Impacts of Global Warming on the World Food Market According to SRES Scenarios

J. Furuya, S. Kobayashi, and S. D. Meyer

***Abstract*—**This research examines possible effects of climatic change focusing on global warming and its impacts on world agricultural product markets, by using a world food model developed to consider climate changes. GDP and population for each scenario were constructed by IPCC and climate data for each scenario was reported by the Hadley Center and are used in this research to consider results in different contexts. Production and consumption of primary agriculture crops of the world for each socio-economic scenario are obtained and investigated by using the modified world food model. Simulation results show that crop production in some countries or regions will have different trends depending on the context. These alternative contexts depend on the rate of GDP growth, population, temperature, and rainfall. Results suggest that the development of environment friendly technologies lead to more consumption of food in many developing countries. Relationships among environmental policy, clean energy development, and poverty elimination warrant further investigation.

***Keywords*—**Global warming, SRES scenarios, World food model.

I. Introduction

THE Intergovernmental Panel on Climatic Change (IPCC) reports that the average air temperature at the end of 21st century will rise 4.0 degrees Celsius from current levels in the case of the fossil energy intensive scenario [1]. Agricultural production will be affected by global warming through changes in yields and market prices. The dominant factor of rising temperature is the increasing concentration of carbon dioxide (CO2), which represents the greatest exhaust quantity among the greenhouse gases (GHG), which increased in value from 280ppm in the pre-industrial period to 386ppm in 2008.

Increasing concentration of CO2 leads to positive impacts on crop growth [2]; however, higher temperatures which form global warming can also obstruct crop growth [3]. The rise in temperature shortens the growth period due to early flowering and fruit bearing, and decreases the nourishment sent to the seed due to increased respiration, and seeds may not fully develop.

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Will producers and consumers of farm products be negatively affected by global warming? To provide an answer to the question, some synthesized models are developed. Parry *et al*. [4]-[6] combined a supply and demand model of agricultural products, i.e., Basic Linked System, and crop models such as CERES-Wheat. On the other hand, Wu *et al*. [7] combined a crop choice model, a crop yield model, i.e., EPIC, and a world food model, i.e., IFPSIM [8]. The former model is based on the supply and demand model of agricultural products and it is extended to a model which can evaluate climate changes. The latter model is based on the GIS based crop yield model and it is extended to the global scale model.

The approach of this research is similar to that of works of Parry *et al*. [4]-[6]. This research examines possible effects of climatic change focusing on global warming and its impacts on world agricultural product markets, by using a world food model (IFPSIM) developed by the Japan International Research Center for Agricultural Sciences (JIRCAS). The basic world food model was developed by Oga and Yanagishima [8] and is extended to consider changes in temperature and rainfall and their impact on crop yields [9]. Furthermore, the model is extended to a stochastic world food model [10]. The term of the outlook is 25 years, which is considered a mid-term projection in this context.

IPCC constructed several socio-economic based scenarios which are called SRES (Special Reports on Emission Scenarios) [11]. GDP and population measures for these scenarios are localized for each country by the Data Distribution Center (DDC) of IPCC and climate data such as temperature and rainfall for each scenario are reported by the Hadley Center. These data are combined for the scenarios used in this research.

II. Model

The JIRCAS world food model, named the International Food and Agricultural Policy Simulation Model (IFPSIM), consists of yield, area, demand, export, import, stock and price linkage functions for 14 commodities and 32 countries or regions [8]. Among the commodities covered are wheat, maize, other coarse grains, rice and soybeans along with other coarse grains include barley, rye, oats, millet and sorghum. Equilibrium prices are obtained from domestic and international market clearing conditions. Furuya and Koyama [9] estimated yield functions of crops including temperature and rainfall as variables, and replaced the original functions with the newly estimated functions in IFPSIM. The estimated yield function is as follows:

$$\ln YH_t = a + b_1 T + b_2 \ln TMP_t + b_3 \ln PRC_t \quad (1)$$

where YH is yield, T is time trend; TMP and PRC are temperature and rainfall in the flowering or silking season. If the climate data are non-stationary, the following difference function is estimated:

$$d\ln YH_t = a + b_2 d\ln TMP_t + b_3 d\ln PRC_t \quad (2)$$

where $d\ln \mathrm{YH}_t = \ln YH_t - \ln YH_{t-1}$, $d\ln TMP_t = \ln TMP_t - \ln TMP_{t-1}$, $d\ln PRC_t = \ln PRC_t - \ln PRC_{t-1}$. In this case, the parameter a in the function (2) is equivalent to the parameter b_1 in the function (1).

