosphere was measured to be 315 ppm in 1958 and 342 ppm in 1983. The amount of CO_2 used for the $2 \times CO_2$ run was always double the $1 \times CO_2$ run. When the concentration of CO_2 is 342 ppm, there are 722 gigatonnes of carbon in the CO_2 molecules in the atmosphere?

There is one property that the GISS model has, which the GFDL and OSU models do not have, that is a diurnal cycle. The climate changes which occurred from the run without a diurnal cycle, compared to the one with it were taken from Dave Rind, GISS 1988 as follows:

– the rain over the warmer land (without a diurnal cycle) increased by up to a few mm per day,

– low-latitude temperature in winter was about 10°C warmer over land without a cycle; while high latitude temperatures were a few degrees warmer,

– near the equator, there was a 50% increase in low clouds over land for no cycle,

– more monsoon activity and greater rainfall occurred with no diurnal cycle.

On the global average, when CO_2 is doubled: GISS warms 4.2°C, GFDL model warms 4.0°C with variable clouds, (with fixed clouds it was 3.0°C warmer), while OSU warms 2.8°C.

It is for the above reasons that we chose to use the GISS model output for our present study.

A good discussion of the attributes of these GCM models with respect to agro impacts is presented in Chen and Parry.[8] Jenne[9] discusses some of the technical aspects (with respect to meteorological attributes) of these models. Figs. 1, 2, and 3 present a comparison of the three main weather variables (precipitation, temperature, and radiation) for each of four climate scenarios at three geographical locations of interest in Southeast Asia: Some biases among models are evident; consequently, one might expect these four climate scenarios to produce significantly different estimates of rice yield.

Is there anything in common to be found among these climate change impacts

Long-term monthly mean values of temperature and precipitation for $1\times CO_2$ and $2\times CO_2$ GISS model runs for Southeast Asia were supplied by Roy Jenne of NCAR for the Southeast Asia UNEP project on Socio-Economic Impacts and Policy Responses Resulting from Climate Change in Southeast Asia.

The climate change scenarios are developed by modifying the daily rainfall amounts using the basic observed daily data for the period (1955-1976). The rainfall days of occurrence are not changed. This is a very important constraint because, if the increase in rain were to occur by increasing the number of days of rain instead of by increasing the intensity, then the associated changes in solar radiation reaching the plant conopy could have as much impact on yield as would the changes in water availability. It is the ràtios of $2\times CO_2/1\times CO_2$ of monthly precipitation which were used to produce the GISS precipitation scenario (shown in Fig. 4). Figs. 5 and 6 show the (average) consequence of applying similar ratios to the daily BASE temperatures and radiation. Since the GISS precipitation values are obtained by multiplying the BASE daily precipitation by a ratio, the variance as well as the mean values will be changed. Since these ratios are a function of latitude and longitude (see Fig. 2, for example) this change in variance will vary from station to station.

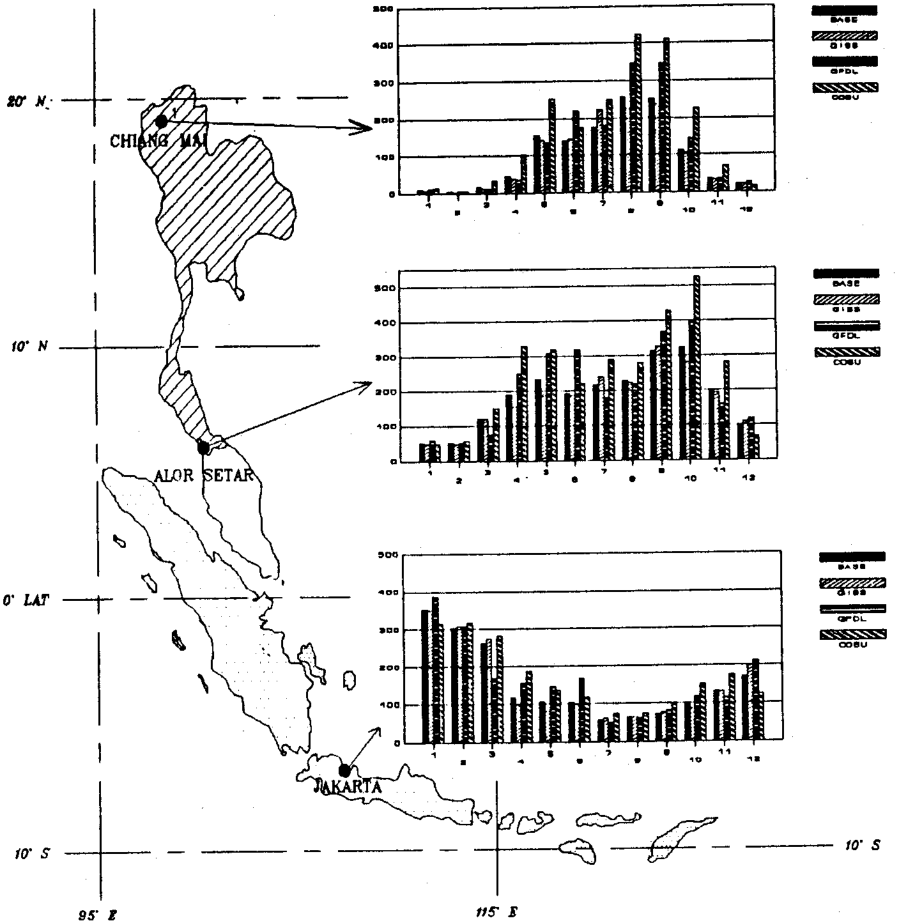


Fig. 1. Monthly Mean Precipitation (mm) for 4 Climate Scenarios.

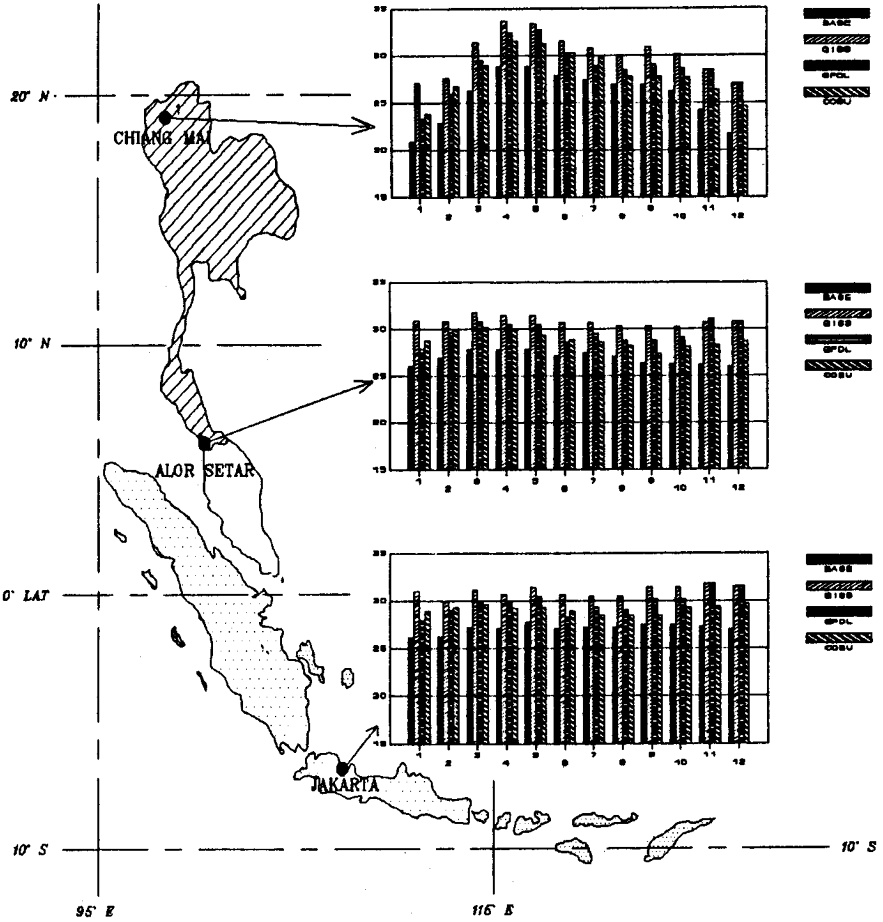


Fig. 2. Monthly Mean Temperature (°C) for 4 Climate Scenarios.

