Climate Scenario Verification
and Impact on Rain-fed Rice Production

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ABSTRACT

Three selected provinces for conducting the research to verify climate scenarios and its' potential impact on rain-fed rice production were Chiang Rai, Sakonnakorn and Sakaeo province. They were located at high, medium and low latitude along Maekong River Basin (MRB), Thailand. Climate data were separately generated to be three scenarios by the Conformal Cubic Atmospheric Model (CCAM) under governing of SEA START RC (Southeast Asia START Regional Center), base year line (1xCO_2, 1980-1989), 1.5xCO_2 (2040-2049), and 2.0xCO_2 (2066-2075). While the observed weather data were recorded and provided by the Department of Meteorology. Simulated and observed weather data of each location were compared and were used to run simulation model for assessment their impacts on rice production. Yield of KDML105 rice variety was simulated by MRB-rice shell. Weather comparisons found that the observed annual rain fall tended to be slightly higher than simulated value. The agreements between observed and simulated value of minimum and maximum temperature were good. The seasonal pattern of the temperature was also good agreement. Simulated rice yields on the best year line were not significant difference to observed yields. The agreement between simulated and recorded rice yields was good. Simulated rice yields under three climate scenarios were not significant difference. Even though, the average rice yields of 2.0 CO_2 scenarios tended to be slightly increased, compared to other two scenarios, but it was also higher standard deviation. Over three locations of 1.0, 1.5 and 2.0 CO_2 scenarios, the average rice yields were 2522 ($\pm$216), 2552 ($\pm$270) and 2836 ($\pm$540) kg ha^{-1}, respectively. In addition, dry, medium and wet year scenarios did not affect on rice yields.

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Introduction

Over the last century, both industrial and agricultural sectors were rapidly developed to meet world population consumption demand. One of by products of those anthropogenic activities was green house gases (GHGs). They contributed rising the global temperature (Matthew *et al*, 1995). Global climate phenomenon was changing due mainly to those GHGs, especially CO_2 concentration. It has been increasing at the rate of about 1.5 ppm year^{-1} (Keeling *et al*, 1984).

Climate is an important factor affecting on agricultural sector. They ultimately affect on every day lively hood of human. Preparation for the future, weather generator can be used to simulate future climate of our planet base on recent anthropogenic activities and base on possibility way to be occurred. Another recent advantage technology is crop model. It can be used to simulate the growth and yield of plant under given necessary inputs, soil properties, weather data, genetic coefficient of target plant, and management of plant cultivation further developing a decision.

Agricultural sector as well as security in food supply for world populations is partly affected by risk and uncertainty of weather behavior (Semenov and Jamieson, 2000). The validated crop simulation models and stochastic weather generator are becoming an integral part of a decision making system. For example, DSSAT is a tool for a risk assessment in a crop production and developing a decision support system (Tsuji *et al*, 1998).

From Chiang Rai province in the north to Sakaeo province in the east region of Thailand is an area of MRB. Most of the peoples in the area are rice growers. They produce rice for their consumption and sell the exceed product for their expenses in every day lively hood. The question is that, what would be happen on their product, if the climate would be changed in the future. Yield predictions under a large uncertainty of future weather have to be derived not in terms of point predictions, but in terms of probability distribution of yields. For example, the next season rice yield of an area will be 4 ton hectare^{-1} and a standard deviation of 0.5 ton hectare^{-1}. Stochastic weather generators and crop simulation models offer a way deriving such a probabilistic distributions (Semenov and Jamieson, 2000).

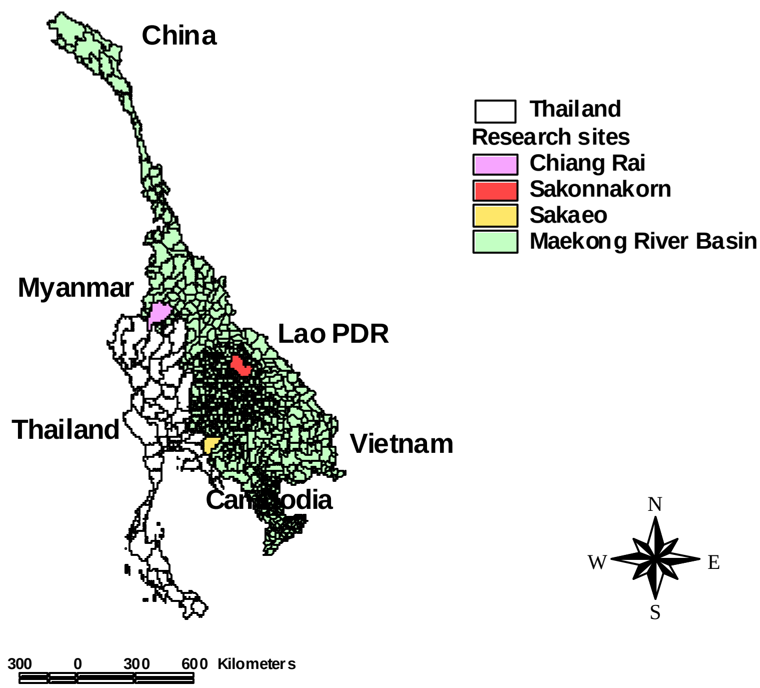
Three provinces along MRB were selected as the representative of low, medium and high latitude of rice production area for conducting the research. The Climate Scenario Verification and Impact on Rain-fed Rice Production was conducted for, (1) analyzing and checking similarity of simulated and observed weather data, (2) simulating rice yields of study areas on the base line year and verify against actual yields, (3) simulating rice yields of the study area on the future climate scenarios and (4) summarize the impact of climate change on rice production under given scenarios.

Sites selection

Three provinces of Thailand located along the MRB were selected (Figure 1). They are:

1. Chiang Rai province, the total area is 1,151,837 hectares. Agricultural activity covers area of 359,271 hectares with a proportion of rice field of 180,490 hectares. The average yield of 2,800 kg ha^{-1}(Center for Agricultural Information, 2000). Weather station coordinate to observe weather data of the province is located at 99.80^{o} E and 19.96^{o} N. The simulated weather data set to be a representative of that coordinates to compare with the observed data is the generated weather of the grid number 2260 of the CCAM.
2. Sakonnakorn province, total area is 931,795 hectares. The activity of agriculture covers area of 374,415 hectares. The rice field proportion is 317,317 hectares with the averaged yield of 2,263 kg ha^{-1} (Center for Agricultural Information, 2000). Weather station coordinate to observe weather data was located at 104.13^{o} E and 17.15^{o} N. While the grid number of generated weather data to compare with the observed value is the data set of the grid number 3384.
3. Sakaeo province, area of the province was 719,514 hectares. Agricultural activities cover area of 310,276 hectares. It is partly covered by 131,959 hectares of paddy field (Center for Agricultural Information, 2000). The productivity of rice field is 1,844 kg ha^{-1}. The coordinate of weather station to observe weather data is located at 102.58^{o} E and 13.70^{o} N, which covered by the grid number of 5436 of simulated weather data generated by CCAM.

Figure 1. Maekong River Basin, map of Thailand and selected sites of the research in the basin



Data collections

Input data sets to simulate rice yields were soil data, weather data, crop management techniques and genetic coefficient of specific rice variety. Soil chemical and physical characteristics were provided by Department of Land Development, Ministry of Agriculture and Cooperative. They were the soil characteristics of paddy field in Thailand, and updated by a group of soil experts. Soil file was show in the attached appendix.

There were two sources of weather data to be compared. The first source is observed weather data. It was provided by the Department of Meteorology. The data sets of three selected provinces for conducting the research were recorded during the year of 1980 to 1989, except Sakonnakorn province there was no 1980 data set to be provided

The second source of simulated weather data set was provided by SEA START RC. CCAM was run to generate data set. It was separated to be three scenarios. Those scenarios were 1.0xCO_2 (CO_2 360 ppm of carbon dioxide) base year line scenario, 1.5xCO_2 (CO_2 540 ppm) and 2.0xCO_2 (CO_2 720 ppm). They were determined to occur during 1980-1989, 2040-2049 and 2066-2075, respectively.

The detail of crop managements was determined by File X. It was a specific format for running the DSSAT model. A set of common cultural practice of the present recommendation for rice production of Rice Research Institute, Department of Agricultural, Ministry of Agriculture & Co-operatives was applied. Crop managements comprised of crop cultivars, planting field, initial condition of the field before planting, planting detail (method and plat density), water management, and both organic and inorganic fertilizer application. The model allows user to modify the environment e.g. solar radiation, maximum/minimum temperature, and amount of rain fall. Beside weather data of three scenarios, the concentrations of CO_2 have to be modified depending on climate scenario before running MRB rice shell.

Rice genetic coefficient is consisted of development coefficients and growth coefficients. Development coefficients determine rice basic vegetative phase, critical photoperiod affecting on panicle initiation, lag phase during the highest of rice plant tillering to panicle initiation and grain filling period. Growth coefficients are potential spikelet per main culm at anthesis stage, potential single grain weight, tillering ability compared with IR 64 and temperature tolerance. These coefficients were experimented and were calculated by rice researcher and rice modeler. The examples of four mentioned input data sets were shown in the appendices.

Materials and Methods

Materials

1. A computer set;

   System: Microsoft XP Professional V.2002

   Processor: Intel Pentium M 1.4GHz

   RAM: 256 MB

   Hard Drive: 40 GB

2. MRB Rice shell
3. Program crop model DSSAT v.4
4. ArcView progam

Methods

Collected data sets were reformatted in to suitable form and allocated before running model. Simulated and observed weather data sets were compared to check similarity. Maximum/minimum temperatures were calculated to find a mean value and its' standard deviation. Line graph of maximum/minimum temperatures of simulated and observed weather data were plotted to see similarity of seasonal pattern. There was no observed solar radiation. It was calculated from sun shine hours and maximum/minimum temperature. So that solar radiation comparison was not made.