The estimated parameters of rainfall and temperature are used in the modified IFPSIM model. Parameters and data for rainfall and temperature are added to the database of the model and yield functions are changed to function (1). If the estimated parameters are not significant at the 10% level, these parameters are set equal to zero. The model covers 14 commodities, including livestock products. The base year of the simulation is 1998 and the projection period is from the base year to 2030, thus, the intercepts of functions are calibrated to the latest data, 2007.

Fig. 1 shows the flowchart of a leader country in the crop sector of the world food model. The leader country is selected from large exporters, for example, the U.S. is the leader country for wheat, maize, and soybeans. In this model, yield, area, production, imports, exports, stock and demand are endogenous variables. Population, gross domestic products (GDP), temperature and rainfall are exogenous variables.

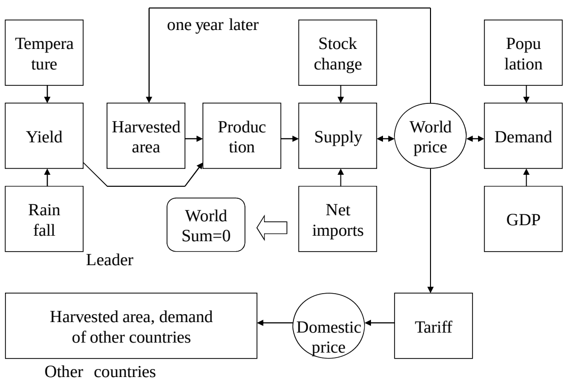

Fig. 1 Flowchart of a leader country of crop sector in the world food model

III. Data

A. Temperature and Rainfall

The data of temperature and rainfall are the average monthly numbers reported by the Hadley Center (HadCM3). Those data are 0.5° grid data and these are averaged to country level. Temperature and rainfall data are monthly data for the flowering or silking season of each crop, as indicated in the cropping calendar of the USDA [12]. Temperature and rainfall in large countries, such as the U.S., vary greatly across regions and therefore large countries are divided into regions based on the cropping map of the USDA [12]. The yield function for "other Africa" does not include climate variables due to insufficient climate data for the region.

The temperature and rainfall variables entering into the yield functions are exogenous to the world food model. To evaluate the effect of changes in temperature and rainfall during flowering or silking seasons on the world food market, these climate variables must be inserted in the model. These climate variables which are provided by DDC are fluctuated based on the initial parameters of the climate model; thus, it is better to smooth these variables for comparing impacts of differences in scenarios. The following simple linear temperature and rainfall models are estimated for obtaining trend lines:

$$TMP_{ijt} = a_{ij}^{T} + b_{ij}^{T} T \quad (3)$$

$$PRC_{ijt} = a_{ij}^{P} + b_{ij}^{P} T \quad (4)$$

where i is the number of country and j is the number of crop, T is time trend.

B. GDP and Population

The IPCC Data Distribution Center (DDC) provides forecasted GDP and population for each country in the SRES A1B, B1, A2, and B2 scenarios [11]. These data are reported in five year intervals and annual data sets are constructed using linear interpolation. The A1B scenario assumes that trade liberalization progresses and the economic growth rate is high. Furthermore, technological progress for the energy industry is well balanced between fossil and clean energies. The annual per capita income is $21,000 in 2050, while population reaches 8.7 billion people. The A2 scenario assumes that each country holds its own culture and trade, labor movement, and that technology transfer is restricted. Given these constraints, per capita GDP grows slowly and the annual average per capita income is $7,200 in 2050, while the world population reaches 11 billion people.

The B1 scenario assumes that consumption of natural resource is at a low level and low CO2 emission energy technology is developed, while the low population growth rate and high economic growth rate are same as those in the A1 scenarios. The B2 scenario assumes that trade is restricted and the cultural practices of each country are maintained such as those in the A2 scenario; however, low CO2 emission energy technology is developed. The per capita income is $12,000 in 2050 while the world population reaches 9.4 billion people in this scenario. Fig. 2 and Fig. 3 show world GDP and population out to the year 2100 respectively. GDP and Population data are aggregated to the 32 countries and regions for the model simulations.