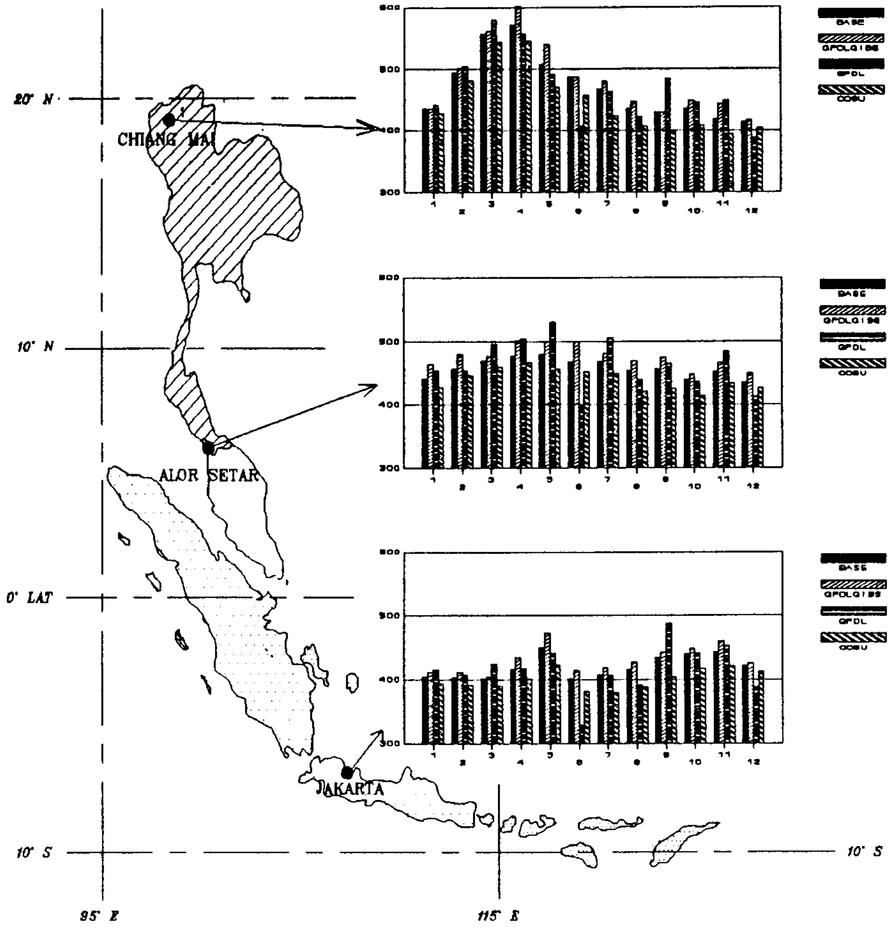


Fig. 3. Monthly Mean Radiation (LY/DAY) for 4 Climate Scenarios.

