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Impacts of Climatic Change on World Agricultural Product Markets: Estimation of Macro Yield Functions

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Abstract

Climatic change through global warming and drought is a major issue for agricultural production. Most researchers who discuss climate changes report the yield changes estimated by using crop process models; however, studies focusing on the impact of climatic change on agricultural product markets are very few. This paper examines the relationship between climatic change and world food markets, i.e., supply and demand of crops, by using a world food model and newly estimated yield functions. These yield functions include rainfall and temperature as climate variables, and the estimated parameters are used in the world food model. The stationarity of these yield data is tested and appropriate functional forms are selected. The results suggest that yields of major crops will decrease because of rising temperatures in many countries and regions, however, market price impacts of changes in production of these crops are not large because of trade. The countries which suffer severe damage because of higher temperature may need to consider changes in cropping patterns and practices.

Discipline: Agricultural economics
Additional key words: global warming, world food model, crop yields, agricultural product markets

Introduction

Global warming caused by concentration of carbon dioxide in the atmosphere will be a major issue in world food markets over the next century. Agricultural production will be affected by climatic changes, such as rising temperature or droughts, mainly through changes in crop yields. The Food and Agriculture Organization of the United Nations (FAO)[1] reported global warming is on balance expected to bring benefits for agriculture; even though it will lead to drought and an increase in agricultural pests in some regions in the mid-term. On the other hand, the Intergovernmental Panel on Climatic Change (IPCC)[3] claimed that most studies indicate that projected warming will negatively affect crop yields in the long term.

The relationship between yield or productivity and climate changes has been investigated since the late 1950's. These studies are based on crop models and expand the relationship between biomass and environment to a regional or global scale. The global model focusing on productivity in dry matter production by Lieth[5] is a forerunner of these studies. Recent models are more sophisticated; for example, Jones and Thornton[4] evaluated the impacts of climate changes on maize production by using a rainfall model, a crop model, and outputs of the Global Circulation Model (GCM).

Development of these biological or ecosystem studies has led to more accurate projection of changes in global vegetation patterns. However, environmental changes in a region will affect agricultural productions in other regions through trade in agricultural products. Considering relationships between food producers and consumers through trade, it is likely that climate change, such as global warming, may cause drastic changes in agricultural markets even in the mid-term. Parry et al.[6] combined crop models, such as CERES-Wheat, and a world food trade model, i.e., Basic Linked System (BLS), and evaluated the risk of hunger. Their model is quite scientific and well organized; however, it is difficult to understand the estimated impacts of climate change in their model and it is likely that there are some problems of aggregation or scale-up in moving from field-level

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models and data to national or global models. It is difficult to think that the parameters of a field model and a national model are the same.

This paper examines possible impacts of climatic change, focusing on global warming, on world agricultural product markets by estimating macro yield functions and using the world food model of JIRCAS (IFPSIM)[7]. The world food model is developed by Oga[7,8] and Yanagishima[7] and it is used for agricultural policy evaluations. The world food model of the International Food Policy Research Institute (IFPRI) (IMPACT)[9] has the same model structure. The term of the outlook is 25 years, i.e., a mid-term projection.

Methods

1. Yield function

Climate variables such as rainfall and temperature will affect crop production. Crop production is yield times harvested area, and it is assumed that only yield is affected by these climate variables. First, the yield data is tested for non-stationarity by using an Augmented Dickey-Fuller (ADF) test. If the yield data are stationary, the following double-log form yield function will be estimated:

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

where YH is yield, T is time trend, PRC is rainfall measured in millimeters, and TMP is temperature measured in degrees Celsius. The estimation method is OLS and if there are serial correlations in the error term, an autoregressive (AR) model is applied. The number of lags of the AR model is determined following the value of Akaike Information Criterion (AIC). Parameters b_2 and b_3 are the elasticities of yield for precipitation and temperature, and these indicate percent changes in yield due to a 1% increase of these variables.

If the yield data are non-stationary, the following first difference function will be estimated:

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

where $d\ln YH_t = \ln YH_t - \ln YH_{t-1}$, $d\ln PRC_t = \ln PRC_t - \ln PRC_{t-1}$, $d\ln TMP_t = \ln TMP_t - \ln TMP_{t-1}$.

2. Data

The data of rainfall and temperature are the average numbers reported by the Global Historical Climatology Network (GHCN: http://www.ncdc.noaa.gov/cgi-bin/res40.pl) of the National Climatic Data Center (NCDC). The climatic variables selected are monthly data for the flowering or silking season of each crop, as indicated in the cropping calendar of the USDA[10]. If the season is not posted in the calendar, one month before the harvesting season is selected as the flowering or silking season. Table 1 shows the selected seasons for each country and commodity. The basic estimation period is from 1961 to 2000.