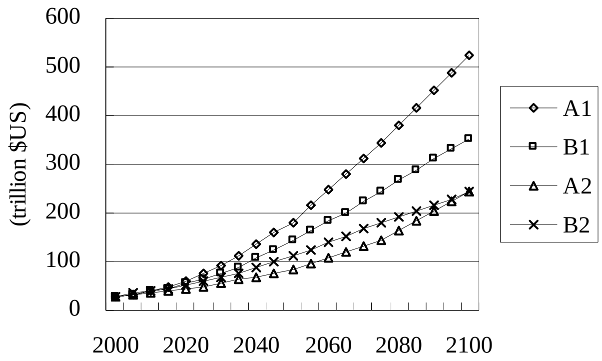

Fig. 2 Total of GDP in the world for SRES scenarios
Source: IPCC Date Distribution Center

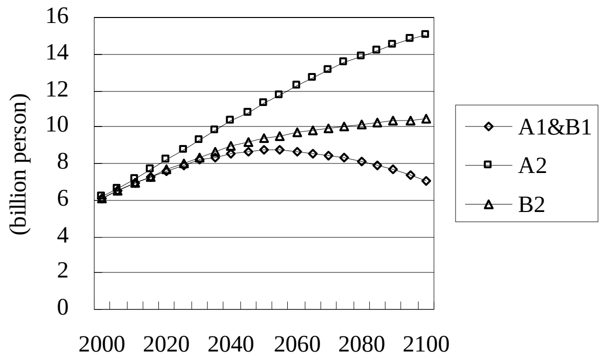

Fig. 3 Population in the world for SRES scenarios
Source: IPCC Date Distribution Center

IV. Simulation Results

A. Assumptions

The assumptions for the simulation are as follows; (1) the cropping calendar is fixed, (2) the cropping region is fixed, (3) the climatic variables directly affect yields, (4) the temperature, which is measured in degrees Celsius for all countries and regions follows the data of HadCM3 for each scenario, (5) all parameters are fixed, and (6) current trade policy is not changed, i.e., tariff rates of the base year are continued throughout the projection.

The yield functions of the simulation model for the U.S. and the European Union for wheat, maize and other coarse grains, rice, and soybeans for all countries, is specified as follows:

$$\ln YH_t = a + 0.1\ln(PI_{t-1}/PI_{t-2}) + b_1T + b_2\ln TMP + b_3\ln PRC \quad (5)$$

where a is the calibrated intercept of these functions, PI is the subsidized producer price, b_1 is the parameter of the time trend, i.e., the annual increase in yield, b_2 is the parameter for temperature, and b_3 is the parameter for rainfall. The yield function of the simulation model of other countries for these crops is specified as function (1).

B. Partial Impacts of Changes in Climate Variables on Production

Changes in production and consumption of crops in the simulation are based not only on climate conditions but also on macro economic conditions. Focusing on partial impacts of changes in temperature and rainfall on the market of these crops, results of each scenario and the baseline, which climate variables are fixed at the base year, are compared.

Table I shows of the percent decline in production of crops in the world under the climate change for average through from 2028 to 2030. The decrease rate is dividing of the difference between the production in a simulation and those in a baseline by that in the baseline. Results show that if climate variables change, productions of wheat and maize will decrease more than rice. According to the results, decrease rates in scenario A2 and B2 of wheat, maize, and other coarse grains are higher than those of A1B and B1. The results suggest that lower economic growth rate and higher population growth rate will extend decreases of productions of these crops under global warming.

TABLE 1
Percent Decline in Production in the World

	A1B	B1	A2	B2
Wheat	7.100	7.038	7.612	7.715
Maize	7.004	7.118	7.193	7.433
Coarse grains	5.191	5.268	5.723	6.050
Rice	4.961	5.087	5.059	4.829
Soybeans	6.207	6.146	6.142	6.052

C. Total Impacts on Production

First, changes in production of wheat, maize, and soybeans in the U.S. are examined. The U.S. is the leader country for these crops in the model. Fig. 4 shows the simulation results of production of wheat through 2030. These results are calibrated to the latest available historical data. The production of wheat will increase from 53 million metric tons (MT) in 2010 to 62 million MT in 2030 for all scenarios; however, the path of production is differs in scenario A1B when compared to the others. The production of wheat in the A1B scenario is stable at first and then increase after 2015, while productions in the other scenarios grow linearly. The difference comes from the steep rise in GDP in the A1B scenario.