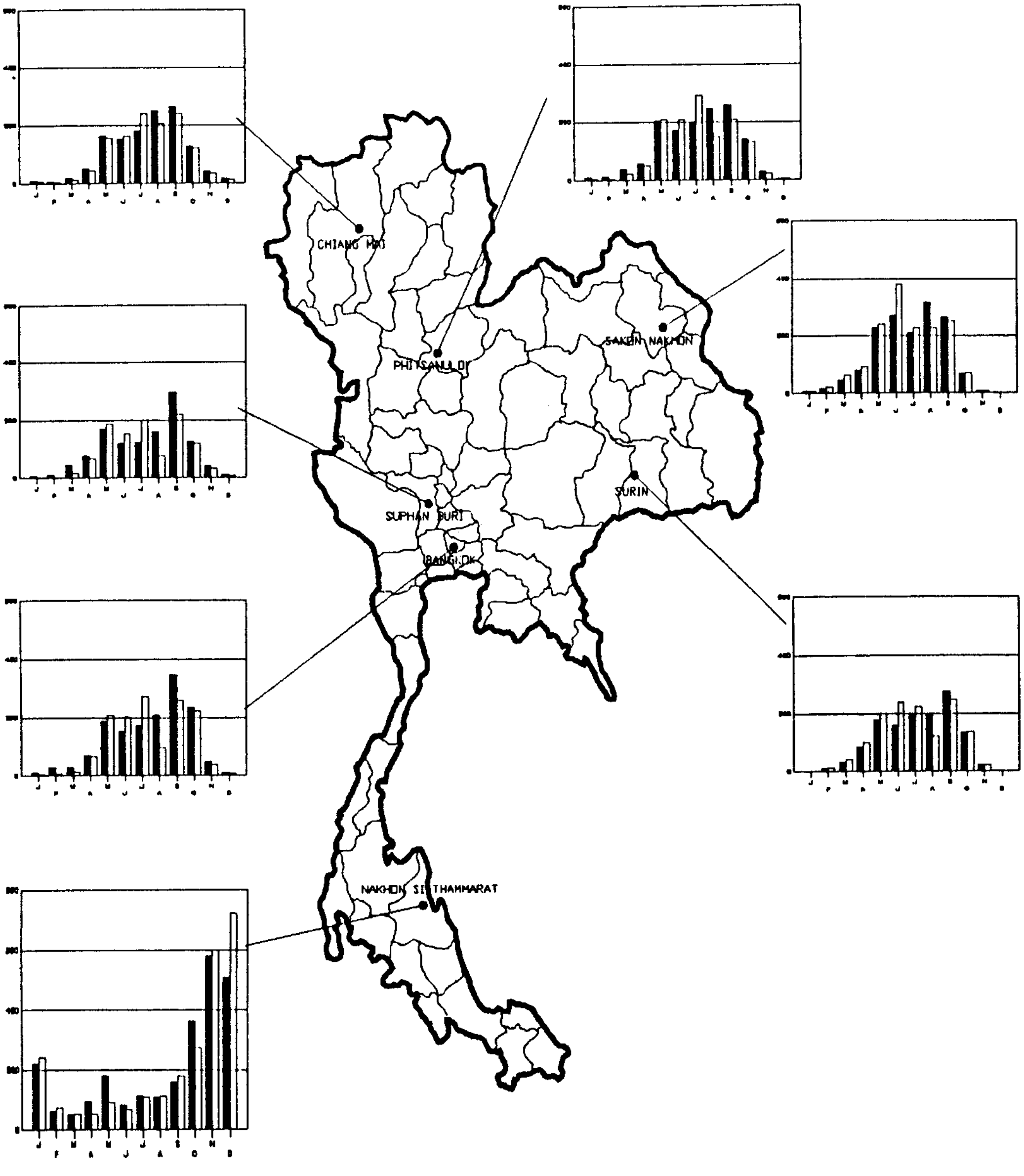


Fig. 4. Monthly Mean Precipitation (mm) Solid Bar = Base; Open Bar = Giss

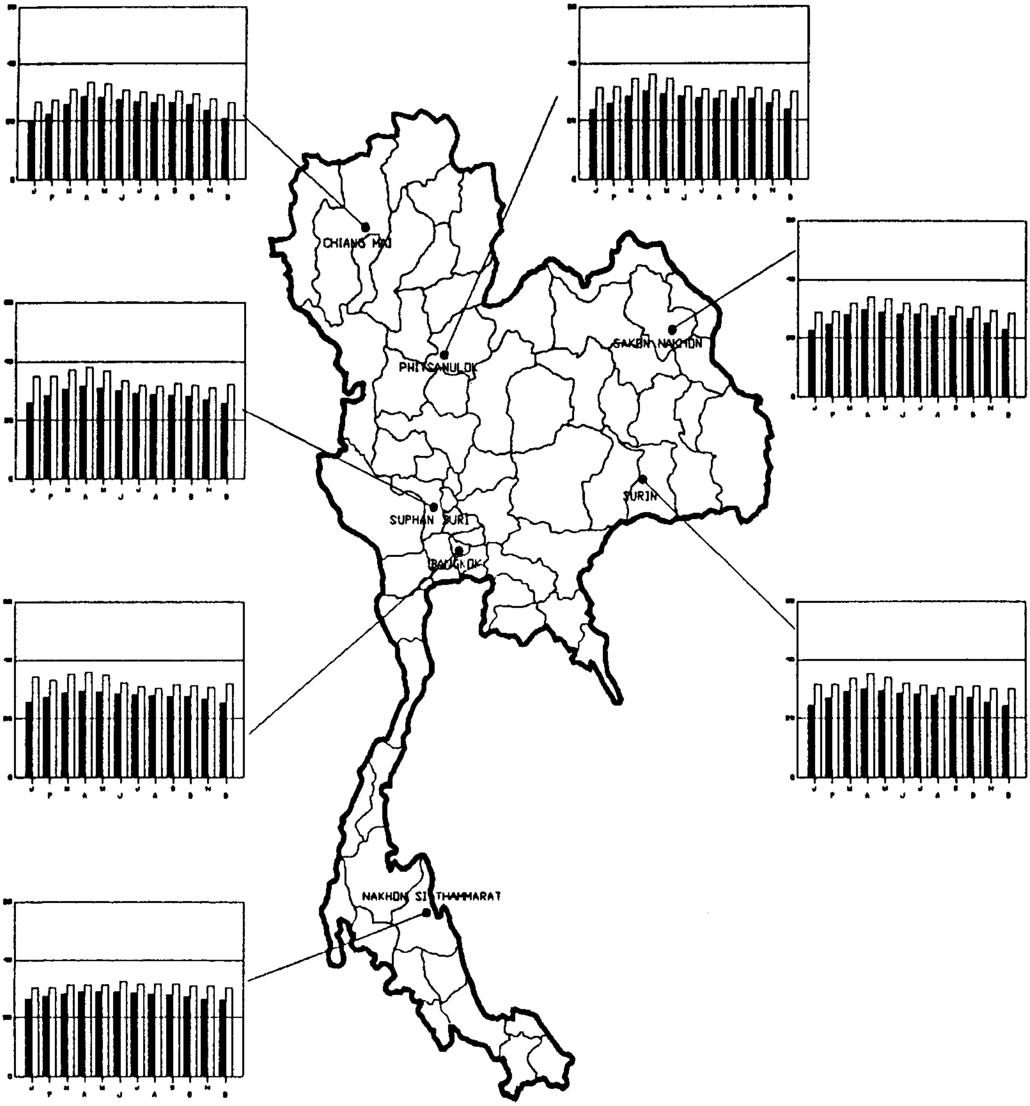


Fig. 5. Monthly Mean Temperature (Deg.c.) Solid Bar = Base; Open Bar = Giss

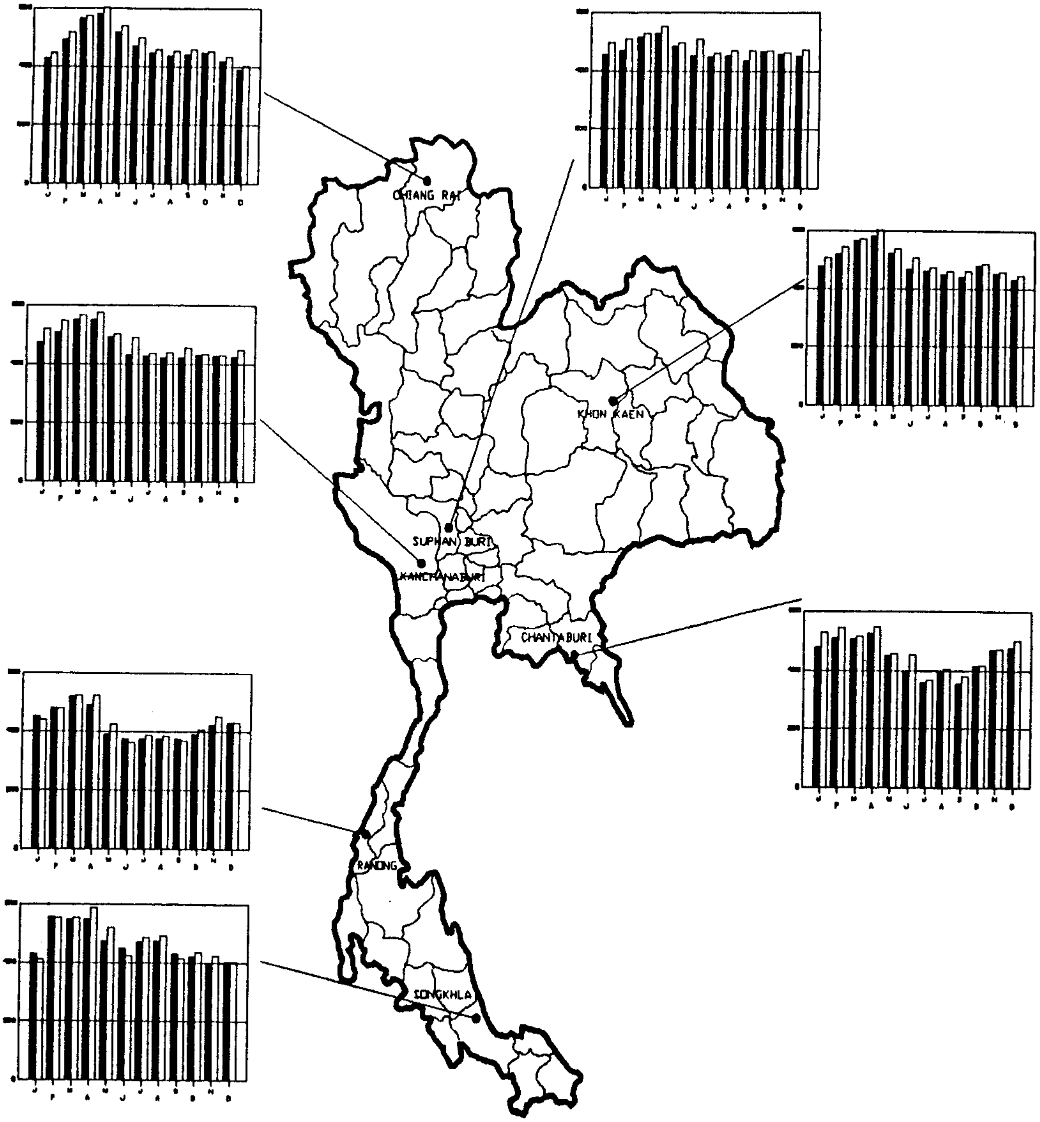


Fig. 6 Monthly Mean Radiation (LY/DAY) Solid Bar = Base; Open Bar = Giss

Figs. 4-6 represent monthly mean values of the minimum climatological data set required for an understanding of some of the results to be shown in the following climate change impact estimates. All seven selected sites are represented with monthly mean precipitation as well as monthly mean temperature for both the BASE and the GISS scenarios; while monthly mean radiation for both the BASE and the GISS scenarios are represented by 7 sites from all 4 regions close by the selected sites. The precipitation pattern in Fig. 4 shows an annual cycle for all seven sites. The precipitation amount obtained from the GISS scenario is mostly equal to or less than that obtained from the BASE except for the month of July from those sites in the North and Central, June from the Northeast and December from the South. Mean temperature obtained from the GISS in all 7 sites is significantly greater than that of the BASE. All sites except Nakhon Sri Thammarat show the temperature to increase greatly in dry season (January to April), while at Nakhon Sri Thammarat the temperature increase is nearly the same for every month. Mean radiation obtained from the GISS is significantly greater for the months of April and May for all sites except Chantaburi than that obtained from the BASE, while at Chantaburi the mean radiation obtained from the GISS is greater than that obtained from the BASE during dry season (January to April).

The Rice Model

The CERES-RICE model has been tested on minimum data sets gathered from experiments in various locations of the world. Such experiments were conducted on upland direct-seeded rice and flooded transplanted rice[10]. The CERES-RICE V2.00 simulation model developed by Godwin and Singh[5] can be used to represent transplanted or direct seeded, rainfed or irrigated, and upland or lowland cultural practices. Bunding can be designed for the paddies; fertilizer application can be imposed with respect to frequency, timing, type, depths and amounts; planting dates, sowing depth, and plant population densities can be specified; and, the straw and root biomass associated with antecedent harvesting practice can be incorporated into the soil nutrient profile. Many other parameters must be set in the model when it is being tuned to a particular site with its specific history of cultural practice and productivity.

Also, of particular relevance to the present study, the genetic characteristics of the crop which is to be simulated must be specified in terms of an 8-vector of coefficients to be discussed in detail below.

One of the strong points of this model is its simulation of the nitrogen cycle in a manner appropriate to anaerobic conditions associated with lowland (flooded) rice, but to aerobic conditions associated with upland rice.

Weak points of the model comprise its inability to account directly for the negative impacts of pests and pathogens, lodging associated with strong winds, and losses associated with harvest practices.

In summary, the versatility of the model with respect to cultural practice controls, the straightforward procedure associated with data input, and the complete, organized and extensive output data sets all combine to make this algorithm exceptionally valuable for applications studies such as the one presented in the paper.

The Genetic Coefficients Related to The Phenology

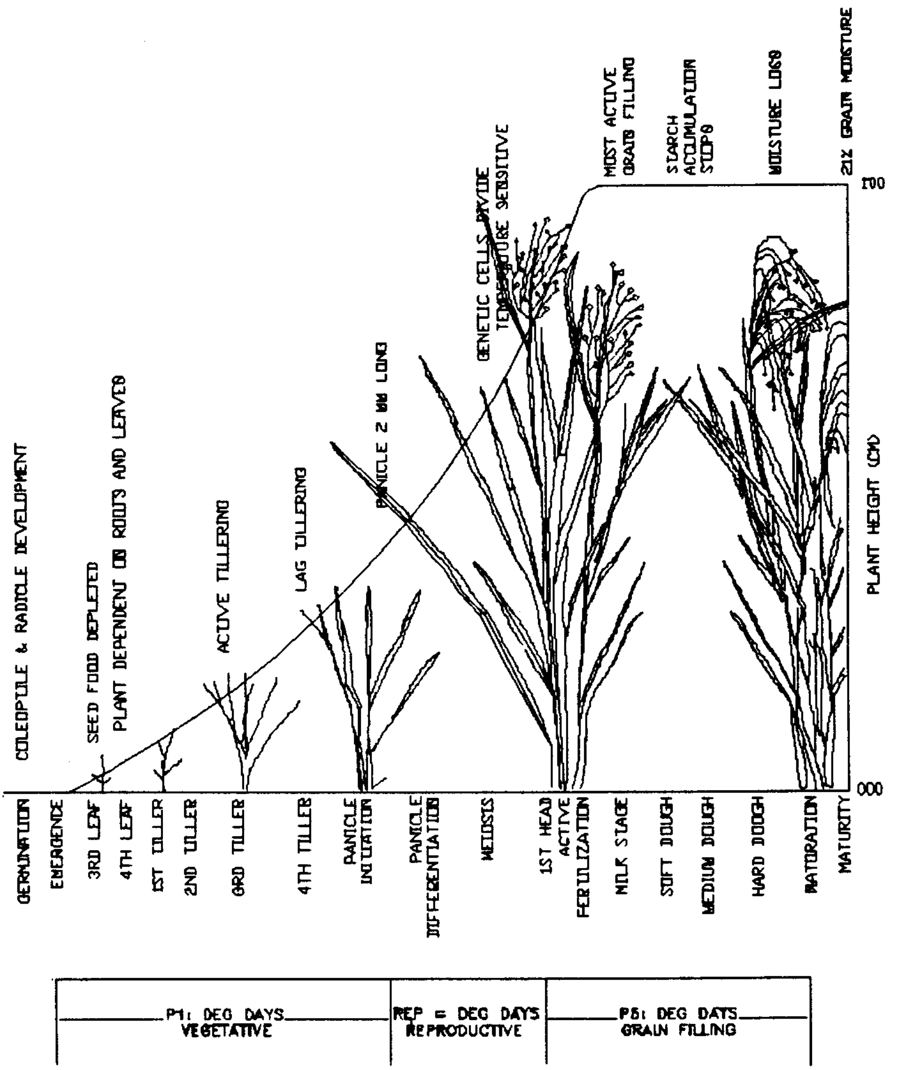
There are eight genetic coefficients used by the model to define the variety chosen for simulation. This 8-vector (P1, P2R, P5, P20, G1, G2, G3, G4) is related to the growth and development of the rice plant as illustrated in Fig. 7 (adapted from De Datta, 1981)[11]. In the present study we have set a base temperature of 8°C to be used together with the daily mean temperature to calculate the daily heat supply provided by the atmosphere to the rice plant. The coefficient P1 represents the cumulative heat (degree days above 8°C) required by the plant to progress through the vegetative phenological stages and to arrive at the reproductive stage. Thus, the calendar time required to pass through this vegetative period is a function of ambient temperature. Similarly, the coefficient P5 represents the number of degree days required for the variety selected to pass through the grain filling and maturation stages. It should be noted that the carbohydrate increase produced by the model during the grain filling period is a function of radiation. Consequently, if the temperature during this stage is increased (thereby decreasing the number of calendar days required) while the radiation is not, then the result will be a decrease in model-estimated yield.