Rainfall and temperature in large countries such as

Table 1. Selected flowering or silking season for each country and commodity

	Wheat	Maize	Other coarse grains	Rice	Soybeans
USA	May, Jun Jun, Jul (SW)	Jul, Aug	Jun, Jul (BA, OA) Aug (SG)	Jul, Aug	Jul, Aug
EU					
Austria	May, Jun	Jul, Aug	Apr, May		Jul, Aug
Belgium	May, Jun	Jul, Aug	Apr, May		
Denmark	May, Jun		Jul, Aug		
Finland	May, Jun		Apr, May		
France	May, Jun	Jul, Aug	Aug	Aug, Sep	Jul, Aug
Germany	Jun, Jul	Jul, Aug	Apr, May, Jun, Jul		Jul, Aug
Greece	May, Jun	Jul, Aug	Apr, May	Aug, Sep	Jul, Aug
Ireland	May, Jun		Apr, May		
Italy	May, Jun	Jul, Aug	Apr, May	Aug, Sep	Jul, Aug
Luxembourg	May, Jun		Apr, May		
Netherlands	May, Jun	Jul, Aug	Apr, May		
Portugal	May, Jun	Jul, Aug	Apr, May	Aug, Sep	
Spain	Apr, May	Jul, Aug	Apr, May	Aug, Sep	Jul, Aug
Sweden	Apr, May		Apr, May		
UK	May, Jun		Apr, May, Jun		

(continued)

Other coarse grains: Barley (BA), rye, oats (OA), millet, sorghum (SG).
SW: Spring wheat.

Table 1. Selected flowering or silking season for each country and commodity (continued)

	Wheat	Maize	Other coarse grains	Rice	Soybeans
Japan	May	Jul, Aug	Apr	Aug, Sep	Aug, Sep
Other W. Europe					
Estonia	Jun	Jul	Jun, Jul		
Norway	Apr, May		Jul, Aug		
Canada	May, Jun Jul (SW)	Jul, Aug	Jul		Jul, Aug
Australia	Sep, Oct		Aug, Sep		
New Zealand	Sep, Oct		Aug, Sep		
ODC (S. Africa)	Sep	Jan, Feb			
East Europe					
Bulgaria	May, Jun	Jul, Aug	Jul, Aug	Aug, Sep	Aug, Sep
Hungary	Apr, May	Jul, Aug	Jul, Aug	Aug, Sep	Aug, Sep
Poland	May, Jun	Jul, Aug	Apr, May		
Romania	May, Jun	Jun, Jul	Jul, Aug	Aug, Sep	Aug, Sep
Czech, Slovakia	May, Jun	Jun, Jul	Jul, Aug		Aug, Sep
Yugoslavia	May, Jun	Jul, Aug	Jul, Aug	Aug, Sep	Aug, Sep
Former USSR					
Russia	Jun Jul (SW)	Jul	Jun, Jul	Aug, Sep	Aug, Sep
Ukraine	Jun	Jul	Jun, Jul	Aug, Sep	Aug, Sep
Kazakhstan	Jun	Jul	Jun, Jul	Jun, Jul	Jun, Jul
Uzbekistan	Feb, Mar	Jul	Jun, Jul	Aug, Sep	Aug, Sep
Mexico	Feb, Mar	Jul, Aug	Sep, Oct Apr, May (SG)		
Brazil	Jul, Aug	Jan		Apr, May	Jan, Feb
Argentina	Sep, Oct	Dec, Jan	Jan, Feb		
Other L. America					
Bolivia	Jul, Aug	Jan	Jul, Aug	Apr, May	Jan, Feb
Chile	Sep, Oct	Dec, Jan	Sep, Oct	Jan	Feb, Mar
Columbia	Jul, Aug	Jan	Jul, Aug	Apr, May	Jan, Feb
Peru	Jul, Aug	Jan	Jul, Aug	Apr, May	Jan, Feb
Paraguay	Jul, Aug	Jan	Jul, Aug	Jan	Jan, Feb
Uruguay	Sep, Oct	Dec, Jan	Sep, Oct	Jan	Feb, Mar
Venezuela	Jul, Aug	Jan	Jul, Aug	Apr, May	Jan, Feb
Nigeria	Aug, Sep	Aug, Sep	Aug, Sep	Aug, Sep	Aug, Sep
Egypt	Mar, Apr	Jul	Mar	Sep	
Other N. E.					
Saudi A.	Mar, Apr	Jul	Mar	Sep	
Syria	Mar, Apr	Jul	Mar	Sep	
Turkey	Feb, Mar	Jul	Mar	Sep	
Algeria	Mar, Apr	Jul	Mar, Apr	Sep	
Libya	Mar, Apr	Jul	Mar, Apr		
Morocco	Mar, Apr	Jul	Mar, Apr	Sep	
Tunisia	Mar, Apr		Mar, Apr		
India	Jan, Feb	Sep, Oct	Sep, Oct	Aug, Sep, Oct	Aug, Sep
Pakistan	Feb, Mar	Sep, Oct	Sep, Oct	Aug, Sep	Aug, Sep
Bangladesh	Jan, Feb	Sep, Oct	Sep, Oct	May, Jun	Aug, Sep
Indonesia		Jan, Feb		Jan, Feb	
Thailand		Jun		Sep	
Malaysia		Sep		Feb	
Philippine		Jun		Jul, Aug	
R. Korea	May	Jul, Aug	Apr	Aug, Sep	Aug, Sep
China	Apr, May	Jun, Jul		Jul, Aug	Jul, Aug

Other coarse grains: Barley (BA), rye, oats (OA), millet, sorghum (SG).
SW: Spring wheat.

the United States vary greatly across regions. Large countries are divided into regions based on the cropping map of the USDA[10]. Table 2 shows the latitude and longitude of the selected regions for each crop. Fig. 1 and Fig. 2 show the selected cropping regions of maize in the United States and soybeans in China, respectively as examples. Climatic data of regions such as the European Union are weighted by countries' shares of production for each crop.