The observed weather data of base year line (CO_2 360 ppm) collected during 1980 to 1989 were used to simulate rice yields to compare with simulated rice yields under generated weather data from the CCAM. The observed weather data were collected from the weather station with in the selected provinces. For unbiased comparisons, the recorded weather data set from a weather station was compared with a generated weather data set at a weather grid area (10x10 km) covering that station. The weather data, soil properties, rice genetic coefficient and rice area within the selected grid were input to simulate the rice yields for making comparisons (Table 1). Beside simulated rice yields of selected grid comparisons, the simulated rice yields under simulated weather data and recorded yields over all rice area of the province in the same period were also compared. KDML105 rice variety was a representative of rice cultivar in three selected provinces. It was a weakly photo sensitive variety. Harvesting date varies from 10 to 30 November depending on plating date and latitude of paddy field. Transplanting method was a common planting technique with a spacing of 20 x 20 centimeter and 3 plants per hill. Ammonium sulphate was broadcasted on flooded field at the rate of 38 kilogram of nitrogen per hectare. Fertilizer application was made two times, during tillering period. Rice plant was cultivated under rain-fed condition.

Table 1. Coordinate of weather stations, grid number of weather data from the CCAM, which covers the weather stations and number of soil group in paddy field covered by the weather grid

Weather station	*Co ordinate* E	N	*WSTA code (CCAM)*	*Soil group*	*Soil series*
Chiang Rai	99.88	19.96	2260	5	Hang dong(Hd)
Sakonnakorn	104.13	17.15	3384	17	Roi et (Re)
Arunyapratate (Sakaeo)	102.58	13.70	5436	17	Roi et (Re)

Source: Data from CCAM weather grid and soil group map of Department of Land Development and Department of Meteorology

Future climate scenarios were generated by the CCAM weather generator base on the existing climate of the past decade (1980-89) and recent anthropogenic activities. Extreme anthropogenic activities of world populations were reasonable to generate the extreme phenomenon, one and a half time of CO_2 concentration of the base year line (540 ppm), and two times of CO_2 concentration of the base year line (720 ppm). Two future scenarios were expected to occur in 2040-2049 and 2066-2075, respectively.

Rice yields under dry year, medium year and wet year of each scenario were simulated to compare the impact of those scenarios. Precipitation was a criterion to separate dry year, medium year and wet year. Less amount of precipitation refer to dry year, medium year and wet year for more rain, respectively.

Results and discussions

The results of the research were separately explained for four parts. The first part showed simulation and observed weather data comparisons. Precipitation characteristics comprising of amount of rainfall, maximum rainfall per day, and numbers of rain fall days were compared. Maximum/minimum temperatures pattern were also compared to see seasonal pattern similarity. The second part was rice yields comparison. Simulated rice yields under generated weather data from CCAM and under observed weather data on base year line were compared. More over, simulated rice yields over the rice areas of the province were also compared with the recorded yields. The third part was simulated rice yields under future climate scenarios to evaluate the impact of climate scenarios on rain-fed rice production. The fourth part was the effect of the selected dry year, medium year and wet year on rice yields.

Simulated and observed weather data comparisons

Chiang Rai weather data comparisons

Annual rain fall, maximum rain fall per day and average temperature was not significant difference between simulated and observed weather data. The agreement of seasonal pattern of temperature was good (Figure 2). Average of annual rain fall, maximum rain fall per day (Figure 5) and average temperature of simulation (Figure 4) were 1,413 ($\pm$74) mm, 63 ($\pm$12) mm and 24.4 ($\pm$0.6) ^{o}C, compared with 1,648 ($\pm$23) mm, 102 (+33) mm and 24.7 (+0.2) ^{o}C of observation, respectively. Number of rain fall day per year of observation weather data (140 $\pm$8 days) was higher than simulation data (115 $\pm$8 days). Consideration of maximum/minimum temperature, the gap between maximum and minimum temperature of simulation (32.0 $\pm$0.8 - 16.7 $\pm$0.5 ^{o}C) was greater than observation (30.7 $\pm$0.3 - 18.8 $\pm$0.2 ^{o}C). However, average temperature was not significant difference between simulated and observed weather data.

There was a good agreement of observation and simulation weather data in term of annual precipitation and daily temperature pattern (Figure 6). But in terms of precipitation distributions (Figure 3) and the gap of maximum and minimum of air temperature would be a little readjusted for more accurate generation scenario.

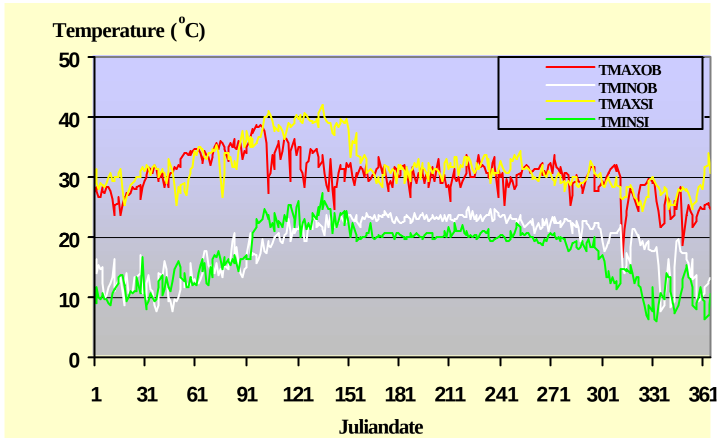


Figure 2. Seasonal pattern of observed and simulated minimum/maximum temperature comparison of Chiang Rai province, 1981 (TMAXOB = maximum temperature of observation, TMINOB = minimum temperature of observation, TMAXSI = maximum temperature of simulation, TMINSI = minimum temperature of simulation)

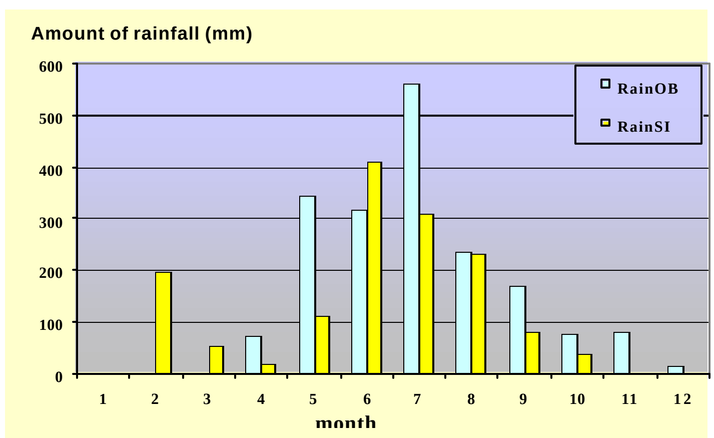


Figure 3. Simulated and observed amount of monthly rain fall comparisons of Chiang Rai province, 1981 (RainOB = observation rain fall RainSI = Simulation rain fall)

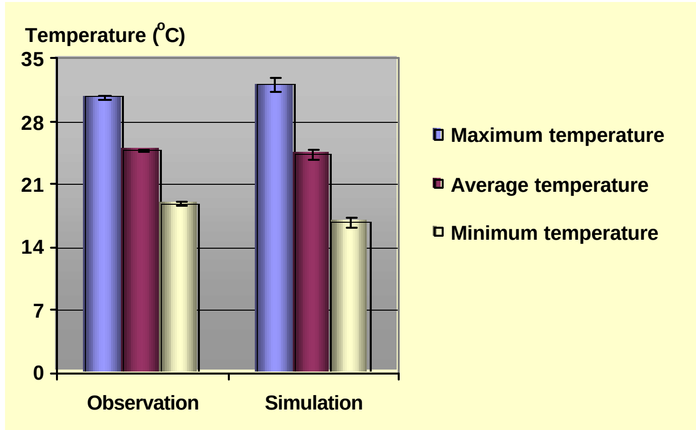


Figure 4. Minimum/minimum and average temperature of observation and simulation weather data comparison of Chiang Rai, 1981 (I = standard deviation)

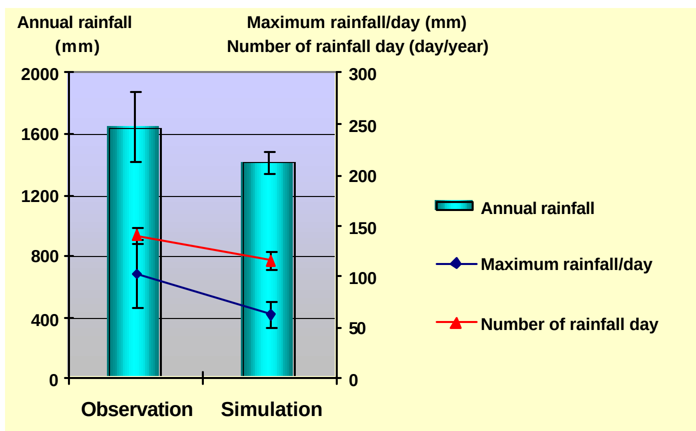


Figure 5. Annual rain fall, maximum of rain fall per day and number of rain fall day per year of observation and simulation comparison of Chiang Rai province, 1981 (I = standard deviation)