The two coefficients P20 and P2R are used together to represent the extent to which the variety is photosensitive. P20, which characterizes the variety selected, is defined as the number of hours of civil daylight per day (DL) at panicle initiation, and is used together with P2R to define the length of the flowering period. There are three ways in which the model can be used together with a non-linear programming (NLP) technique to select an "optimal" 8-vector of genetic coefficients.

i) If a crop with unknown varietal coefficients has been grown for several years in an area where one has a record of (straw and grain) yields, cultural practice, weather and soil profile characteristics, then one can use the NLP algorithm to select that set of genetic coefficients which will minimize, for example, the variance of model-estimated straw and grain yields about their observed values. This optimization would be subject to constraints imposed by plant physiologists familiar with the area.

ii) If one wishes to select from a menu of available varieties, that variety which would optimize the straw and/or grain yield for a given soil, climate and cultural practice, one need only use the model to enumerate the model estimates one variety at a time for the period of climatic-record. One would then use the mean yield and its variance estimated by the model for each variety to study the relative risks before choosing the "best" variety.

iii) Suppose one wishes to develop a variety-defining set of genetic coefficients which would optimize yield for a given (possibly new) climate scenario, under realistic constrains imposed by a plant breeder. In this case, the desired (realistic) cultural



GENETIC COEFFICIENTS

P1 = DEGREE DAYS ABOVE 8° C
P5 = DEGREE DAYS ABOVE 8° C
P20 = OPTIMUM PHOTO PERIOD;HRS
DL = CIVIL DAYLIGHT FOR LAT;HRS
REP = NOT PHOTO SENSITIVE DEG DAYS
+ P2R*(DL-P20)
P2R = DEG DAYS PER HOUR

G1 = POTENTIAL GRAIN NUMBER
G2 = KERNEL WEIGHT (GRAMS/KERNEL)
G3 = TILLERING FACTOR
G4 <1 JAPONICA = LOW TEMP
=1 NON-JAPONICA = HIGH TEMP

Fig. 7. Rice Genetic Coefficients Related to Phenology (Adapted from De Datta, 1981).

practice could be specified for the chosen site (and soil), and the NLP algorithm could be run using the given climate scenario subject to the imposed genetic coeffiecient constraints. Optimization criteria could be profit maximization or risk minimization depending, for example, on factors such as whether the rice were to be grown as a cash crop or as a food crop.

It is this third use of the RICE MODEL yield optimization technique which we will now illustrate.

Optimizing The Genetic Cofficients

Pitsanulok in the northern region of Thailand has been chosen as the site to illustrate the methodology used to test the value of changing a subset of the genetic coefficients in order to improve the yield characteristics of the rice grown in that area. We would like to select a variety of rice (or to breed a new one) which would increase the long term (say 20 year) mean rice yield while at the same time decrease its variance. In this sense, we would like to discover what set of genetic coefficients would be best suited to the current climate, and also what set would be best suited to a future (in our case, the GISS $2\times CO_2$) climate.

Figs. 8, 9, and 10 will be used to illustrate some of the important features of our approach to achieving such "varietal characteristic optimization". Each point on the 5×5×5 3-dimensional arrays in Figs. 8 and 10 represents a mean value of rice yield associated with a 20-year run of the rice model. Thus these two figures are to be used to compare 2500 years of rice "grown" under the BASE climate scenario with 2500 years of rice "grown" under the GISS climate scenario. Fig. 9 represents the standard deviation associated with Fig. 8.

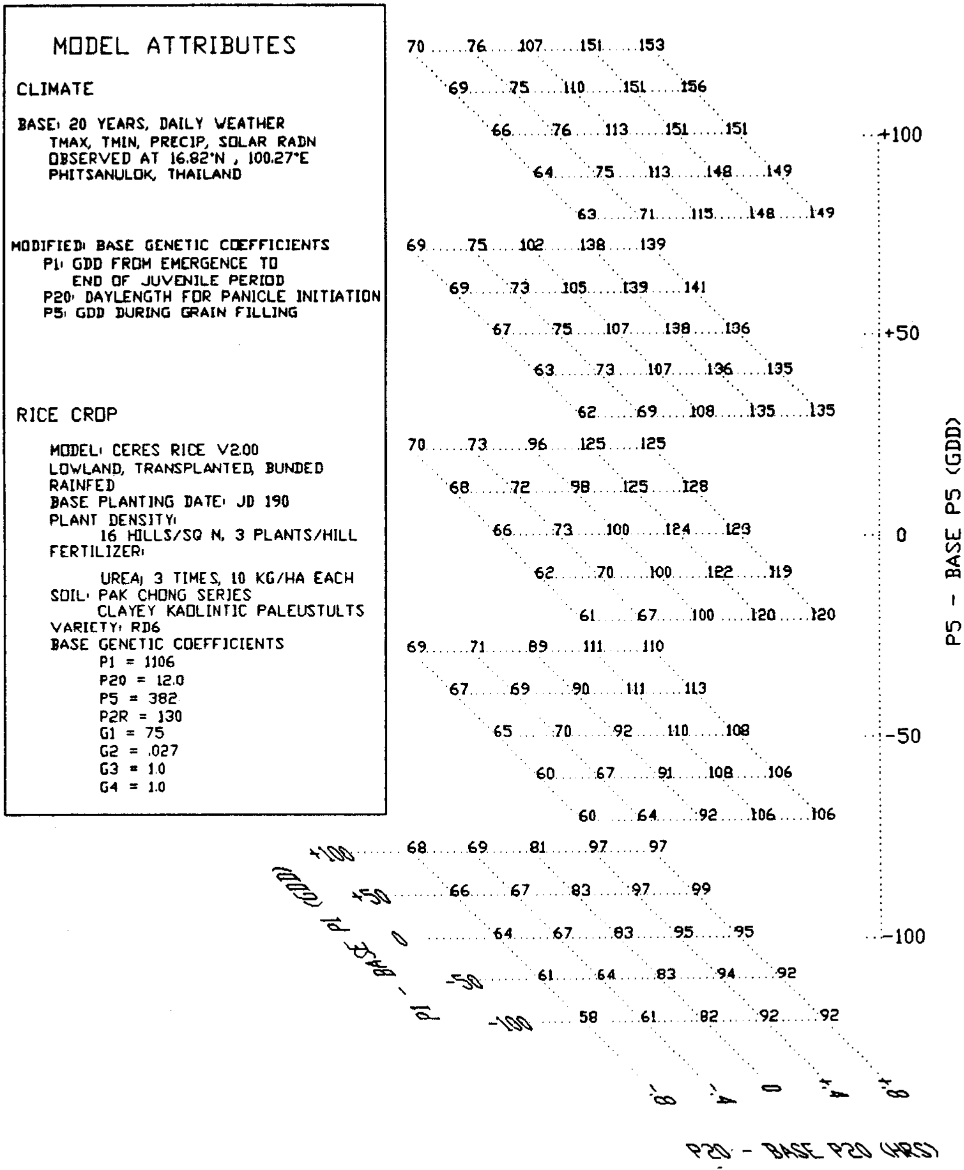
The three axes represent deviations of the three genetic coefficients (P20, P1, P5) from a set of base coefficients which is shown in the box on the left side of the figure and used to describe the RD6 variety which is grown in the area. The entries shown in the arrays have been normalized as follows. (Note: at the center point (0,0,0), P20 = 12.0 hrs, P1 = 1106 deg. days, P5 = 382 deg. days.)

In Fig. 8 each of the 125 20-year mean yields has been divided by the mean yield at the center point (0,0,0) and then multiplied by 100.

In Fig. 9, each of the 125 standard deviations associated with the mean values of Fig. 8, has been divided by the standard deviation at the center point (0,0,0) and then multiplied by 100.

In Fig. 10, the output from these GISS scenario runs has been treated in the same manner as was the BASE scenario output for Fig. 8.