The crops in the model are wheat, maize, other coarse grains, rice, and soybeans. The other coarse grains include barley, rye, oats, millet, and sorghum. The countries and regions of this study are based on those in the International Food and Agricultural Policy Simulation Model (IFPSIM)[7] of JIRCAS. Yield functions for other African, other East Asian, and other developing countries are not estimated due to insufficient climate data. The yield and production data for each crop is that of the FAO Statistical Database[2]. The yield of other coarse grains is the summation of production of all five crops divided by total harvested area.

3. Simulation of the world food model

The estimated parameters of rainfall and temperature are used in the modified version of the IFPSIM[7]. The model is written by FORTRAN program and functions are included in the program because of the easiness of developments, while these functions are different files in the original model. Parameters and data of rainfall and temperature are added to the data base of the model and yield functions are changed as mentioned later. 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 period of the projection is from the base year to 2025.

The assumptions of 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 measured in degrees Celsius of all

Table 2. The latitude and longitude of the selected regions for each crop

	Wheat	Maize	Other coarse grains	Rice	Soybeans
USA	32-46N 95-105W 37-42N 82-91W 42-49N 111-120W 46-49N 95-111W	38-46N 82-102W	41-49N 87-120W (BA, OA) 26-41N 88-103W (SG)	31-37N 88-93W 27-31N 91-98W 36-40N 119-123W	38-46N 82-100W 29-38N 85-93W
Canada	-44N 76-84W -54N 95-114W	-44N 77-84W -46N 74-76W	-54N 95-114W (BA)		-43N
Australia	25-31S 146-151E, 31-39S 131-150E 29-35S 112-124E		25-31S 146-151E 31-39S 131-150E 29-35S 112-124E (BA)		
Russia	-62N -60E -69N 56-100E -56N -56E	-52N -50E	-69N -100E (BA)		
Mexico	105W- 17-22N 99-105W	-22N 91W-	17-22N 99W- (SG)		
Brazil	20S- 48-55W	-13S -49W 13S- 58W-		-9S -50W 9S-	12-30S 47-58W
Argentina	30-39S 57-65W	30-39S 57-65W	30-38S 60-65W (SG)		30-36S 58-65W
India	25N- 74E-	Whole country	Whole country	Whole country	20-28N 74-84E
Pakistan	71E-	71E-	71E-	71E-	71E-
Indonesia		5-10S 105-116E		5-10S 105-116E	
China	27-38N 102-121E	23-31N 102-110E 33-40N 110-120E 40-48N 120-130E		18-35N 100-123E	34-40N 110-120E 40-47N 120-130E

Other coarse grains: Barley (BA), rye, oats (OA), millet, sorghum (SG).

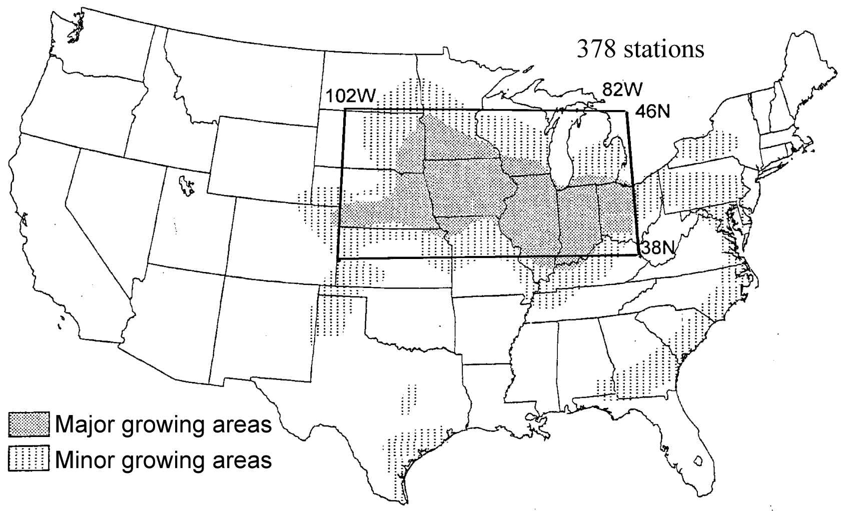

Fig. 1. Cropping region of maize in the United States
This map was originally drawn by the USDA[8] and modified.

countries and regions increases 0.05% per year, and (5) all parameters are fixed. The fourth assumption means that if the current temperature is 20ºC, it will increase 0.5ºC in the next 50 years and if the temperature is 30ºC, it will increase 0.8ºC during the same period. The IPCC[3] reported that the temperature of the GCM outputs will increase from 0.8 to 2.6ºC by 2050, then, our assumption of rising temperature is moderate.