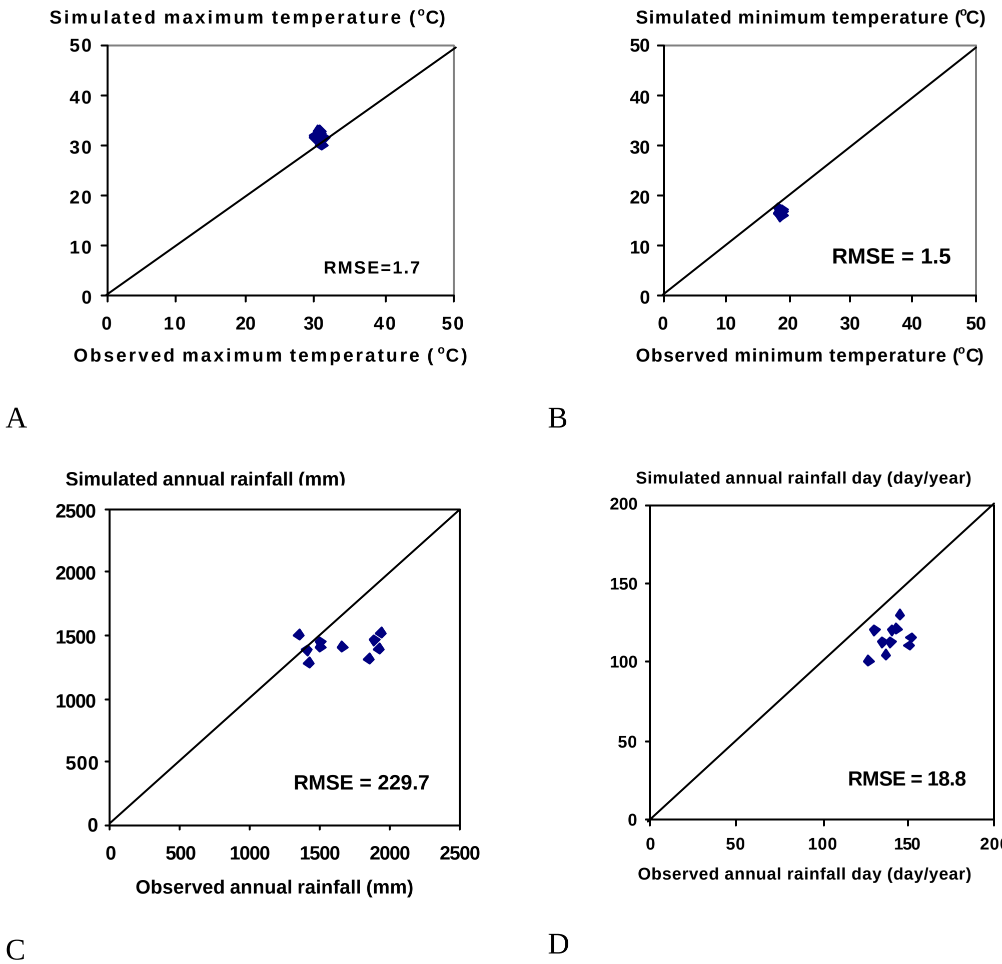


Figure 6. Comparisons of observed and simulated weather data of Chiang Rai province during 1980-1989, A = maximum temperature, B = minimum temperature C = annual rain fall and D = number of rain fall day per year.

Sakonnakorn weather data comparisons

There was no significant difference of annual rain fall, maximum rain fall per day (Figure 10), maximum/minimum and average temperature of simulated and observed weather data (Figure 9). The agreement of seasonal pattern of temperature was good (Figure 7). Even the average ten years of annual rain fall of observation (1,576 mm) was higher than simulation in term of average value, but standard deviation (286) of which was high, so that there was no significant difference. Same as Chiang Rai province, there was a significant difference of the number of rain fall day per year. The average ten year of rain fall day of simulation was 89 ($\pm$9) days per year compared with 130 ($\pm$10) days of observation. The over all agreement of weather data between simulation and observation was good, both quantity and seasonal pattern (Figure 11), except the distribution of precipitation (Figure 8).

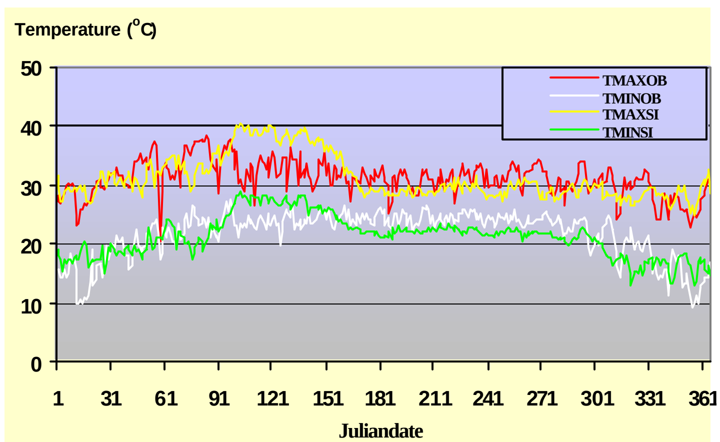


Figure 7. Seasonal pattern of observed and simulated minimum/maximum temperature comparisons of Sakonnakorn province, 1981 (TMAXOB = maximum temperature of observation, TMINOB = minimum temperature of observation, TMAXSI = maximum temperature of simulation, TMINSI = minimum temperature of simulation)

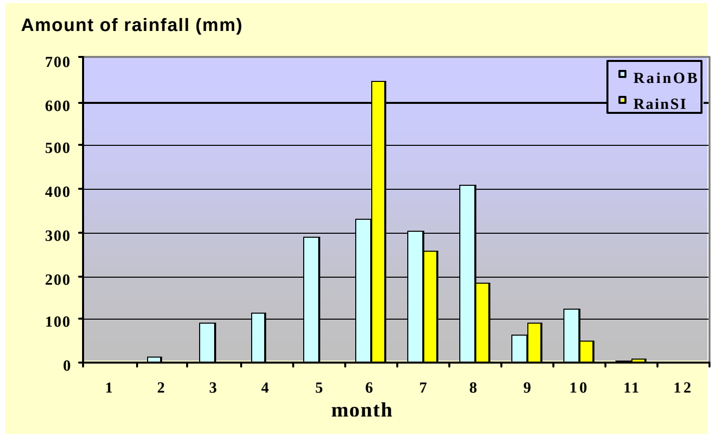


Figure 8. Simulated and observed amount of monthly rain fall comparisons of Sakonnakorn province, 1981 (RainOB = observation rain fall, RainSI = Simulation rain fall)

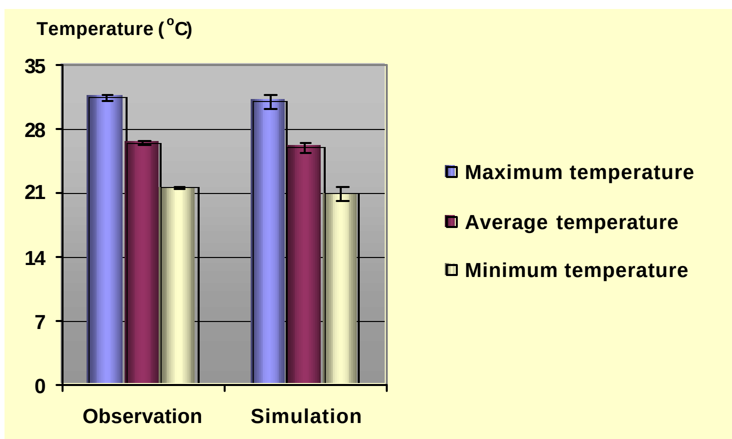


Figure 9. Maximum/minimum and average temperature of observation and simulation weather data comparison of Sakonnakorn province, 1981 (I = standard deviation)

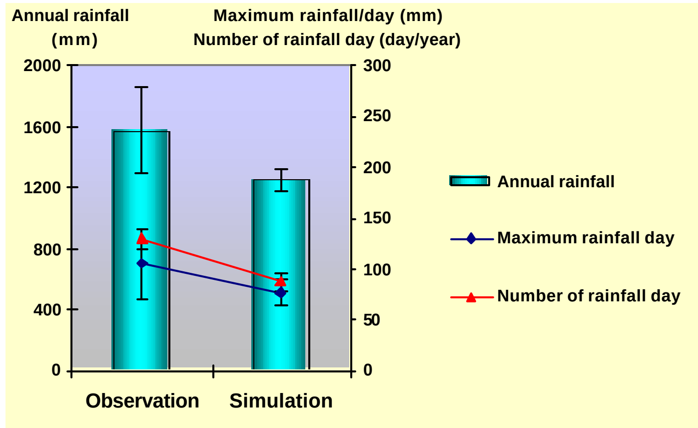


Figure 10. Annual rain fall, maximum of rain fall per day and number of rain fall day per year of observation and simulation comparison of Sakonnakorn province, 1981 (I = standard deviation)