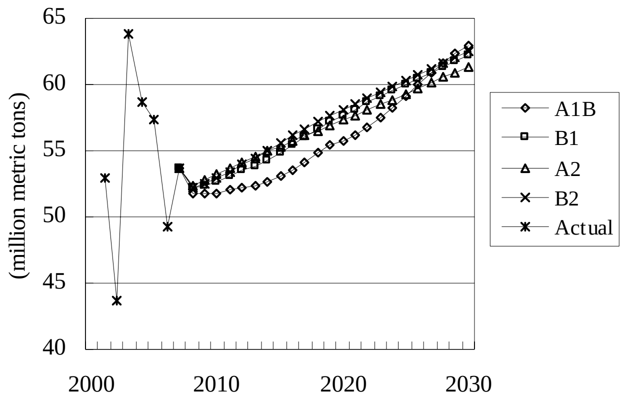

Fig. 4 Production of wheat in the U.S.

Fig. 5 shows the simulation results of production of maize during the same period. The production of maize in the A2 scenario increases from 310 million MT in 2010 to 375 million MT in 2030, and the B1 and B2 scenarios also follow this trend. The production growth rate of maize in the A1B scenario is the lowest among the scenarios, because productions of maize in Argentina and Brazil will increase under the condition of climate, GDP, and population of the A1B scenario.

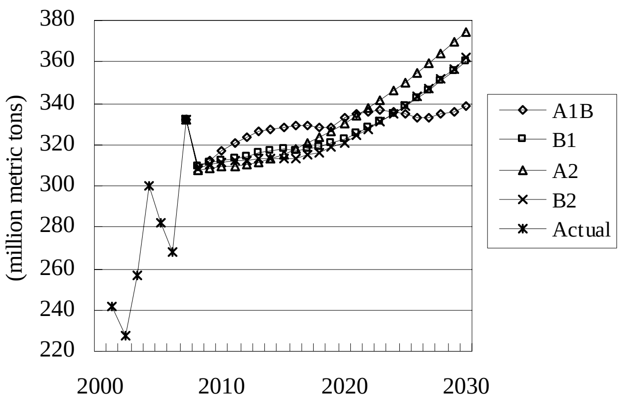

Fig. 5 Production of maize in the U.S.

Fig. 6 shows the simulation results for production of soybeans in the U.S. The production paths are clearly different in each scenario, and production will hit ceiling before 2030 for all scenarios. In particular, production in the A2 scenario decreases from 80 million MT in 2010 to 74 million MT in 2030. Economic growth in the A2 scenario is the slowest and income elasticity of demand of meal and feed are relatively high. The slower economic growth decreases the demand for soybeans. Furthermore, temperature levels in the A2 scenario are higher than that of the other scenarios. The industry related to soybeans in the U.S. could incur substantial damage under the restricted trade and fossil energy dependent society.

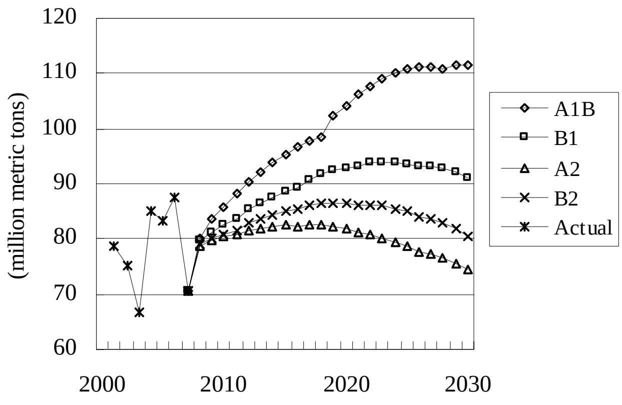

Fig. 6 Production of soybeans in the U.S.

Fig. 7 shows the simulation results of effects on production of rice in China. The production outlooks are distinct for the different SRES scenarios: Production of rice will increase under scenarios A2 and B2 while it will decrease under scenarios B1 and A1B. Changes in temperature and rainfall do not affect changes in production of rice in China because the estimated parameters of climate variables in the yield function of rice are zero do to offsetting effects. Higher temperature will decrease the nourishment sent to the seed, on the other hand, it will decrease probability of cold-weather damage of the crop in this country. The differences in GDP for each scenarios leads to differences in trends in rice production. Higher GDP leads to smaller demand for rice due to the negative income elasticity of demand of rice, and the changes in demand decrease the production of rice.

The global warming affects crop production paths in the following two ways; changes in GDP and population and changes in temperature and rainfall. The latter changes result from the former changes.