The yield function of the simulation model of the United States and the European Union for wheat, maize, other coarse grains, and rice is specified as follows:

$$\ln YH_t = \ln YH_{t-1} + 0.1\ln(PI_{t-1}/PI_{t-2}) + \ln(1 + b_1) + b_2\ln PRC + b_3\ln TMP + a \quad (3)$$

The yield function of the simulation model of other countries for these crops and all countries for soybeans is specified as follows:

$$\ln YH_t = \ln YH_{t-1} + \ln(1 + b_1) + b_2\ln PRC + b_3\ln TMP + a \quad (4)$$

where PI is the subsidized producer price, b_2 is the parameter of rainfall, b_3 is the parameter of temperature, b_1 is the parameter of the time trend, i.e., the annual increase in yield, and a is the calibrated intercept of these functions.

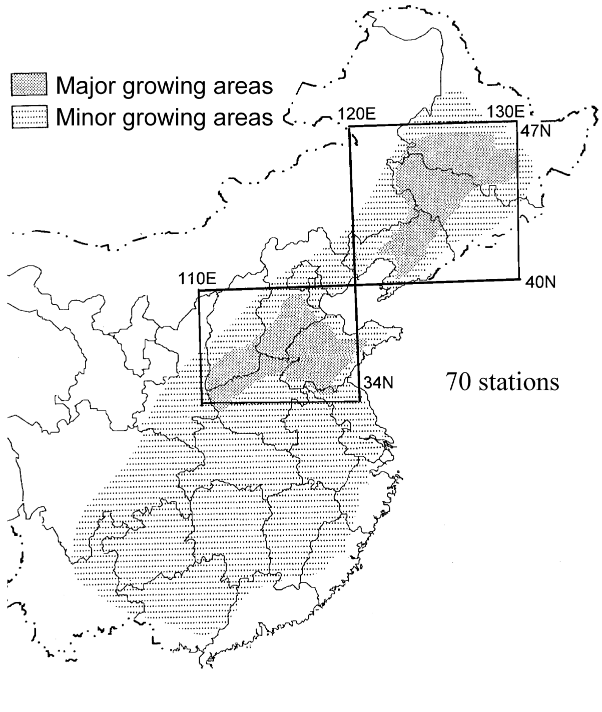

Fig. 2. Cropping region of soybeans in China
This map was originally drawn by the USDA[8] and modified.

Results

1. Estimation of yield functions

Table 3 through Table 7 show the results of the double log linear function (1) or the log first difference yield function (2). These Tables also show the results of ADF tests of yield data. If the probability of non-stationarity is less than 10%, the yield function (1) is estimated; otherwise, the yield function (2) is estimated. In the case of non-stationary yield data, the parameter of the time trend is the intercept of function (2). The estimation periods of these functions are determined by the availability of yield or climate data.

The results show that rainfall has a significant positive effect on production of maize and other coarse grains. These crops are basically upland crops and yields

Table 3. The results of the estimation of yield functions of wheat for selected regions

Countries	Trend	Rainfall	Temp.	Adj.R^2	DW	Est.	Period	ADF pv
USA	0.0144*	0.0180	-0.2414	0.1586	2.026	AR1	62-00	0.1080
	(1.73)	(0.30)	(-0.87)					(D)
EU	0.0285***	-0.1170*	-1.0760***	0.9748	1.656	OLS	61-00	0.0671
	(38.04)	(-1.89)	(-4.82)					(L)
Japan	0.0105***	-0.1191	0.3652	0.7753	1.568	OLS	61-00	0.0909
	(7.10)	(-1.42)	(1.22)					(L)
Canada	0.0308	0.3443***	-0.0961	0.3758	1.703	OLS	62-89	0.1344
	(0.92)	(3.94)	(-0.20)					(D)
Australia	0.0095***	0.4427***	0.3681	0.4949	2.122	OLS	61-93	0.0818
	(3.18)	(3.93)	(0.53)					(L)
New Zealand	0.0186***	-0.2137***	-0.6004***	0.4115	1.881	AR6	62-00	0.9879
	(4.42)	(-3.16)	(-3.28)					(D)
East Europe	0.0171	-0.0617	-0.6596***	0.2038	2.555	OLS	62-00	0.8306
	(1.11)	(-0.76)	(-3.20)					(D)
Former USSR	0.0120	0.2995	-0.9399*	0.5103	2.001	AR1	62-00	0.1930
	(0.80)	(1.58)	(-1.70)					(D)
Mexico	0.0275	0.0027	0.3716	-0.0431	2.420	OLS	62-92	0.8398
	(1.48)	(0.18)	(0.84)					(D)
Brazil	0.0288	-0.1986**	-0.4820	0.5579	1.978	AR2	62-00	0.4154
	(1.60)	(-2.56)	(-1.07)					(D)
Argentina	0.0168***	0.0778	-0.2900	0.7224	2.039	AR1	61-00	0.0037
	(7.10)	(1.30)	(-0.57)					(L)
Other L. A.	0.0198***	-0.0469	-0.8420**	0.8961	2.223	AR1	61-90	0.0140
	(3.52)	(-0.79)	(-2.24)					(L)
Nigeria	0.0081	-0.0799	-0.0999	0.4731	2.010	AR7	62-80	0.1598
	(0.56)	(-0.55)	(-0.48)					(D)
Egypt	0.0253**	-0.0210**	-0.3481**	0.1971	2.047	OLS	62-96	0.8916
	(2.38)	(-2.20)	(-2.32)					(D)
India	0.0316***	0.0504**	-0.3325*	0.9753	2.134	AR1	61-00	0.0937
	(18.65)	(2.09)	(-1.99)					(L)
Pakistan	0.0289**	-0.0413**	-0.4821***	0.2209	2.503	OLS	62-94	0.3609
	(2.11)	(-2.26)	(-3.08)					(D)
Bangladesh	0.0368	0.0029	-1.6634**	0.1510	1.683	OLS	62-90	0.6044
	(1.69)	(0.17)	(-2.63)					(D)
Rep. of Korea	0.0147	0.0301	0.1775	0.2235	1.994	AR2	62-00	0.2627
	(1.02)	(0.70)	(0.22)					(D)
China	0.0480***	-0.0799	-0.5303*	0.0928	2.051	OLS	62-00	0.5865
	(3.52)	(-1.55)	(-1.81)					(D)