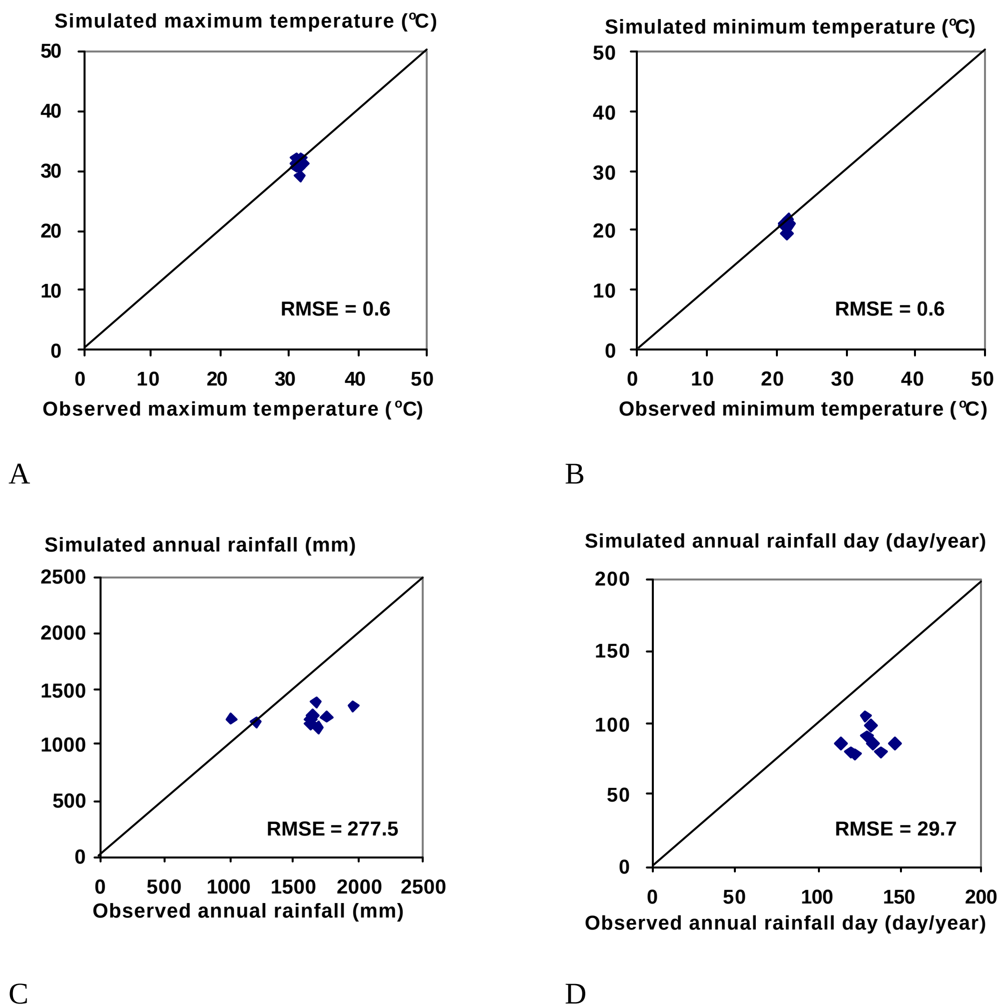


Figure 11. Comparisons of observed and simulated weather data of Sakonnakorn province during 1980-1989, A = maximum temperature, B = minimum temperature C = annual rain fall and D = number of rain fall day

Sakaeo weather data comparison

The agreement of seasonal pattern of temperature was good (Figure 12). The annual rail fall and the number of rain fall day per year was not significant difference between simulation and observation data (Figure 15). Maximum rain fall per day of observation was 84 ($\pm$20), which was higher than 48 ($\pm$14) of simulation (Figure 15). The maximum/minimum and average temperature of observations were 33.4 ($\pm$0.3), 23.3 ($\pm$0.2) and 28.3 ($\pm$0.3) ^{o}C, which were higher than 31.9 ($\pm$0.6), 20.6 ($\pm$0.3) and 26.2 ($\pm$0.5) ^{o}C of simulation, respectively (Figure 14). The agreement of precipitation pattern of simulation and observation was good, in term of rain fall distribution compared with the other two provinces (Figure 13). The over all agreement of weather data between simulation and observation was good (Figure 16).

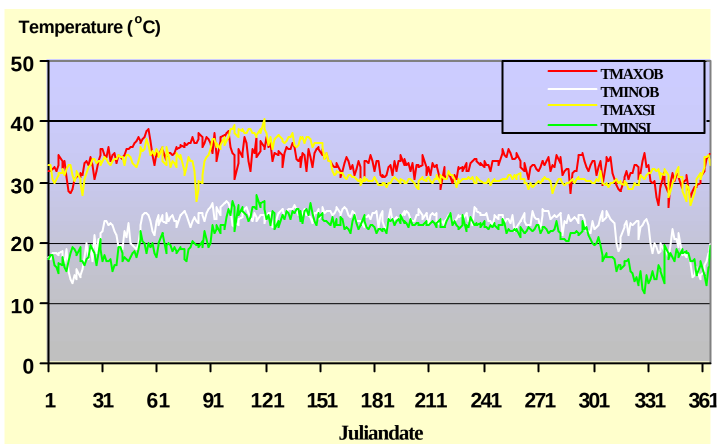


Figure12. Seasonal pattern of observed and simulated minimum/maximum temperature comparisons of Sakaeo province, 1981 (TMAXOB = maximum temperature of observation, TMINOB = minimum temperature of observation, TMAXSI = maximum temperature of simulation, TMINSI = minimum temperature of simulation)

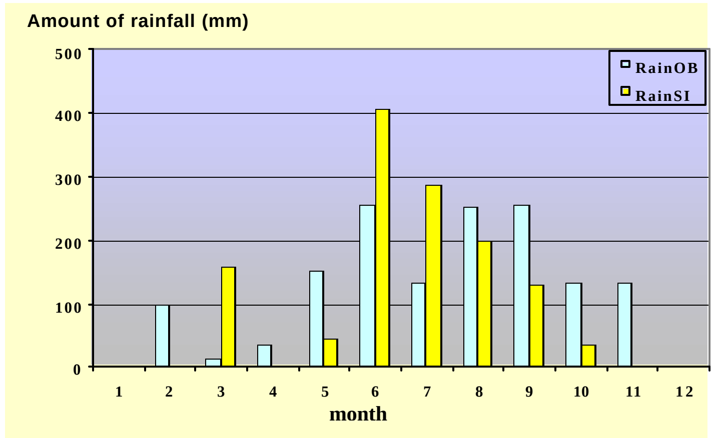


Figure 13.Simulated and observed amount of monthly rain fall comparisons of Sakaeo province, 1981 (RainOB = observation rain fall, RainSI = Simulation rain fall)

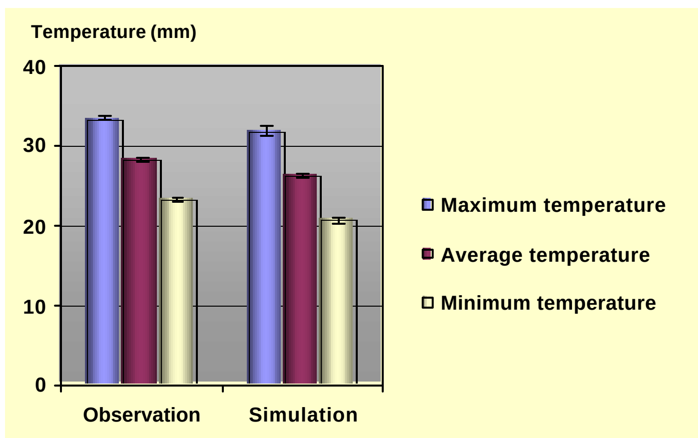


Figure 14.Maximum/minimum and average temperature of observation and simulation weather data comparison of Sakaeo province, 1981 (I = standard deviation)

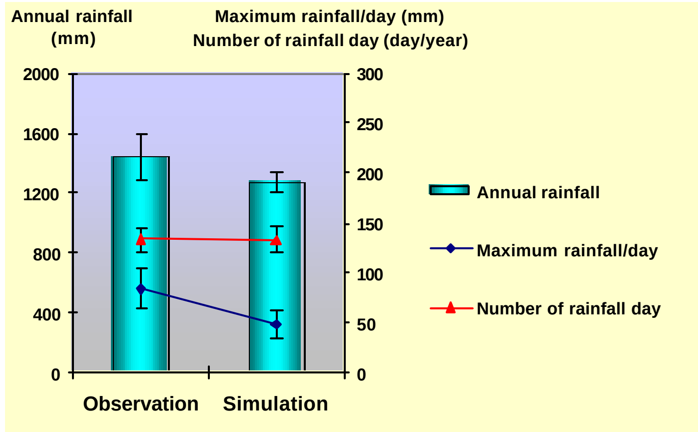
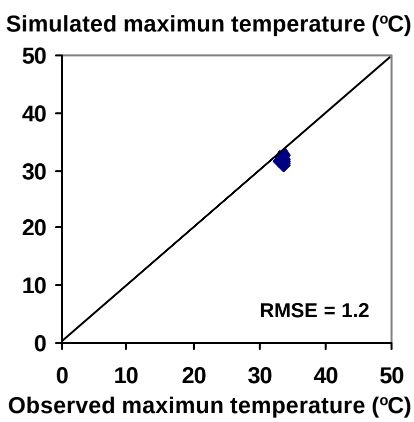
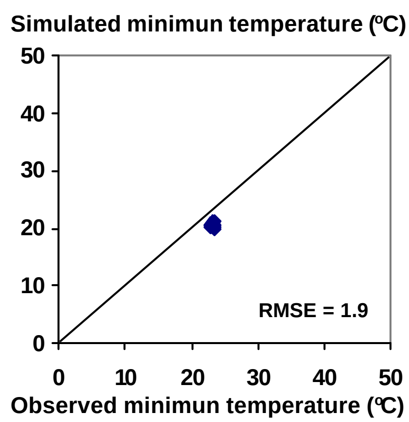


Figure 15. Annual rain fall, maximum of rain fall per day and number of rain fall day per year of observation and simulation comparison of Sakonnakorn province, 1981 (I = standard deviation)



A



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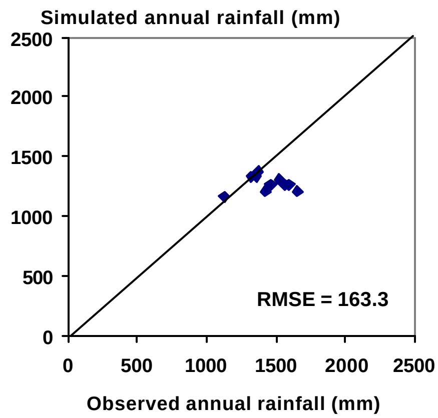

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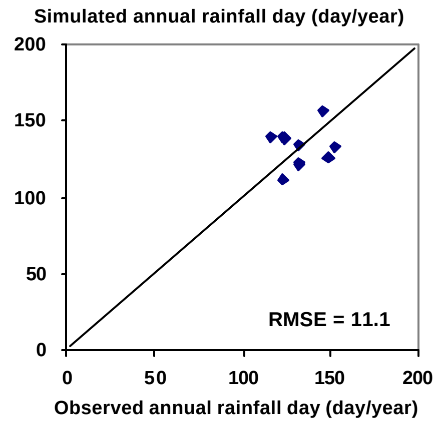


D

Figure 16. Comparisons of observed and simulated weather data of Sakaeo province during 1980-1989, A = maximum temperature, B = minimum temperature C = annual rain fall and D = number of rain fall day

Rice yields on the base year line

Comparison of simulated rice yields under generated and under observed weather data of the base year line was not significant difference (Figure 17). The rice yields under simulated weather data were 2,984 (±195), 1829 (±77) and 1,956 (±241) kg ha^{-1} compared with 2,984 (±195), 1,871 (±156) and 1906 (±39) kg ha^{-1} under observation weather data of Chiang Rai, Sakonnakorn and Sakaeo province, respectively. Beside the effect of soil fertility, there is a tendency for rice yield to be higher at higher latitudes (Mathews *et al.*, 1995). Comparison of simulated rice yield under generated weather data with recorded yield (of Office of Agricultural and Economic) found that recorded yield at Chiang Raiwas slightly higher than simulated yield. Vice versa, simulated yields under observed weather data were slightly higher than recorded yield at Sakonnakorn and Sakaeo province. How ever, over all agreement between recorded and simulated yield was good (Figure 18).