Although the model input parameters are given on these figures, there are two additional farm practice related medel constraints which vary with P20, P2, and P5. Since P20 governs the flowering date in this photosensitive variety (RD6), and since P1 specifies the length of the vegetative period (see Fig. 7), the sowing date has been made



MODEL ATTRIBUTES

CLIMATE

BASE: 20 YEARS, DAILY WEATHER
TMAX, TMIN, PRECIP, SOLAR RADN
OBSERVED AT 16.82°N , 100.27°E
PHITSANULOK, THAILAND

MODIFIED: BASE GENETIC COEFFICIENTS
P1: GDD FROM EMERGENCE TO
END OF JUVENILE PERIOD
P20: DAYLENGTH FOR PANICLE INITIATION
P5: GDD DURING GRAIN FILLING

RICE CROP

MODEL: CERES RICE V2.00
LOWLAND, TRANSPLANTED, BUNDED
RAINFED
BASE PLANTING DATE: JD 190
PLANT DENSITY:
16 HILLS/SQ M, 3 PLANTS/HILL
FERTILIZER:
UREA; 3 TIMES, 10 KG/HA EACH
SOIL: PAK CHONG SERIES
CLAYEY KAOLINTIC PALEUSTULTS
VARIETY: RD6
BASE GENETIC COEFFICIENTS
P1 = 1106
P20 = 12.0
P5 = 382
P2R = 130
G1 = 75
G2 = .027
G3 = 1.0
G4 = 1.0

3-DIMENSIONAL ARRAY VALUES REPRESENT:

-100 * MODIFIED GENETICS CROP STATISTIC/BASE CLIMATE CROP STATISTIC

-STATISTIC PLOTTED: 20 YEAR MEAN YIELD RATIOS * 100

Fig. 8. Model Estimates of Impacts on Rice Production Given Specific Changes in The Genetic Coefficients as Indicated Sowing Date and Fertilizer Application Dates Determined by Modified P1 and P20

MODEL ATTRIBUTES

CLIMATE

BASE: 20 YEARS, DAILY WEATHER
TMAX, TMIN, PRECIP, SOLAR RADN
OBSERVED AT 16.82°N , 100.27°E
PHITSANULOK, THAILAND

MODIFIED: BASE GENETIC COEFFICIENTS
P1: GDD FROM EMERGENCE TO
END OF JUVENILE PERIOD
P20: DAYLENGTH FOR PANICLE INITIATION
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RICE CROP

MODEL: CERES RICE V2.00
LOWLAND, TRANSPLANTED, BUNDED
RAINFED
BASE PLANTING DATE: JD 190
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UREA; 3 TIMES, 10 KG/HA EACH
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CLAYEY KAOLINTIC PALEUSTULTS
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BASE GENETIC COEFFICIENTS
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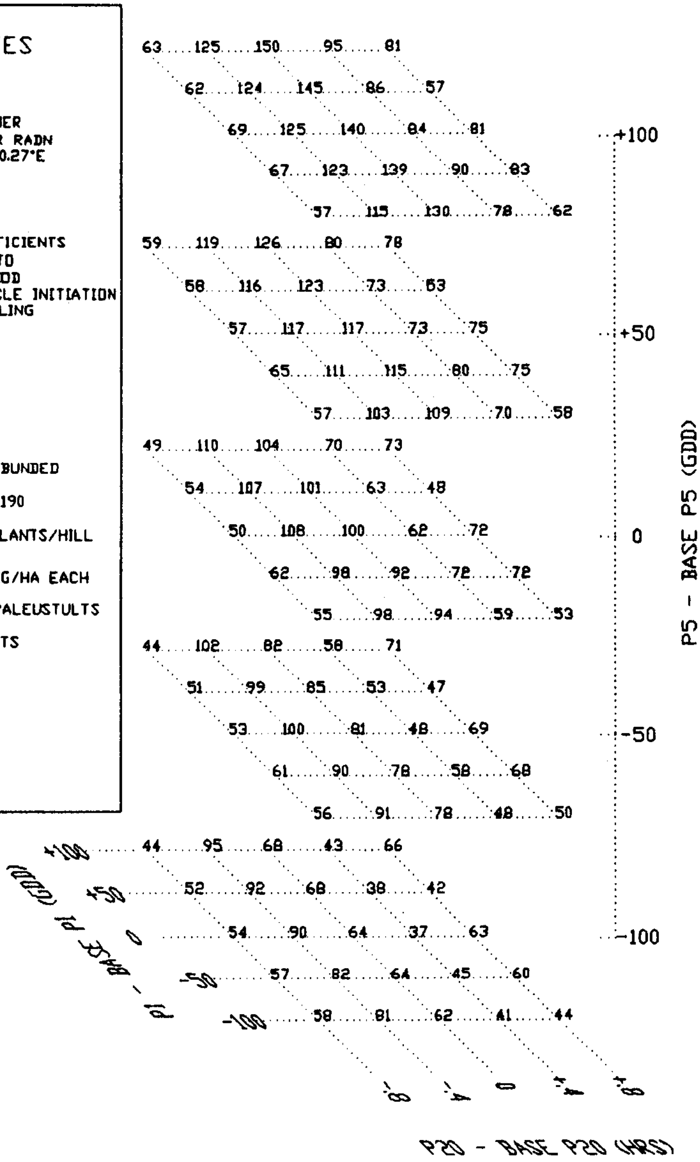


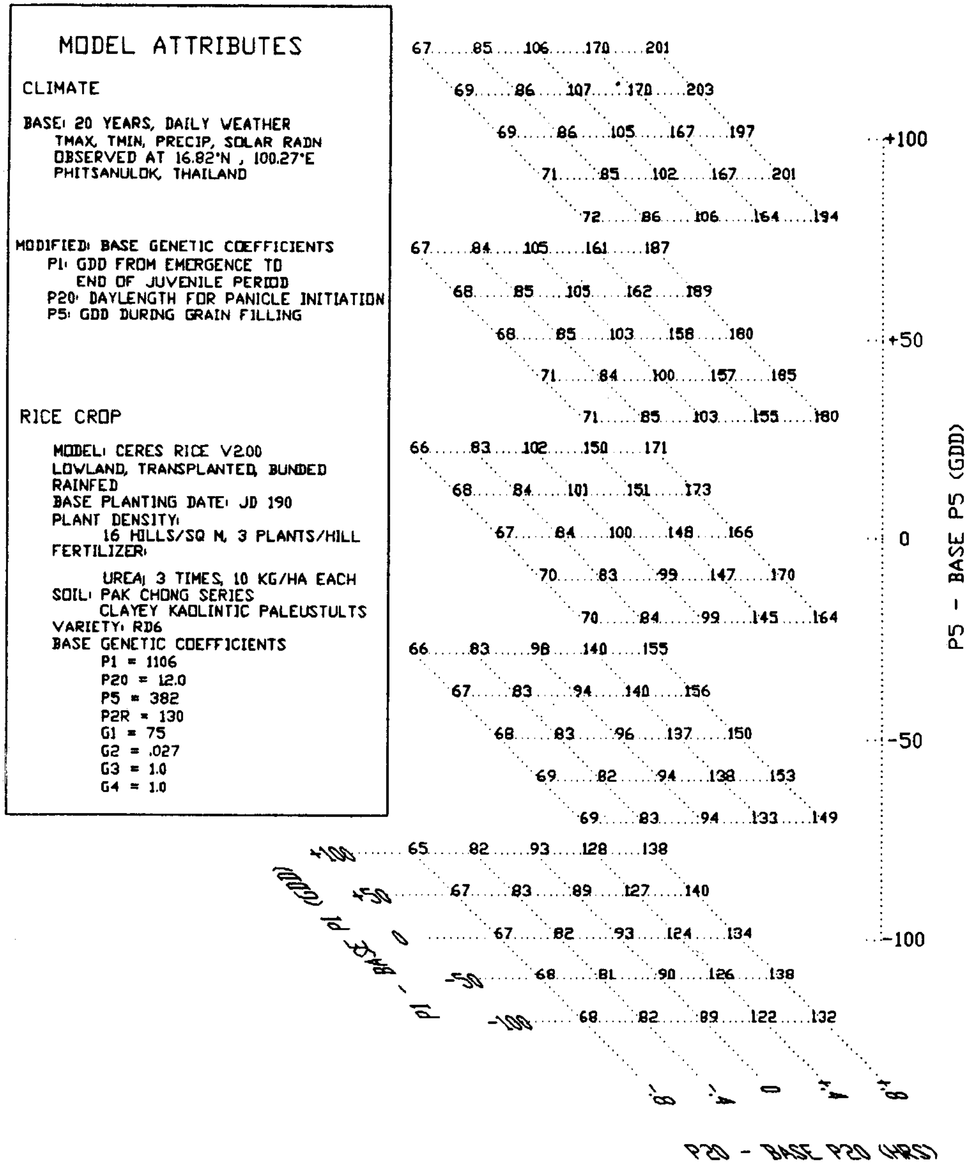
P5 - BASE P5 (GDD)	P1 - BASE P1 (GDD)	-8	-4	0	+4	+8
+100	+100	63	125	150	95	81
	+50	62	124	145	86	57
	0	69	125	140	84	81
	-50	67	123	139	90	83
	-100	57	115	130	78	62
+50	+100	59	119	126	80	78
	+50	58	116	123	73	63
	0	57	117	117	73	75
	-50	65	111	115	80	75
	-100	57	103	109	70	58
0	+100	49	110	104	70	73
	+50	54	107	101	63	48
	0	50	108	100	62	72
	-50	62	98	92	72	72
	-100	55	98	94	59	53
-50	+100	44	102	82	58	71
	+50	51	99	85	53	47
	0	53	100	81	48	69
	-50	61	90	78	58	68
	-100	56	91	78	48	50
-100	+100	44	95	68	43	66
	+50	52	92	68	38	42
	0	54	90	64	37	63
	-50	57	82	64	45	60
	-100	58	81	62	41	44

3-DIMENSIONAL ARRAY VALUES REPRESENT:

-100 * MODIFIED GENETICS CROP STATISTIC/BASE CLIMATE CROP STATISTIC

-STATISTIC PLOTTED: STANDARD DEVIATION RATIOS * 100

Fig. 9. Model Estimates of Impacts on Rice Production Given Specific Changes in The Genetic Coefficients as Indicated Sowing Date and Fertilizer Application Dates Determined by Modified P1 and P20



MODEL ATTRIBUTES

CLIMATE

BASE: 20 YEARS, DAILY WEATHER
TMAX, TMIN, PRECIP, SOLAR RADN
OBSERVED AT 16.82°N , 100.27°E
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BASE PLANTING DATE: JD 190
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SOIL: PAK CHONG SERIES
CLAYEY KAOLINTIC PALEUSTULTS
VARIETY: RD6
BASE GENETIC COEFFICIENTS
P1 = 1106
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P5 = 382
P2R = 130
G1 = 75
G2 = .027
G3 = 1.0
G4 = 1.0

3-DIMENSIONAL ARRAY VALUES REPRESENT:

-100 * MODIFIED GENETICS CROP STATISTIC/GISS CLIMATE CROP STATISTIC

-STATISTIC PLOTTED: 20 YEAR MEAN YIELD RATIOS * 100

Fig. 10. Model Estimates of Impacts on Rice Production Given Specific Changes in The Genetic Coefficients as Indicated Sowing Date and Fertilizer Application Dates Determined by Modified P1 and P20

compatible with these two variables at the beginning of each 20-year run. It is the 20-year mean value of P1 for the climate scenario input, which is used together with the date implied by P20 to calculate the average sowing date. The fertilizer application schedule is also controlled by the sowing dates and the date of the end of the vegetative period; consequently, this set of input parameters is also recalculated at the beginning of each 20-year run segment of the program. Each run of 2500 crop years such as is illustrated in Fig. 8 required about 15 hours of running time on a 10 mega hertz 80286/287 PC.