***: 1% significant, **: 5% significant, *: 10% significant.
ADF pv: Provability values of Augmented Dickey-Fuller test.
L: Log linear function is estimated. D: Difference function is estimated.

Table 4. The results of the estimation of yield functions of maize for selected regions

Countries	Trend	Rainfall	Temp.	Adj.R^2	DW	Est.	Period	ADF pv
USA	0.0185*** (17.53)	0.1855*** (2.80)	-1.2259*** (-3.88)	0.8976	1.806	OLS	61-00	0.0005 (L)
EU	0.0294** (2.58)	0.1377*** (3.26)	-0.1349 (-0.47)	0.2372	2.499	OLS	62-00	0.5240 (D)
Japan	-0.0023 (-0.22)	-0.0218 (-0.28)	0.0677 (0.10)	0.2934	1.820	AR2	62-00	0.5343 (D)
Canada	0.0120** (2.08)	0.0919* (1.80)	-0.3916 (-1.34)	0.6729	2.005	AR2	62-89	0.8468 (D)
East Europe	0.0126 (0.91)	0.4759*** (6.66)	0.0510 (0.11)	0.6856	2.031	AR1	62-00	0.8114 (D)
Former USSR	0.0037 (0.25)	0.0764 (1.24)	-0.7638** (-2.14)	0.4504	2.027	AR1	62-00	0.8610 (D)
Mexico	0.0242* (1.86)	-0.0634 (-1.58)	-0.0152 (-0.06)	0.0170	1.759	OLS	62-90	0.1707 (D)
Brazil	0.0202** (2.37)	0.0224 (0.29)	-1.152 (-1.36)	0.2645	2.110	AR2	62-00	0.8361 (D)
Argentina	0.0290*** (3.43)	0.2521*** (4.46)	-1.1910*** (-2.79)	0.7556	2.114	AR2	63-00	0.2690 (D)
Other L. A.	0.0210*** (4.10)	-0.0074 (-0.18)	-0.0767 (-0.78)	0.2494	2.294	AR1	63-91	0.2972 (D)
Nigeria	0.0183 (0.36)	0.7189 (1.73)	-2.6916 (-0.70)	0.0741	2.164	OLS	62-80	0.1362 (D)
India	0.0174** (2.12)	-0.0770 (-0.85)	-1.8611 (-1.53)	0.4787	2.051	AR2	62-00	0.4568 (D)
Pakistan	0.0113*** (9.59)	0.0049 (0.38)	-0.3088 (-1.18)	0.8164	2.204	OLS	61-94	0.0274 (L)
Bangladesh	0.0071 (0.33)	0.0735 (1.52)	-0.5205 (-0.37)	0.1890	1.832	AR1	62-90	0.2684 (D)
Indonesia	0.0273** (2.73)	-0.0467 (-1.41)	-0.0753 (-0.28)	0.5941	2.240	AR2	62-90	0.1929 (D)
Thailand	0.0154 (0.86)	-0.0378 (-0.50)	-2.4399** (-2.25)	0.2487	2.136	AR1	62-00	0.5094 (D)
Malaysia	0.0087 (0.67)	-0.1283 (-1.29)	1.9240 (0.91)	0.5536	2.347	AR8	62-00	0.9429 (D)
Philippine	0.0240*** (6.72)	0.0068 (0.50)	0.0399 (0.16)	0.2167	2.141	AR3	62-92	0.9959 (D)
Rep. of Korea	0.0452** (2.16)	0.0927 (1.04)	-0.5742 (-0.81)	0.1568	1.966	AR1	62-00	0.9583 (D)
China	0.0367*** (5.99)	0.1683*** (2.88)	-0.9130* (-1.98)	0.4530	1.927	AR2	62-00	0.7218 (D)

***: 1% significant, **: 5% significant, *: 10% significant.
ADF pv: Provability values of Augmented Dickey-Fuller test.
L: Log linear function is estimated. D: Difference function is estimated.