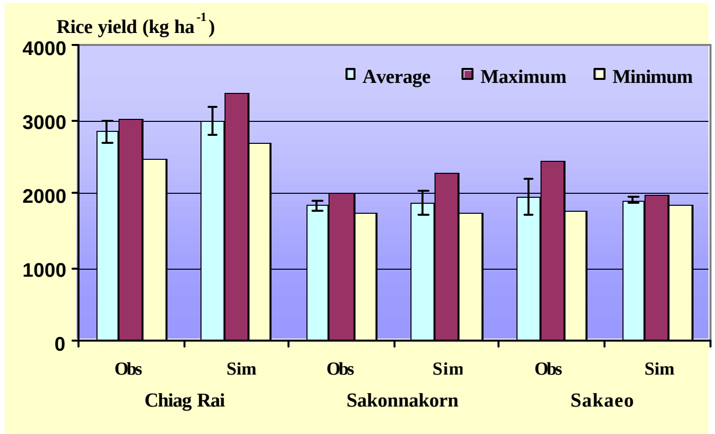
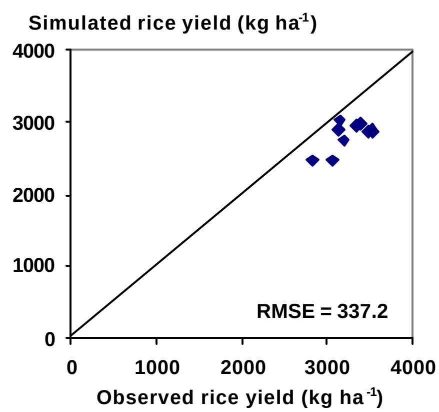
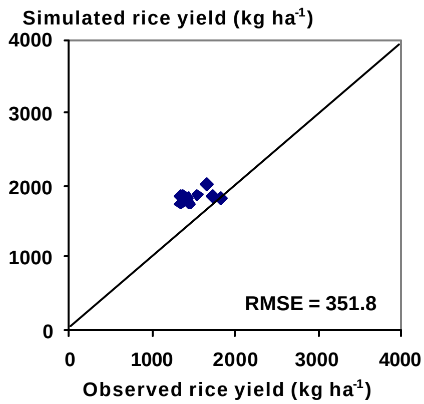


Figure 17. Comparison of simulated rice yields under observation and generated weather data on base year line (1981-89) of Chiang Rai, Sakonnakorn and Sakaeo province



A



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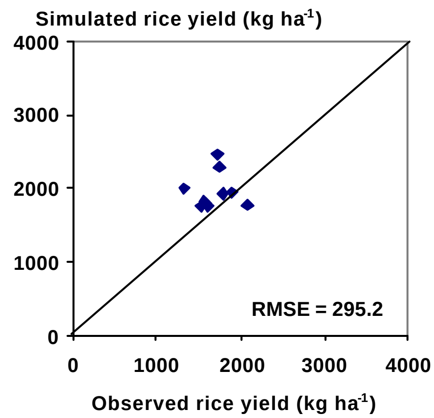

C

Figure 18. Comparisons of recorded rice yields and simulated rice yield under generated weather data from CCAM weather generator over all rice area of the province, A = Chiang Rai, B = Sakonnakorn and C = Sakaeo province.

Rice yields on the future climate scenarios

The research found that the rice yields were not significant difference between the 1.0 CO_2 (base year line), 1.5 CO_2 and 2.0 CO_2 scenarios of over three locations, Chiang Rai, Sakonnakorn and Sakaeo province (Figure 19). The base line year of Chiang Rai gave simulated rice yield of 2,768 ($\pm$394) kg ha^{-1}, while the rice yield under 1.5 CO_2 and 2.0 CO_2 scenarios were 2,844 ($\pm$517) and 3,455 ($\pm$986) kg ha^{-1} (Figure 20-22), respectively. How ever, the average rice yield of Chiang Rai tended to be increased due to CO_2 concentration (Matthews *et al.*, 1995). Simulated rice yields under three CO_2 scenarios of Sakonnakorn were 2,363 ($\pm$540), 2,311 ($\pm$508) and 2,433 ($\pm$797) kg ha^{-1} (Figure 23-25), where as simulated rice yields of Sakaeo province were 2,435 ($\pm$869), 2,500 ($\pm$783) and 2,619 ($\pm$970) kg ha^{-1}, respectively (Figure 26-28).

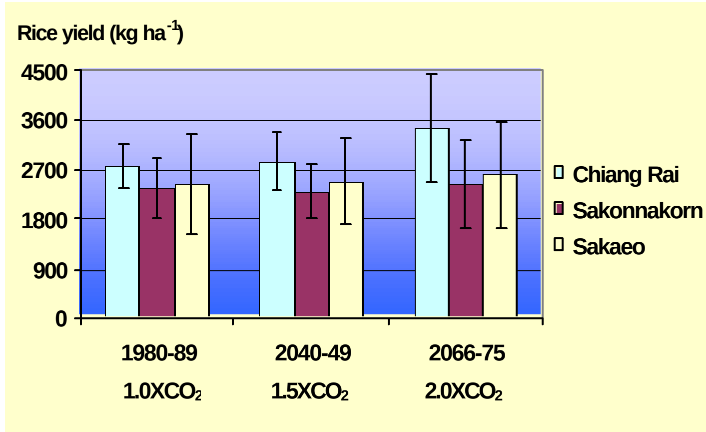

Figure 19. Simulated rice yields under three scenarios of three provinces

Effect of dry, medium and wet year

Effect of dry, medium and wet years of each scenario on three locations was quantified. The research found that the dry, medium and wet year selected from generated scenarios did not affect on rice yields. The average yields over three scenarios of three provinces were 2,609, 2,655 and 2,651 kg ha^{-1} with the average standard deviation of 739, 756 and 856 kg ha^{-1} of the dry, the medium and the wet year, respectively. Consideration of CO_2 concentration, it tended to increase on rice yield the research found that the average rice yields over three provinces were 2,534, 2,568 and 2,814 kg ha^{-1} of 1.0, 1.5 and 2.0 CO_2, respectively. How ever, standard deviations were also high. There was a research found that doubling of CO_2 could increase yield by 34% for ORIZA1 and 21% for SIMRIW model (Matthews *et al.*, 1995).

Table 2. Simulated rice yields under selected dry, medium and wet year of three scenarios in Chiang Rai, Sakonnakorn and Sakaeo province

Locations	Scenarios	Selected years					
		Dry		Medium		Wet	
		Yield	SD	Yield	SD	Yield	SD
		kg ha^{-1}		kg ha^{-1}		kg ha^{-1}	
Chiang Rai	1.0CO_2	2685	537	2340	399	2781	638

	$1.5CO_2$	2834	480	2678	480	2700	574
	$2.0CO_2$	2553	875	3402	1104	3248	975
Sakonnakorn	$1.0CO_2$	2544	557	2459	591	2635	1083
	$1.5CO_2$	2644	887	2257	617	2355	842
	$2.0CO_2$	2615	1137	2771	1400	2812	1384
Sakaeo	$1.0CO_2$	2421	732	2481	743	2456	720
	$1.5CO_2$	2657	623	2633	671	2360	681
	$2.0CO_2$	2527	823	2878	796	2516	803

In addition, rice yields were simulated under 1,264 mm of annual rain fall, 33.4 ^{o}C and 21.7 ^{o}C of average maximum/minimum temperature of driest year, compared with rice yields under 1,547 mm of precipitation, 32.4 ^{o}C and 21.5 ^{o}C of average maximum/minimum temperature of wettest year of Sakaeo province. There was no significant difference between two simulated yields, 2,593 ($\pm$1,037) kg ha^{-1} for wet year and 2,595 ($\pm$1,043) kg ha^{-1} for dry year. Considering of precipitation amount during rice growing period, there was 925 mm for wet year and 1,043 mm for dry year. It indicated that the distribution and amount of rain fall during growing period was more significant than the total amount of rain fall.

Conclusions

The research found that overall agreement between simulated and observed weather data was good in terns of seasonal pattern. Distribution of rain fall (the number of rain fall day per year) and the amount of rainfall in some area has to be a little readjusted.

There was not significant difference between rice yields under simulated and observed weather data on the best year line. There was a good agreement between recorded rice yields and simulated rice yield under generated weather data from the CCAM. The rice yields under three scenarios 1.0, 1.5 and 2.0 CO_2 were not significant difference, how ever; it tended to be higher when CO_2 concentration was increased. The rice yields under dry, medium and wet year were also not significant difference due mainly to amount of rain fall during growing period. Chiang Rai paddy field gave higher yield than Sakonnakorn and Sakaeo province.