The following information can be drawn from the presentations of rice model output shown in these three figures, given the soil, cultural practice, and climate assigned to this site in northern Thailand.

i) Greater mean yields under both the GISS and the BASE climate scenarios could be expected from a variety which flowered earlier and had a longer grain filling period than that of RD6 (as represented by our basic set of P1, P20, P5 coefficients).

ii) Changing the length of the vegetative period seems not to have had much impact on the 20-year mean yields; however, the yield variability does seem to increase as the time between transplanting and panicle initiation increases.

iii) The rate of increase in mean yield, as one increases P20 and P5, is greater in the case of the GISS climate scenario than it is in the case of the BASE climate scenario.

In order to compare Fig. 8 with Fig. 10 in terms of actual yield estimates, one must know that the yield associated with the center reference point (0,0,0) on Fig. 10 is only 71.5% as large as the estimate at point (0,0,0) in Fig. 8.

One reason for the results mentioned in i) above is associated with the fact that a larger value of P20 leads to an earlier sowing (and hence, transplanting) date, which then makes better use of the rainy season (see Fig. 4).

Also, one of the reasons for the result mentioned in iii) above is associated with the increased use of the enhanced radiation during grain filling shown in Fig. 6 to be available earlier in the growing season under the GISS scenario.

Clearly, Figs. 8 and 9 represent simply some of the attributes of a 3-space starting vector for an NLP (non-linear programming) solution to an optimization algorithm. Such an algorithm also requires an objective function to evaluate convergence toward a solution. In order to provide for an incorporation into an objective function of the relative merits of mean yield increase and yield variability decrease, we have used (at present in a subjective manner) the coefficient of variation of model output yield estimates as a criterion for selecting the coefficients which would define the *Improved Varieties* to be examined in the following section. The more objective NLP optimization will comprise the next, much more extensive, step in our research.

Illustrative Results

The methodology described in section III was used to obtain the model output yield data which went into the production of Figs. 11 and 12.

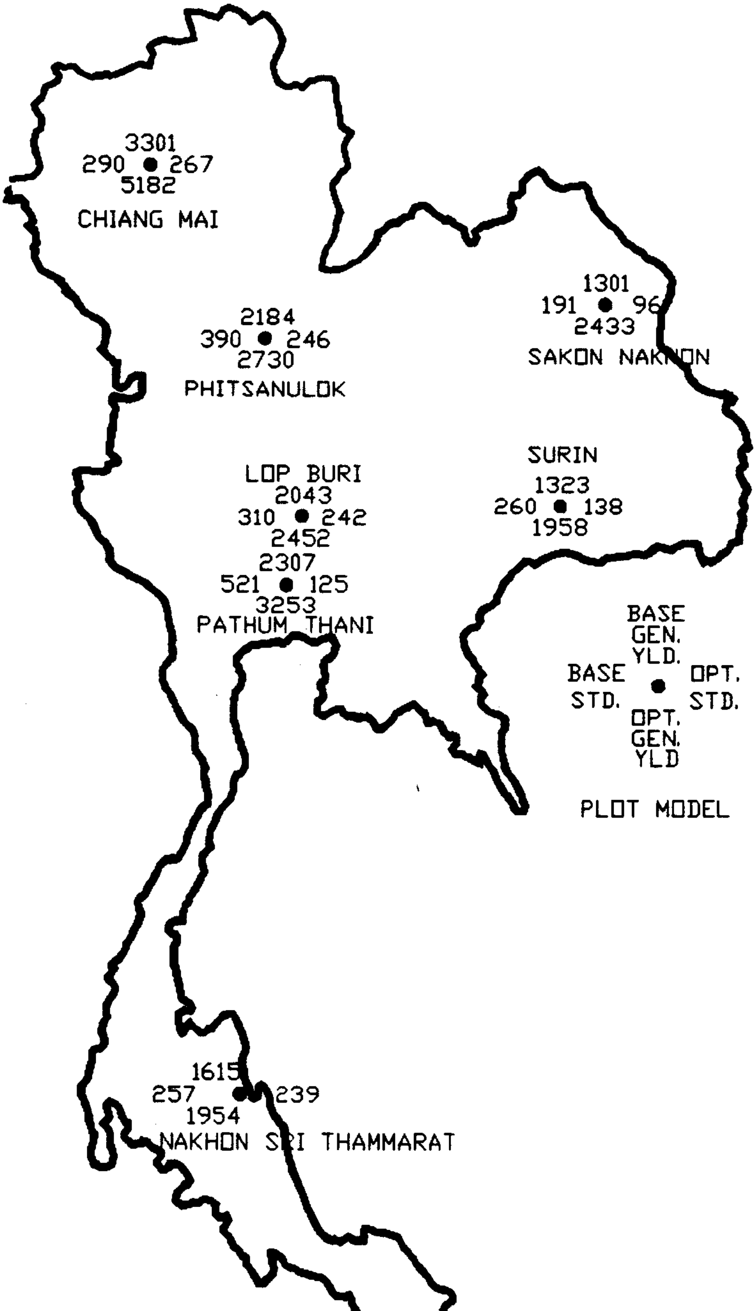


Fig. 11. Base Climate Data Yields (KG/HA) Model Output Scaled Via Observed Mean Yields (1973-1988)

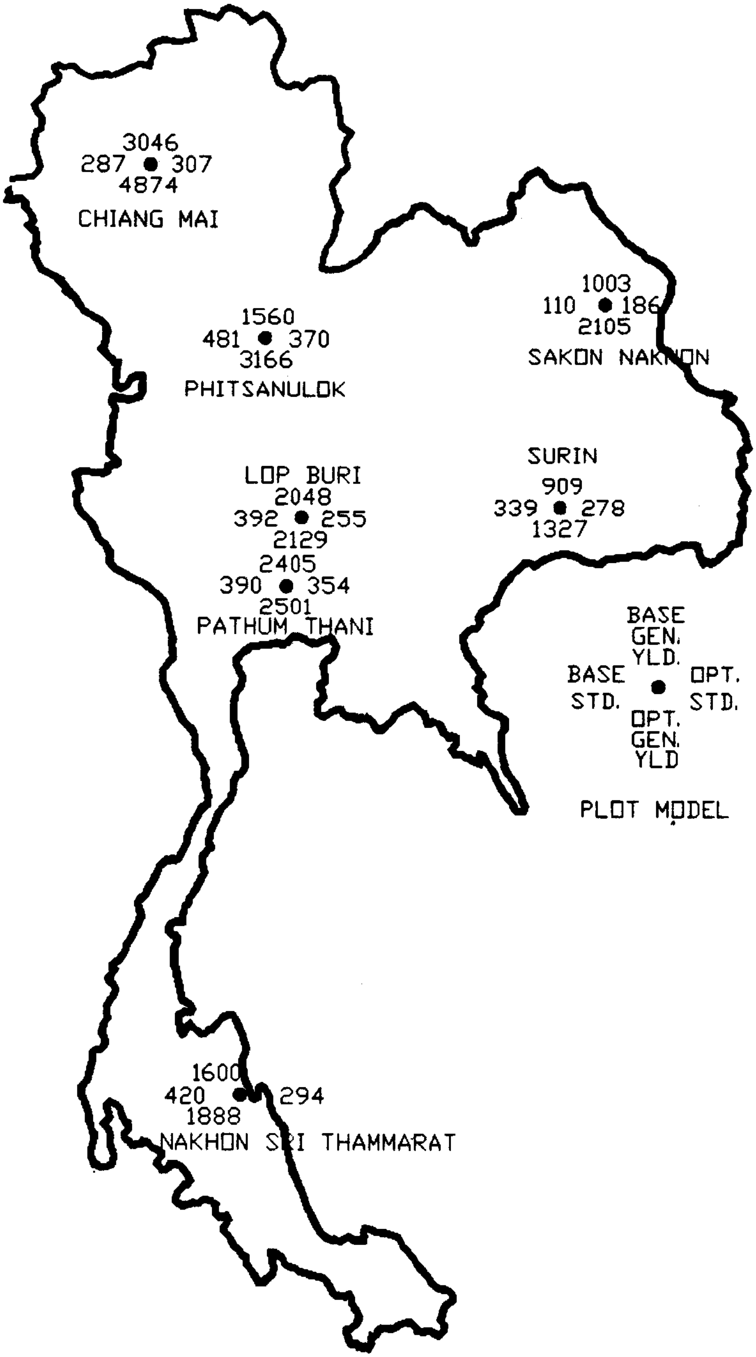


Fig. 12. Giss Climate Data Yields (KG/HA) Model Output Scaled Via Observed Mean Yields (1973-1988)

In order to constrain the variability within and among stations to be (insofar as this was possible) the consequence of influences exerted by the climate scenarios, we have kept the following features common to all runs:

- the soil profile,
- the transplanting option,
- the bunded paddy option, and
- most of the cultural practice options (the exceptions being sowing (and so, transplanting) and fertilization dates).