Table 5. The results of the estimation of yield functions of other grains for selected regions

Countries	Trend	Rainfall	Temp.	Adj.R^2	DW	Est.	Period	ADF pv
USA	0.0200** (2.55)	0.0292 (0.46)	-1.5252*** (-3.66)	0.5121	2.200	AR1	62-00	0.1602 (D)
EU	0.0179*** (16.47)	-0.0173 (-0.22)	-0.7720*** (-2.96)	0.9200	1.791	OLS	61-00	0.0530 (L)
Japan	0.0077*** (6.53)	-0.0950 (-1.51)	-0.3487** (-2.34)	0.6374	1.637	OLS	61-00	0.0553 (L)
Canada	0.0177*** (12.80)	0.1889*** (3.34)	-0.4890* (-1.85)	0.8710	1.811	AR2	61-89	0.0376 (L)
Australia	0.0189*** (9.97)	0.4234*** (4.82)	-0.1104 (-0.29)	0.8212	2.384	OLS	61-93	0.0068 (L)
New Zealand	0.0186* (1.95)	0.0732 (1.01)	-0.0799 (-0.78)	0.2742	2.190	AR2	62-00	0.7031 (D)
East Europe	0.0076 (0.53)	-0.0179 (-0.39)	-0.4919** (-2.20)	0.0706	2.252	OLS	62-00	0.9247 (D)
Former USSR	0.0129 (1.32)	0.5057** (2.48)	-1.5887*** (-3.26)	0.6597	1.982	AR2	62-00	0.3715 (D)
Mexico	0.0313* (1.93)	-0.0365 (-0.82)	-0.0621 (-0.38)	-0.0428	2.136	OLS	62-90	0.4686 (D)
Argentina	0.0239* (1.82)	0.1437** (2.51)	-1.4389*** (-3.32)	0.5576	1.993	AR1	62-00	0.3810 (D)
Other L. A.	0.0236*** (16.28)	0.2206*** (6.34)	-0.0920 (-0.78)	0.7661	2.168	AR3	62-90	0.7681 (D)
Nigeria	0.0155 (0.63)	0.7275** (2.51)	-4.8730* (-1.79)	0.3698	1.980	AR1	62-80	0.4374 (D)
Egypt	0.0044 (0.55)	-0.0006 (-0.12)	-0.0852 (-0.96)	-0.0344	2.167	OLS	62-94	0.4877 (D)
India	0.0211*** (10.56)	0.1027 (1.53)	-3.3952*** (-3.56)	0.8734	1.871	AR1	61-00	0.0285 (L)
Pakistan	0.0064 (1.42)	0.0028 (0.38)	-0.2922* (-1.71)	0.3669	2.078	AR3	62-94	0.3645 (D)
Bangladesh	-0.0008 (-0.27)	-0.0724* (-1.78)	-2.8003** (-2.37)	0.7393	1.767	AR1	61-90	0.0547 (L)
Rep. of Korea	0.0178*** (5.90)	-0.0684 (-1.42)	-0.2073 (-0.49)	0.7150	1.949	AR1	61-00	0.0394 (L)

***: 1% significant, **: 5% significant, *: 10% significant.
ADF pv: Provability values of Augmented Dickey-Fuller test.
L: Log linear function is estimated. D: Difference function is estimated.

Table 6. The results of the estimation of yield functions of rice for selected regions

Countries	Trend	Rainfall	Temp.	Adj.R^2	DW	Est.	Period	ADF pv
USA	0.0176*** (2.77)	-0.0028 (-0.12)	-1.1226*** (-4.10)	0.3183	1.703	OLS	62-00	0.5848 (D)
EU	0.0053*** (4.91)	0.0088 (0.22)	1.2821*** (3.23)	0.6748	1.731	OLS	61-00	0.0489 (L)
Japan	0.0094 (1.59)	-0.2303*** (-4.84)	1.0426*** (3.94)	0.7139	2.000	AR1	62-00	0.1899 (D)
East Europe	0.0065 (0.38)	-0.0130 (-0.22)	0.7896*** (2.85)	0.3632	1.865	AR1	62-00	0.1878 (D)
Former USSR	0.0051 (0.45)	-0.0101 (-0.26)	0.2594 (1.07)	0.0081	1.990	OLS	62-00	0.5504 (D)
Brazil	0.0313*** (16.23)	0.1348** (2.16)	-0.4542 (-0.99)	0.9199	1.631	OLS	61-00	0.0025 (L)
Other L. A.	0.0187* (1.92)	-0.0069 (-0.09)	-0.1239 (-0.38)	-0.0710	1.782	OLS	62-90	0.3337 (D)
Nigeria	0.0312* (1.85)	0.5159 (1.34)	-0.1700 (-0.05)	0.5465	2.180	AR2	62-80	0.9808 (D)
Egypt	0.0136 (1.29)	-0.0077 (-0.86)	-0.1396 (-0.47)	-0.0214	2.072	OLS	62-92	0.9319 (D)
India	0.0205*** (3.57)	0.0367 (0.59)	-1.9938** (-2.35)	0.4697	1.921	AR2	62-00	0.1062 (D)
Pakistan	0.0168 (1.41)	-0.0107 (-0.57)	0.3242 (0.93)	-0.0045	1.907	OLS	62-94	0.2118 (D)
Bangladesh	0.0160** (2.33)	0.0641 (1.23)	0.1869 (0.27)	0.2858	1.872	AR1	62-90	0.9096 (D)
Indonesia	0.0310*** (3.93)	-0.0393 (-0.80)	-0.1010 (-0.25)	-0.0490	1.798	OLS	62-90	0.9383 (D)
Thailand	0.0089** (2.10)	0.1043 (1.42)	0.2441 (0.22)	0.3472	1.924	AR2	62-00	0.5702 (D)
Malaysia	0.0085 (1.08)	-0.0027 (-0.17)	-0.3264 (-0.92)	-0.0254	2.086	OLS	62-00	0.5797 (D)
Philippine	0.0230** (2.23)	0.0539 (1.38)	-0.9427 (-1.51)	0.1393	1.922	OLS	62-99	0.6881 (D)
Rep. of Korea	0.0143 (1.58)	-0.0481 (-1.32)	1.3020*** (2.88)	0.3501	2.021	AR2	62-00	0.3389 (D)
China	0.0288*** (3.30)	-0.0106 (-0.23)	-0.2157 (-1.29)	0.0561	1.856	AR1	62-00	0.7707 (D)