Acknowledgements

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Reference s

Center for Agricultural Information. 2000. Agricultural Statistics of Thailand Crop Year 1998/99. Office of Agriculture Economics, Ministry of Agriculture & Co-operatives, Bangkok, Thailand. 311 p.

Keeling, C. D., A. F. Carter and W. G. Mook, 1984. Seasonal, Lattitudinal and secular variations in the abundance and isotopic ratios of atmospheric CO2. J. Geophys. Res. 89:4615-4628.

Matthew, R. B., M. J. Kropff and D. Bachelet. 1995a. Introduction, p. 3-7. In R. B. Mattews, M. J. Kropff, D. Bachelet and H. H. V. Laar (eds). Modeling the Impact of Climate Change on Rice Production in Asia. CAB INTERNATIONAL, Wallingford, UK.

Matthew, R. B., T. Horie, M. J. Kropff, D. Bachelet, H. G. Centeno, J. C. Shin, S. Mohandass, S. Sing, Zsu Defeng and Moon Hee Lee. 1995b. A Regional Evaluation of the Effect of Future Climate Change on Rice Production in Asia, p. 95-139. In R. B. Mattews, M. J. Kropff, D. Bachelet and H. H. V. Laar (eds). Modeling the Impact of Climate Change on Rice Production in Asia. CAB INTERNATIONAL, Wallingford, UK.

Semenov, M. A. and P. D. Jamieson. 2000. Using Weather Generators and Crop Modeling, p. 119-142. In M. V. K. Sivakumar (ed). Climate Prediction and Agriculture. International START Secretariat, Washington DC, USA.

Tsuji, G. Y., G. Hoogenboom and P. K. Thornton (eds.). 1998. Understanding Options for Agricultural Production. Kluwer Academic, Dordrecht, 399 p.

Appendix A

Weather data file

```
*WEATHER DATA : XXXX
@ INSI      LAT     LONG  ELEV   TAV   AMP REFHT WNDHT
  2043    20.35    99.85   -99  00.0   0.0   -99   -99
@DATE  SRAD  TMAX  TMIN  RAIN
40001 14.45 23.89  9.16   .00
40002 15.22 21.54  8.30   .00
40003 15.56 20.11  3.06   .00
40004 15.43 22.25  3.90   .00
40005 14.32 24.05  4.27   .00
40006 15.37 25.15  4.79   .00
40007 15.27 23.92  6.82   .00
40008 15.74 23.51  7.39   .00
40009 15.81 23.72  7.44   .00
40010 15.69 21.21  8.45   .00
40011 15.35 20.26  6.36   .00
40012 16.72 19.11  5.18   .00
40013 17.15 19.42  5.00   .00
40014 16.95 20.81  3.13   .00
40015 17.38 22.42  1.66   .00
40016 17.13 24.78   .36   .00
40017 17.18 25.99   .83   .00
40018 16.79 28.03  1.93   .00
40019 17.13 29.52  2.76   .00

40020 17.09 29.07  4.37   .00
40021 15.11 28.28 10.71   .00
40022 14.66 26.39  7.83   .00
40023 15.34 26.61  6.34   .00
40024 16.17 30.64  7.22   .00
40025 16.19 31.94  8.39   .00
40026 16.63 34.13 11.72   .00
40027 15.55 33.61 12.82   .00
40028 16.08 32.52  9.34   .00
40029 16.80 31.36  9.33   .00
40030 10.59 23.21  8.81   .00
40031 15.07 29.42  9.22   .00
40032 15.02 29.12 10.15   .00
40033 11.79 25.06 11.12   .00
40034 13.80 24.47 10.61   .00
40035 13.82 24.15  8.03   .00
40036 16.31 25.89  6.66   .00
40037 16.79 26.95  7.64   .00
……………………………………
……………………………………
……………………………………
```

40363	15.17	28.70	8.84	.00
40364	11.67	25.19	10.92	.00
40365	10.48	23.59	10.62	.00

Appendix B

Soil data file

```
 THRI          DLD       LO         Phen(Pn)***
@SITE     COUNTRY       LAT    LONG USDA FAMILY
 NONGKHAI   THAILAND                   L-sk,mixed,subactive,iso Aeric Plinthic Paleaquults
@ SCOM  SALB  SLU   SLDR  SLRO  SLNF  SLPF  SMHB  SMPX  SMKE
 BN                                    IB    IB    IB
@  SLB SLMH   SLLL  SDUL  SSAT  SRGF  SSKS  SBDM  SLOC  SLCL  SLSI  SLCF  SLNI  SLHW
SLHB  SCEC
      Ap

      Bt

      Bt

      Btc

       BCg

       BCg


 THRI          DLD       SALO       Roi Et(Re)***
@SITE     COUNTRY       LAT    LONG USDA FAMILY
 KALASIN    THAILAND                   Fine-loamy,mixed,su bactive,iso Aeric Kandiaquults
@ SCOM  SALB  SLU   SLDR  SLRO  SLNF  SLPF  SMHB  SMPX  SMKE
 BN                                    IB    IB    IB
@  SLB SLMH   SLLL  SDUL  SSAT  SRGF  SSKS  SBDM  SLOC  SLCL  SLSI  SLCF  SLNI  SLHW
SLHB  SCEC
      Ap

      BA

      Btg

      Btg

      Btg

      BCg
```

Appendix C

Crop management file (File X)

```
  EXP.DETAILS: DTSP        RI EFFECTS OF APPL. N & ENVIR. ON RICE

  GENERAL
@PEOPLE
-
@ADDRESS
-
@SITE
-

  TREATMENTS                        -------------FACTOR LEVELS------------
@N R O C TNAME.................... CU FL SA IC MP MI MF MR MC MT ME MH SM
                 -  -   NPK
                  kg ha-   of applied N
                   kg ha-   of applied N
                     kg ha-   of applied N
                     kg ha-   of applied N
                     kg ha-   of applied N

  CULTIVARS
@C CR INGENO CNAME
   RI TR        KDML

  FIELDS
@L ID_FIELD WSTA....  FLSA  FLOB  FLDT  FLDD  FLDS  FLST SLTX  SLDP  ID_SOIL    FLNAME
   DTSK                         -             IB                          -              THRI            -
@L ...........XCRD ...........YCRD .....ELEV .............AREA .SLEN .FLWR .SLAS


  INITIAL CONDITIONS
@C   PCR ICDAT  ICRT  ICND  ICRN  ICRE  ICWD ICRES ICREN ICREP ICRIP ICRID ICNAME
     RI                 -                                                              -
@C  ICBL  SH  O  SNH    SNO

  PLANTING DETAILS
@P PDATE EDATE  PPOP  PPOE  PLME  PLDS  PLRS  PLRD  PLDP  PLWT  PAGE  PENV  PLPH
SPRL                         PLNAME
```

- T H
-

IRRIGATION AND WATER MANAGEMENT
@I EFIR IDEP ITHR IEPT IOFF IAME IAMT IRNAME
- - - - - - -
@I IDATE IROP IRVAL IIRV
IR
IR
IR
IR

FERTILIZERS (INORGANIC)
@F FDATE FMCD FACD FDEP FAMN FAMP FAMK FAMC FAMO FOCD FERNAME
FE AP - - - - - -
FE AP - - - - - -
FE AP - - - - - -
FE AP - - - - - -
FE AP - - - - - -
FE AP - - - - - -
FE AP - - - - - -
FE AP - - - - - -
FE AP - - - - - -
FE AP - - - - - -

RESIDUES AND ORGANIC FERTILIZER
@R RDATE RCOD RAMT RESN RESP RESK RINP RDEP RMET RENAME
RE - - - - -

ENVIRONMENT MODIFICATIONS
@E ODATE EDAY ERAD EMAX EMIN ERAIN ECO EDEW EWIND ENVNAME
A A A A A M A A

SIMULATION CONTROLS
@N GENERAL NYERS NREPS START SDATE RSEED SNAME....................
GE S Effects of appl. N & envi
@N OPTIONS WATER NITRO SYMBI PHOSP POTAS DISES CHEM TILL
OP Y Y Y N N N N N
@N METHODS WTHER INCON LIGHT EVAPO INFIL PHOTO HYDRO NSWIT MESOM
ME M M E R S C R G
@N MANAGEMENT PLANT IRRIG FERTI RESID HARVS
MA R R R R M
@N OUTPUTS FNAME OVVEW SUMRY FROPT GROUT CAOUT WAOUT NIOUT MIOUT DIOUT
LONG CHOUT OPOUT
OU N N Y N N N N N N N N N

@ AUTOMATIC MANAGEMENT
@N PLANTING PFRST PLAST PH OL PH OU PH OD PSTMX PSTMN
PL
@N IRRIGATION IMDEP ITHRL ITHRU IROFF IMETH IRAMT IREFF

```
   IR                                   IB       IB
@N NITROGEN    NMDEP NMTHR NAMNT NCODE NAOFF
   NI                                  IB       IB
@N RESIDUES    RIPCN RTIME RIDEP
   RE
@N HARVEST     HFRST HLAST HPCNP HPCNR
   HA
```