The model output yields and their standard deviations were calibrated using the 16-year time series (1973-1988) of province-level reported yields (production/harvested area) for the province in which each model site was located. Thus, in the case of the BASE climate scenario runs for Chiang Mai, the 20-year model run mean for the basic genetics (point 0,0,0) was scaled to be 3301 kg/ha and its standard deviation to be 290 kg/ha (see Fig. 11). The *Improved Variety* for this same site, again under the present (BASE) climate was found to have a 20-year (scaled) mean yield of 5182 kg/ha and a standard deviation of 267 kg/ha.

Fig. 12 shows the same type of results for the GISS scenario runs.

Further, following the Chiang Mai results, if the same variety and cultural practice "currently" applied were to find continued application into a GISS climate regime, then the mean yield could be expected to drop to about 92.3% of its present value. However, if the "improved" variety which we designed for the GISS climate with its associated changes in sowing date and fertilizer application dates) were to be planted when a GISS scenario prevailed, then the mean yield would increase to about 148% of its present value.

Figs. 11 and 12 show some interesting variations in the impact of our climate change scenario across Thailand.

It is seen from Fig. 11 that at present the mean yield in the two provinces shown in the central region is between 2.0 and 2.5 tons/ha; in the northern province of Chiang Mai it is about 50% higher than this; and, in the northeastern region it averages about 40% lower. Continued use of the currently planted varieties and cultural practice into a GISS climate would find little change in the mean yields in the central and southern regions; however, such continued use in the northern and northeastern regions would bring about significant decreases in yields, as can be seen by comparing Figs. 11 and 12.

Although it might be tempting to draw conclusions concerning the geographical variations in climate change impacts based on the above results, considerable caution must be exercised. The impacts shown can be as readily produced by differences in sowing date and in the genetic coefficients as they can in the changes between climate scenarios. This means that the actual climate change impacts must comprise a careful composite of all varieties grown in an area and under the actual cultural practices employed, in order to approach an expression of potential reality. Our present study is a first step in this direction; but it does show that the job can be done.

Table 1 shows the varieties currently used at the sites selected, as well as the ones chosen for our study.

TABLE 1. Major Rice Varieties of Rice Used at Sites Chosen

Site	Varieties Planted (Selected Subset)	Variety Chosen For Present Study
Chiang Mai	RD6, RD15, KDML105	RD6
Phitsanulok	RD6, KDML105	RD6
Sakon Nakhon	RD6, RD15	RD15
Surin	RD6, RD15	RD15
Lop Buri	RD15, KTH17	KTH17
Pathum Thani	LPT123, KTH17, KDML105	LPT123
Nakhon Sri Thammarat	RD13, NPY132	NPY132

Aggregating to The National Level

The sites discussed above will now be used to represent over 90% of the rice productivity in Thailand. This statement represents the result obtained from the following rather simplistic procedure.

1. The sites selected were constrained to:

– be closely related to experimental station data which could represent the cultural practice, soils, and varietal characteristics of the surrounding area,

– be represented from a climatological point of view by daily weather data from a nearby station of the Thailand Meteorological Department and covering at least a 20-year time period, and,

– be numerous enough to represent adequately all of the four regional subdivisions of the nation.

2. Complete time series (1973-1988) for major rice yield (calculated from production and harvested area) were obtained[1] for all 73 provinces and were grouped into the following four commonly designated regions: Northern, Northeastern, Central, and Southern. Simple correlations among all stations within each region were calculated both from the raw 16-year time series, and from the time series with the linear time trends for each first removed. Those provinces whose "observed yield" time series showed a significant correlation with the yield time series of the nearest site (described above) were assigned to be represented by the model output for that site. Both sets of correlation coefficients were used in this determination, although in the few cases of disagreement the set obtained from the series containing the technological trend was the deciding factor.

3. The seven selected subsets totalling 54 of the 73 provinces in the nation, were found by the above method to represent 91.16% of the major rice grown in Thailand in the 1988/89 season.

It is clear that there are much more sophisticated statistical approaches to solving the site selection/aggregation problem than the simple pragmatic methodology used here. We have used some of these in other studies of a similar nature[6], and plan eventually to incorporate the appropriate methodology into the current research. Nonetheless, the method presented above is adequate for our current illustrative purpose.

Potential National Economic Impact of Climate Change on Major Rice Production

Next we convert our geographically distributed major rice production changes into economic terms, and then aggregate these to the national level. As our monetary reference point we take the 1988/89 farm value (National Total) of major rice to be 73000 million baht[1]. We consider the following 3 strategies with respect to rice production under the BASE and GISS climate scenarios:

i) plant the optimal variety in each area under current conditions,

ii) plant the current varieties under both climates, and

iii) plant the current variety for the BASE climate but plant the optimal variety under the GISS climate.

We use Fig. 13 to answer the questions implied by all three strategies as far as major rice production is concerned, and to address strategies i) and iii) as far as the economic impact potential is concerned.

From the figure it is clear that, even under the present climate regime, there would be a considerable advantage associated with planting varieties whose genetic characteristics (as represented by P1, P20, P5) were more appropriate than those we have chosen, given that the optimal planting and fertilizer application practices were followed. The **economic gain** at the National level following strategy i) would be about 41% (30000 million baht/year), with most of this being realized in the Northern and Northeastern regions.

Under strategy ii), the change to a GISS climate scenario would result in a considerable loss in major rice production in the Northern and Northeastern regions. Over the remainder of the country not much change would result, based on the results from our rice model input configuration. The National level **economic loss** from following this strategy would be about 16% (11500 million baht/year).

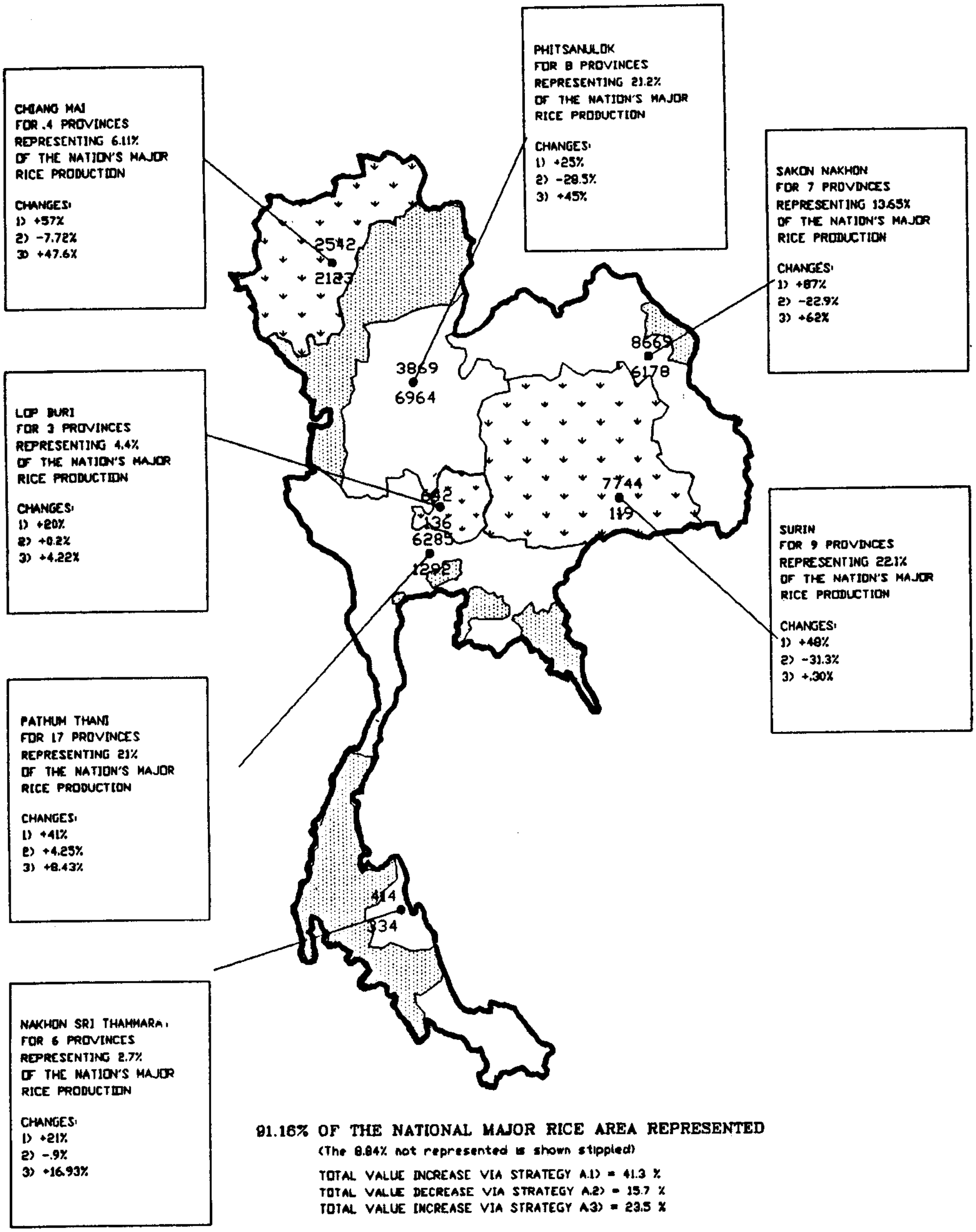
Under strategy iii) if we continued to use the same varieties and cultural practice under the present climate, but conducted a plant breeding (and/or selection) program to permit the planting of optimal varieties (with optimal farm cultural practice) under a future GISS climate, then instead of a loss of 11500 million baht/year we could anticipate an **economic gain** of about 17000 million baht/year (23.5%). In this case once again, the largest gains could come from the Northern and Northeastern geographical areas of the country.