***: 1% significant, **: 5% significant, *: 10% significant.
ADF pv: Provability values of Augmented Dickey-Fuller test.
L: Log linear function is estimated. D: Difference function is estimated.

Table 7. The results of the estimation of yield functions of soybeans for selected regions

Countries	Trend	Rainfall	Temp.	Adj.R^2	DW	Est.	Period	ADF pv
USA	0.0132*** (17.22)	0.2203*** (3.53)	-0.7911*** (-2.86)	0.8886	1.949	OLS	61-00	0.0508 (L)
EU	0.0128 (0.86)	0.0745 (1.43)	0.4875 (1.01)	0.1440	2.013	AR1	62-00	0.5785 (D)
Japan	0.0144* (1.73)	-0.3346*** (-3.96)	-0.1918 (-0.30)	0.5363	1.906	AR2	62-00	0.2039 (D)
Canada	0.0044 (0.25)	0.0872 (0.98)	-0.4281 (-0.66)	0.5464	2.231	AR1	62-89	0.4409 (D)
East Europe	0.0262 (1.40)	0.0109 (0.14)	-0.8503** (-2.23)	0.4253	2.070	AR2	62-00	0.7662 (D)
Former USSR	0.0101 (0.31)	-0.1767 (-1.31)	-0.5004 (-0.72)	0.1852	2.027	AR1	62-00	0.4406 (D)
Brazil	0.0199 (0.83)	0.0787 (0.65)	-0.9585 (-1.24)	0.0388	2.370	OLS	62-00	0.1412 (D)
Argentina	0.0253 (1.37)	0.0279 (0.38)	-0.8497 (-1.14)	0.4610	2.112	AR1	62-91	0.4142 (D)
Other L. A.	0.0129 (1.39)	0.0267 (0.24)	-0.9487* (-2.02)	0.3943	2.130	AR3	62-91	0.8962 (D)
Nigeria	-0.0113 (-0.62)	-0.0212 (-0.14)	-0.1415 (-0.10)	-0.1181	2.249	OLS	62-80	1.0000 (D)
India	0.0191 (0.62)	0.1550 (1.32)	0.1551 (0.07)	-0.0068	2.414	OLS	62-00	0.5784 (D)
Pakistan	0.0159 (0.77)	-0.0031 (-0.06)	-0.7352 (-0.86)	0.1260	1.988	AR1	62-94	1.0000 (D)
Rep. of Korea	0.0254 (1.57)	-0.0368 (-1.11)	0.3437 (0.78)	-0.0081	2.331	OLS	62-00	0.9657 (D)
China	0.0267*** (2.73)	0.1374** (2.19)	0.4357 (1.09)	0.3510	2.227	AR1	62-00	0.9062 (D)

***: 1% significant, **: 5% significant, *: 10% significant.
ADF pv: Provability values of Augmented Dickey-Fuller test.
L: Log linear function is estimated. D: Difference function is estimated.

are significantly affected by rainfall. For wheat, rainfall has a significant positive effect on yields in Canada, Australia, and India while the effect of rainfall on wheat yields is negative in the European Union, New Zealand, Brazil, Egypt, and Pakistan. Rainfall has a positive effect on rice yield in Brazil and soybeans yield in the United States, but negative effect on rice and soybeans in Japan. The results suggest that in countries where the rainfall is lower than the optimum levels for the crops, the parameter has a positive sign. Furthermore, in the case of Japan where the rate of irrigated fields is high, there is a negative correlation between rainfall and temperature, then, lower temperature caused by more rainfall leads to lower yield as shown in the following paragraph. In the consideration of the hypothesis that there is an optimum level of rainfall, quadratic functions were estimated for some countries; however, desirable results were not obtained. In the case of wheat, the elasticity of Australia is 0.4427, indicating that if rainfall increases 10%, the yield will increase 4.427%.