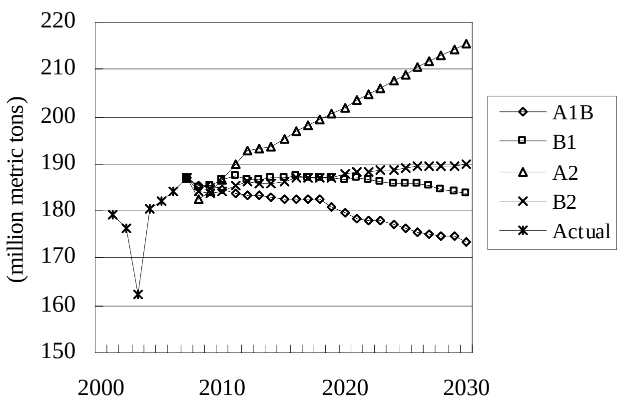

Fig. 7 Production of rice in China

D. Total Impacts on Consumption

First, increasing rates of consumption in two large population countries are investigated. Table II shows the increasing rate of per capita consumption of several primary agricultural commodities in China. The rate of growth shown is the difference in consumption between 2010 and 2030 divided by consumption in 2010. The growth rate of the A1B scenario is higher than other three. Particularly, consumption of coarse grains and soybeans increase steadily under the A1B scenario, because higher income leads to greater consumption of livestock products and feed input demand will increase. The consumption of rice decreases for all scenarios due to the negative income elasticity of demand.

TABLE II
GROWTH RATE OF PER CAPITA CONSUMPTION IN CHINA

	A1B	B1	A2	B2
Wheat	43.43	32.83	28.86	39.99
Maize	50.08	37.56	20.43	33.14
Coarse grains	72.21	38.06	19.86	45.67
Rice	-9.25	-5.04	-2.81	-5.95
Soybeans	35.48	22.92	15.06	24.94

Table 3 shows the growth rate of per capita consumption in India. The growth rate of consumption of rice is quite high, while that of maize is almost zero. The growth rate for soybeans is high for A1B, B1, and B2 scenarios; however, in scenario A2 it is quite a bit lower. This distinction comes from the restricted trade under the A2 scenario.

TABLE III
GROWTH RATE OF PER CAPITA CONSUMPTION IN INDIA

	A1B	B1	A2	B2
Wheat	54.98	62.24	22.52	51.55
Maize	6.97	12.53	-1.15	8.33
Coarse grains	28.36	36.21	16.85	33.82
Rice	100.42	102.61	72.08	91.52
Soybeans	84.95	92.72	16.69	68.73

Second, differences in the growth rate of per capita consumption of B1 and A1B are investigated. Both scenarios emphasize economic progress; however, the B1 scenario assumes that low CO2 emission energy technology will be developed. Thus, the difference in scenario is regarded as the difference of technological progress for clean energies. Fig. 8 shows the world map of differences in the growth rate of per capita consumption of wheat in the B1 and A1B scenarios. The map shows that per capita consumption of wheat in African and South Asian countries will increase under the scenario of technological progress resulting in low CO2 emissions.

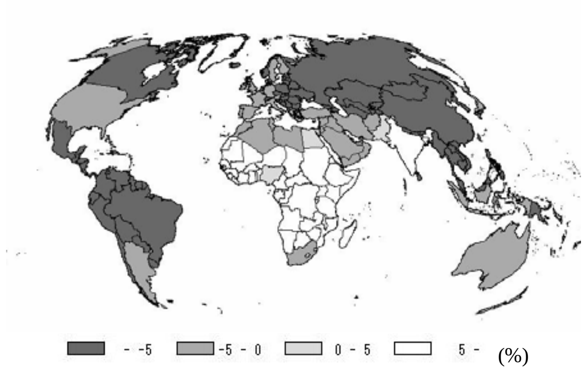

Fig. 8 Differences in increasing rate of per capita consumption of wheat for B1 and A1B

V. CONCLUSION

Simulation results show that crop production in some countries or regions will have different paths depending on several conditioning factors. These conditioning factors include stronger GDP growth, population, temperature, and rainfall. Changes in the latter climatic variables are affected by differences in assumptions about technological progress in the development of low CO2 emission energy production and economic growth. Results suggest that the development of environment friendly technologies leads to greater consumption of food in many developing countries. Relationships among environmental policies, clean energy development, and poverty elimination are worthy of future study. These results are based on the mid-term simulation where available cropping regions and the parameters for the supply and demand model are fixed. To obtain more accurate simulation results, it is very likely that a long-term supply and demand model considering changes in income elasticities and shifts of cultivation zones is required.

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