The above impacts constitute **direct effects** which could be entered into the appropriate sectors of a suitably disaggregated input-output economic model for the country in order to obtain multiplier effects and final demand information with respect to the gross domestic product. The consequences of such investigations based on weather-related impacts have been reported, for example, by Grubb[12] and by Cooter[13].

Policy Implications

The first inference to be drawn from our results our results is that considerable national benefits would accrue from the completion of a more comprehensive study concerning the optimization of rice farming practice under **the present climate.** A policy which would promote more extensive rice breeding in response to climate impacts such as those presented and which would enhance farmer-related extension services to bring about optimal cultural practices would be cost beneficial.

The second inference to be drawn is that if no appropriate action is taken, then a change to a GISS-type climate could quite likely decrease the national major rice production significantly.



CHIANG MAI
FOR .4 PROVINCES
REPRESENTING 6.11%
OF THE NATION'S MAJOR
RICE PRODUCTION

CHANGES:
1) +57%
2) -7.72%
3) +47.6%

PHITSANULOK
FOR 8 PROVINCES
REPRESENTING 21.2%
OF THE NATION'S MAJOR
RICE PRODUCTION

CHANGES:
1) +25%
2) -28.5%
3) +45%

SAKON NAKHON
FOR 7 PROVINCES
REPRESENTING 13.65%
OF THE NATION'S MAJOR
RICE PRODUCTION

CHANGES:
1) +87%
2) -22.9%
3) +62%

LOP BURI
FOR 3 PROVINCES
REPRESENTING 4.4%
OF THE NATION'S MAJOR
RICE PRODUCTION

CHANGES:
1) +20%
2) +0.2%
3) +4.22%

SURIN
FOR 9 PROVINCES
REPRESENTING 22.1%
OF THE NATION'S MAJOR
RICE PRODUCTION

CHANGES:
1) +48%
2) -31.3%
3) +.30%

PATHUM THANI
FOR 17 PROVINCES
REPRESENTING 21%
OF THE NATION'S MAJOR
RICE PRODUCTION

CHANGES:
1) +41%
2) +4.25%
3) +8.43%

NAKHON SRI THAMMARA:
FOR 6 PROVINCES
REPRESENTING 2.7%
OF THE NATION'S MAJOR
RICE PRODUCTION

CHANGES:
1) +21%
2) -.9%
3) +16.93%

91.16% OF THE NATIONAL MAJOR RICE AREA REPRESENTED
(The 8.84% not represented is shown stippled)

TOTAL VALUE INCREASE VIA STRATEGY A.1) = 41.3 %
TOTAL VALUE DECREASE VIA STRATEGY A.2) = 15.7 %
TOTAL VALUE INCREASE VIA STRATEGY A3) = 23.5 %

Fig. 13. Rainfed Paddy Major Rice Model Estimates
A. Yield Changes Shown in Boxes:
1) Planting Optimal Variety Under Current Conditions
2) Planting Current Variety Under Both Climates
3) Planting Current Variety for Base Climate and Optimal Variety for Giss Climate
B. Crop Value Changes Shown on Map in Million Baht/Year:
Above ● Following A.1) Strategy
Below ● Following A.3) Strategy

The third clear implication of our study is that any climate change impacts on rice production in Thailand brought about by a GISS-type scenario can be offset by a policy which would insure careful advance planning in the areas of rice breeding and extension service farm practice information dissemination.

Thailand is a major rice exporting country. What would be the possible change in the demand for these exports brought about by a GISS-type climate change in the ASEAN region? We produced the results shown in Table 2 as a suggestive "first response" to this question. These figures indicate that an absence of the appropriate policy response in the countries shown would produce an increased demand for Thai rice, should it be available.

TABLE 2: Potential Impacts of a Type Climate Change on Rice Production in The Countries Shown

Site	Percent Model-Estimated Change In Rice Production From Present
Nakhon Sri Thammarat, Thailand	−0.9%
Manila, Philippines	−0.8%
Saigon, Vietnam	−5.6%
Alor Setar, Malaysia	−7.5%
Jakarta, Indonesia	−4.7%

Conclusions

The results of our study seem to warrant the following inferences.

i) Decreases in rice production in Southeast Asia, as implied by the GISS GCM $2 \times CO_2$ climate change scenario, can be more than overcome if appropriate and timely actions are taken by the agricultural community.

ii) A national policy which would enhance such activity in the rice breeding and agricultural extension services would be cost beneficial.

iii) Optimization procedures such as the one implied in the above work require the incorporation of a policy-relevant value system. This means that if the results are to be of objective and quantitative value to the policy maker's decision making process, then he and his colleagues (economists, resource managers, social scientists, etc.) must be involved in, and provide vital input to, the analysis activity as the project evolves.

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บทคัดย่อ

ข้าวเป็นแหล่งอาหารที่สำคัญของคน เพาะปลูกกันมากในแถบเอเชียตะวันออกเฉียงใต้ ประเทศไทยปลูกข้าวมากเป็นอันดับที่ห้าของโลก ผลผลิตข้าวของไทยและพม่าต่อจำนวนประชากรอยู่ในอันดับสูงสุด คือประมาณปีละ 1/3 ตันต่อคน พื้นที่ที่ใช้ในการปลูกข้าวของไทย เป็นประมาณหนึ่งในสี่ของพื้นที่เพาะปลูกทั้งหมด ในปี 2531 สินค้าข้าวคิดเป็นร้อยละ 12.6 ของผลผลิตมวลรวม และเป็นร้อยละ 8.6 ของสินค้าส่งออกของไทย ข้อมูลเหล่านี้ชี้ให้เห็นถึงความสำคัญทั้งในระดับภูมิภาคและระดับประเทศ ที่ไทยควรจะมีนโยบายที่จะเพิ่มผลผลิตข้าวที่อาจจะลดลงเนื่องจากการเปลี่ยนสภาพอากาศในแต่ละท้องถิ่น

ความเป็นไปได้ในการเปลี่ยนสภาพอากาศ สรุปจากสามรูปแบบของลักษณะอากาศของโลกได้ถูกนำมาแสดงไว้ โดยได้เลือกศึกษาเฉพาะลักษณะอากาศที่มีผลกระทบต่อผลผลิตข้าว ในการคาดคะเนผลผลิต ปัจจัยสี่ประการได้ถูกนำมาพิจารณาโดยใช้โปรแกรมคอมพิวเตอร์ ปัจจัยเหล่านี้ได้แก่ วิธีการเพาะปลูก ลักษณะดิน สภาพอากาศ และพันธุ์ข้าวที่ใช้ปลูก

บทความเรื่องนี้ได้แสดงให้เห็นว่า การเปลี่ยนสภาพอากาศสามารถนำมาใช้ในกรณีของข้าว ในการสร้างข้อมูลที่เกี่ยวกับลักษณะทางพันธุกรรมที่มีผลต่อการคาดคะเนผลผลิต วิธีการนี้ได้ใช้ดัดแปลงลักษณะทางพันธุกรรมของข้าวพันธุ์ต่าง ๆ โดยการปลูกในพื้นที่ 7 แห่งทั่วประเทศไทย เพื่อที่จะคัดเลือกพันธุ์ที่ให้ผลผลิตสูงในสภาพอากาศของท้องถิ่นนั้น ๆ โดยจะต้องมีการปรับปรุงเรื่องเวลาของการหว่านข้าวและการให้ปุ๋ย ผลผลิตที่ได้ในแต่ละพื้นที่ได้ถูกนำมารวบรวมและเปลี่ยนให้เป็นข้อมูลทางเศรษฐศาสตร์ในรูปรายได้บาทต่อปี เพื่อที่จะได้นำมาพิจารณาในระดับชาติถึงผลประโยชน์ที่จะได้รับในการเพาะปลูกข้าวพันธุ์ที่ได้ทำการคัดเลือกมา

การศึกษาเรื่องนี้สรุปได้ว่า ควรจะมีนโยบายระดับชาติในการที่จะชี้นำให้ผู้ขยายพันธุ์ข้าวได้พิจารณาถึงความเป็นไปได้ที่สภาพอากาศเปลี่ยน มีอิทธิพลต่อโปรแกรมการผสมพันธุ์ข้าว และนโยบายที่จะสนับสนุนการให้ความรู้ด้านการเกษตรแก่ชุมชนเกษตรกร โดยเน้นความสำคัญด้านการคัดเลือกพันธุ์ข้าว ลักษณะอากาศของแต่ละท้องถิ่น และวิธีการที่ใช้ในการเพาะปลูก เพื่อลดต้นทุนการผลิต การศึกษาในลักษณะเช่นนี้ควรจะทำให้กว้างขวางขึ้น เพื่อที่จะได้รวบรวมข้อมูลที่จะนำมาใช้ประโยชน์ในการวางแผนระดับชาติและระดับภูมิภาค