Appendix D

```
RICE GENETIC COEFFICIENTS

*RICE GENOTYPE COEFFICIENTS: RICER030 MODEL
!
! COEFF        DEFINITIONS
! ========     ===========
! VAR#         Identification code or number for a specific cultivar.
! VAR-NAME     Name of cultivar.
! ECO#         Ecotype code for this cultivar points to the Ecotype in
the ECO
!              file (currently not used).
! P1           Time period (expressed as growing degree days [GDD] in øC
above
!              a base temperature of 9øC) from seedling emergence during
which
!              the rice plant is not responsive to changes in photoperiod.
This
!              period is also referred to as the basic vegetative phase
of the
!              plant.
! P20          Critical photoperiod or the longest day length (in hours)
at
!              which the development occurs at a maximum rate. At values
higher
!              than P20 developmental rate is slowed, hence there is
delay due
!              to longer day lengths.
! P2R          Extent to which phasic development leading to panicle
initiation
!              is delayed (expressed as GDD in øC) for each hour increase
in
!              photoperiod above P20.
! P5           Time period in GDD øC) from beginning of grain filling (3
to
!              4 days after flowering) to physiological maturity with a
base
!              temperature of 9øC.
! G1           Potential spikelet number coefficient as estimated from
the
!              number of spikelets per g of main culm dry weight (less
lead
!              blades and sheaths plus spikes) at anthesis. A typical
value
!              is 55.
! G2           Single grain weight (g) under ideal growing conditions,
i.e.
!              nonlimiting light, water, nutrients, and absence of pests
!              and diseases.
! G3           Tillering coefficient (scaler value) relative to IR64
cultivar
!              under ideal conditions. A higher tillering cultivar would
have
!              coefficient greater than 1.0.
! G4           Temperature tolerance coefficient. Usually 1.0 for
varieties
```

```
!             grown in normal environments. G4 for japonica type rice
growing
!             in a warmer environment would be 1.0 or greater. Likewise,
the
!             G4 value for indica type rice in very cool environments or
!             season would be less than 1.0.
!

@VAR#  VAR-NAME........   ECO#    P1   P2R    P5   P2O    G1    G2    G3
G4
!                                  1     2     3     4     5     6     7
8
TR0001 KDML105          IB0001 502.31233.0 386.5  12.8  45.7 .0270  1.00
0.95
TR0002 KDML105Jun       IB0001 580.01344.0 390.0  12.7  75.0 .0238  1.00
1.00
TR0003 KDML105Jul       IB0001 580.01000.0 390.0  12.7  75.0 .0238  1.00
1.00
TR0004 KDML105Aug       IB0001 580.0 100.0 390.0  12.7  75.0 .0238  1.00
1.00
TR0005 NIEW SANPATONG   IB0001 495.81283.4 364.2  12.7  40.7 .0277  0.70
0.85
TR0006 SUPANBURI 60     IB0001 540.0 154.7 497.0  11.9  77.7 .0280  1.00
1.03
TR0007 CHAINAT 1        IB0001 570.0 122.8 334.8  11.9  63.1 .0278  1.00
1.00
TR0008 DOA 1            IB0001 388.5  20.0 381.8  12.0  73.8 .0275  1.10
1.15
!
```

Appendix E

Map of simulated rice yield under generated scenarios of Chiang Rai, Sakonnakorn and Sakaeo province

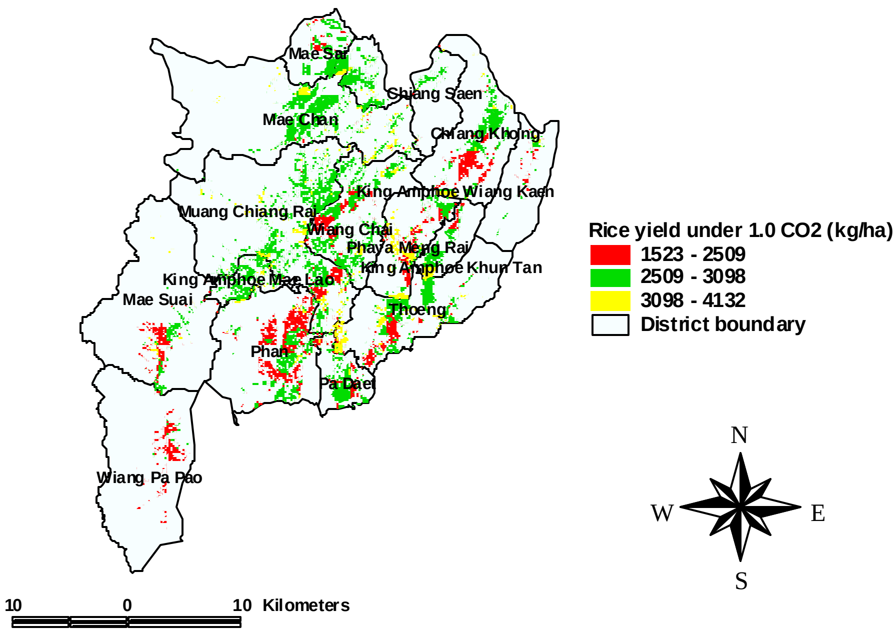

Figure 20. Simulated rice yield under the base year line (1.0 CO_2 scenario) of Chiang Rai province

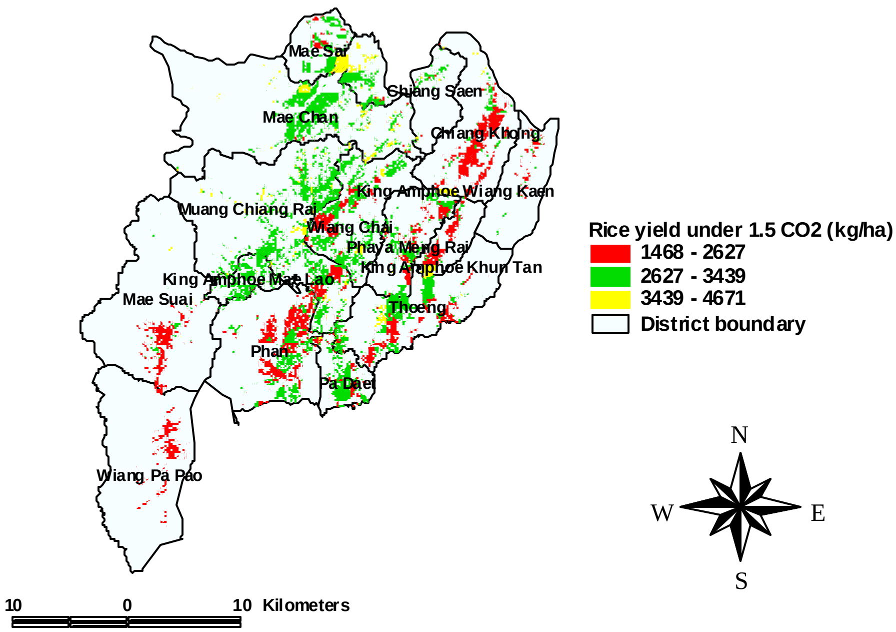

Figure 21. Simulated rice yield under the 1.5 CO_2 scenario of Chiang Rai province

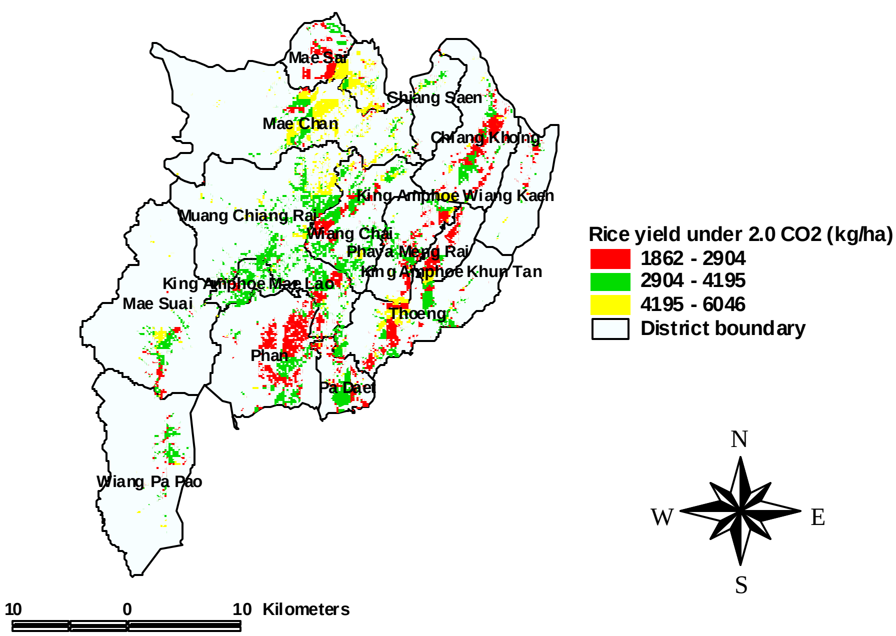

Figure 22. Simulated rice yield under the 2.0 CO_2 scenario of Chiang Rai province

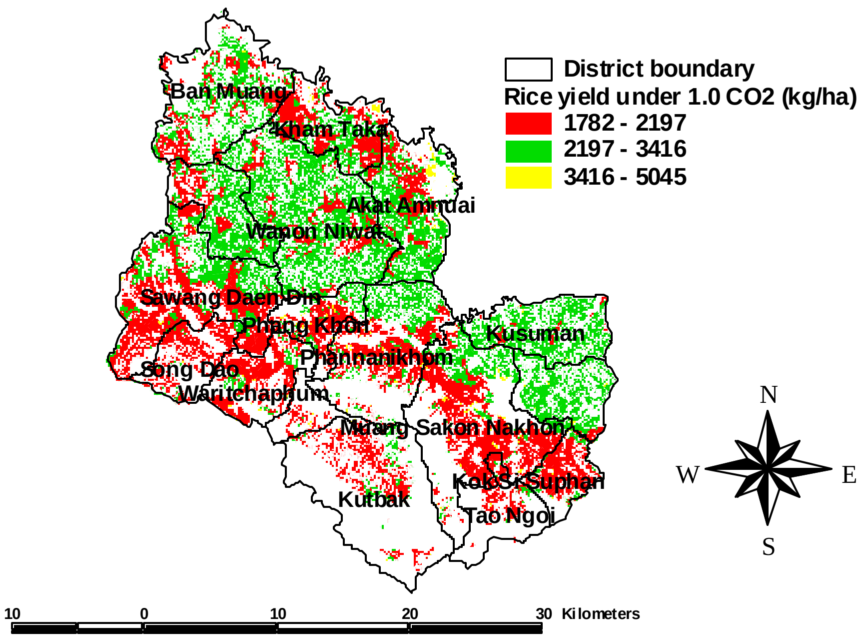

Figure 23. Simulated rice yield under the 1.0 CO_2 scenario of Sakonnakorn province

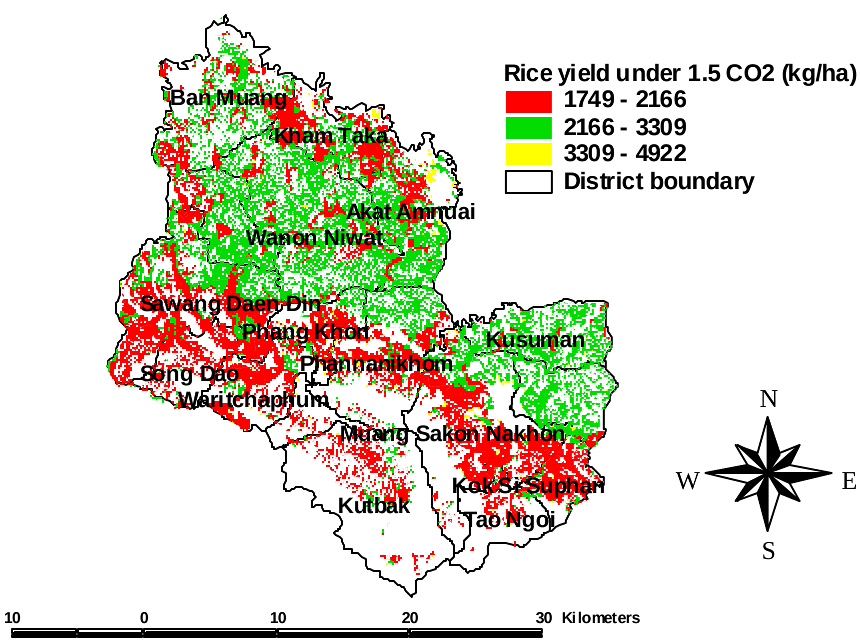

Figure 24. Simulated rice yield under the 1.5 CO_2 scenario of Sakonnakorn province

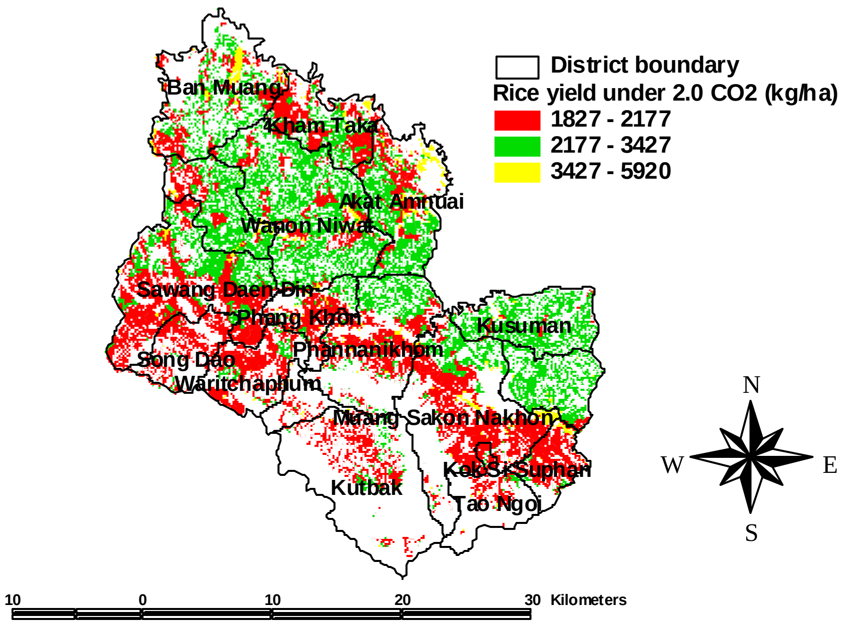

Figure 25. Simulated rice yield under the 2.0 CO_2 scenario of Sakonnakorn province

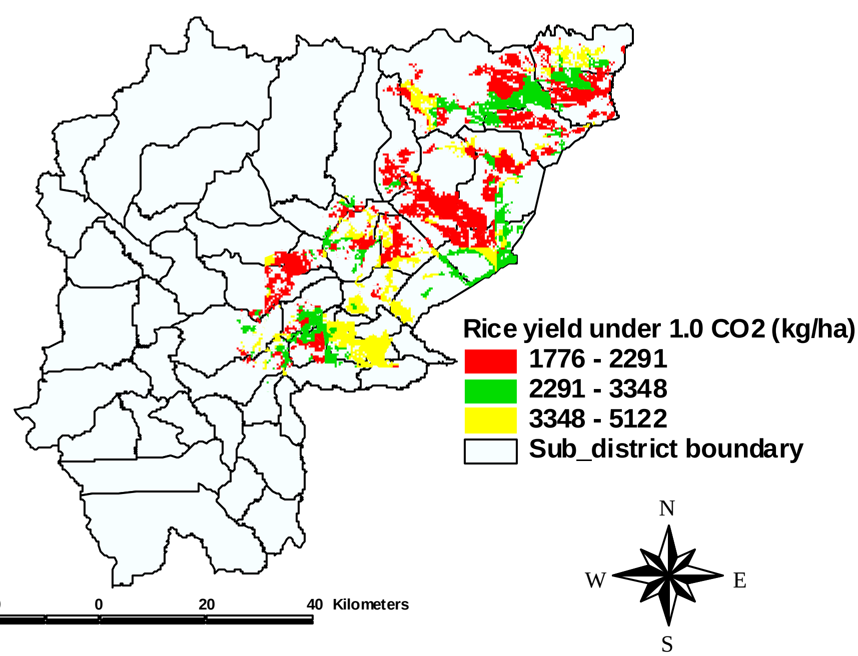

Figure 26. Simulated rice yield under the 1.0 CO_2 scenario of Sakaeo province

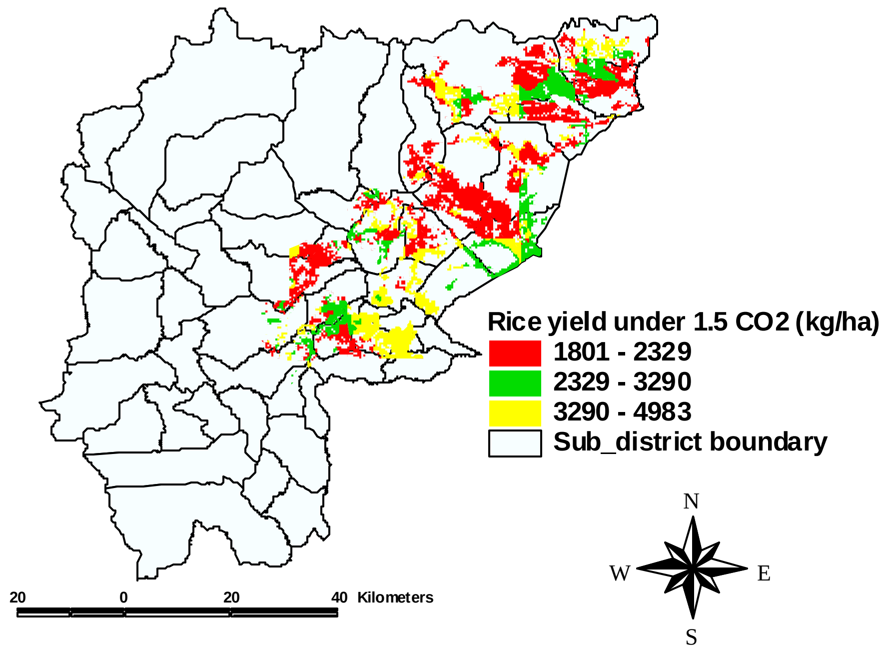

Figure 27. Simulated rice yield under the 1.5 CO_2 scenario of Sakaeo province

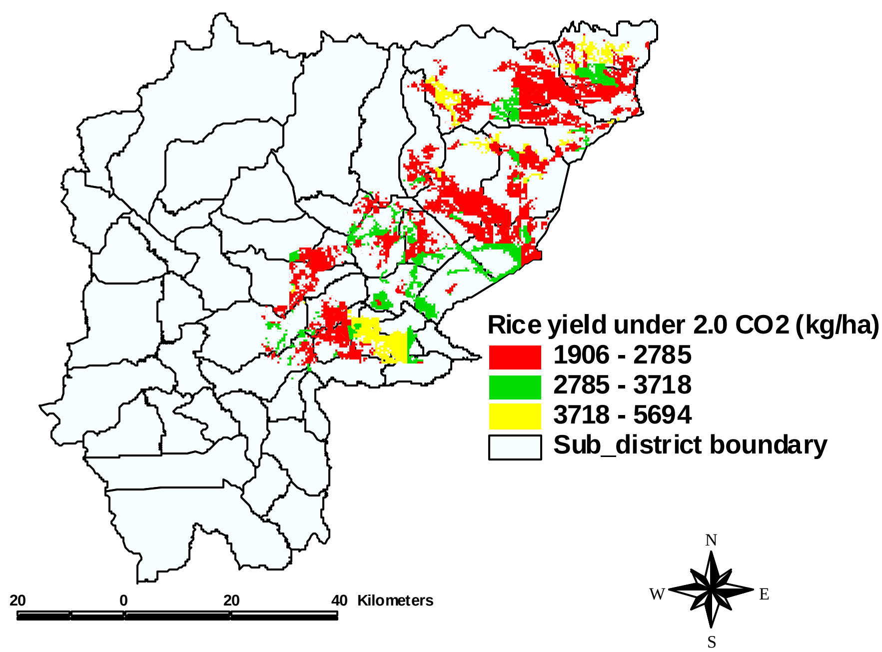

Figure 28. Simulated rice yield under the 2.0 CO_2 scenario of Sakaeo province