On the other hand, higher temperatures have a negative effect on production of most crops except for rice. If temperature is higher than an optimum value, the quantity of the dry matter of the whole plant reduced by respiration will be greater than that of the dry matter increased by photosynthesis. As the net quantity of the dry matter is decreased, the yield of the crop will also be reduced. The effects of temperature are large in Bangladesh for wheat, Thailand for maize, India and Bangladesh for other coarse grains, and India for rice, suggesting that South Asian countries are quite vulnerable to higher temperatures. The sign of parameters of temperature variables for rice probably depends on latitude; countries located in high latitudes have positive temperature elasticities and in low latitudes have negative elasticities. Rice cropping in European countries, South Korea and

Japan is vulnerable to low temperature in the flowering season. In the case of wheat, the elasticity for the European Union, –1.076, indicates that if temperature increases 10%, the yield of wheat will decrease 10.76%.

2. Simulation of the world food model

In the IFPSIM[7], changes in yields lead to changes in world production and world commodity prices. The new world prices lead to changes in planted area, because the area is a function of domestic prices, which are in turn linked to the world prices. In the case of wheat, rising temperatures do not affect estimated U.S. yields. However, estimated parameters indicate that production of other countries will be reduced by the climate change. In the end, the world price will increase and the acreage of wheat in the United States will increase.

Fig. 3 through Fig. 6 show the outlook for production of wheat, maize, other coarse grains, and soybeans in the United States, the price leader for these crops. Fig. 3 shows that the production of wheat in the case of higher temperatures increases 20.8 million MT (metric tons) between 2005 and 2025, while the baseline production of wheat increases 12.4 million MT during the same period. The U.S. production in the case of higher temperatures is greater than that in the baseline, because the world price of wheat increases due to the decrease in production in other countries, and the U.S. yield of wheat is not affected by a rise in temperature.

On the other hand, U.S. production of maize, other coarse grains, and soybeans in the case of higher temperatures are lower than those of the baseline. Fig. 4 shows that the production of maize in the case of higher temperatures is 34.0 million MT lower than that of the baseline in 2025. Fig. 5 shows that production of other coarse grains will not change over the 2005–2025 period under the rising temperature scenario, while the production in the baseline will increase 5.6 million MT during the period. Fig. 6 shows that the production of soybeans in the case of higher temperatures is 7.1 million MT lower than that of the baseline. These results suggest that rising temperatures during the flowering or silking stage seriously decrease yields of maize, other coarse grains, and

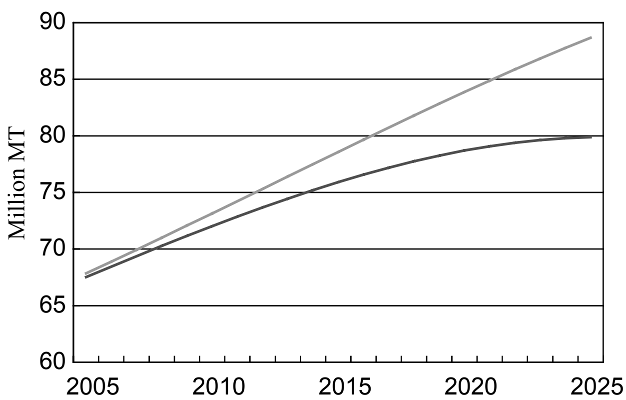

Fig. 3. Production of wheat in the United States

—: Base line. —: Temp. up.

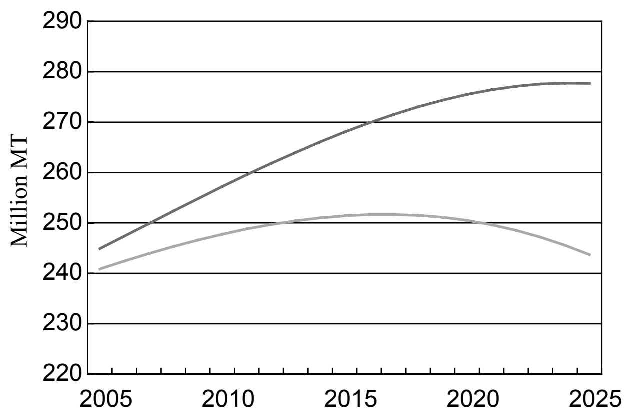

Fig. 4. Production of maize in the United States

—: Base line. —: Temp. up.

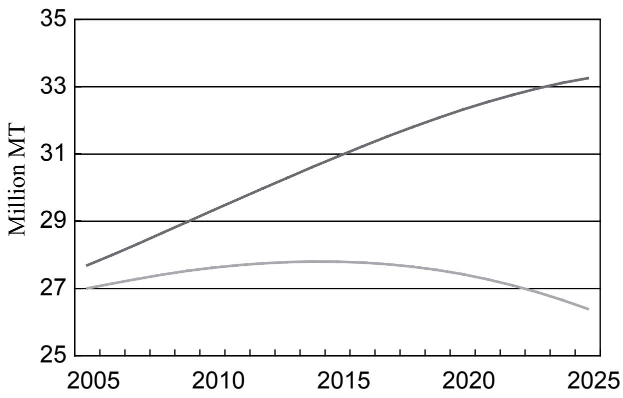

Fig. 5. Production of other coarse grains in the United States

—: Base line. —: Temp. up.

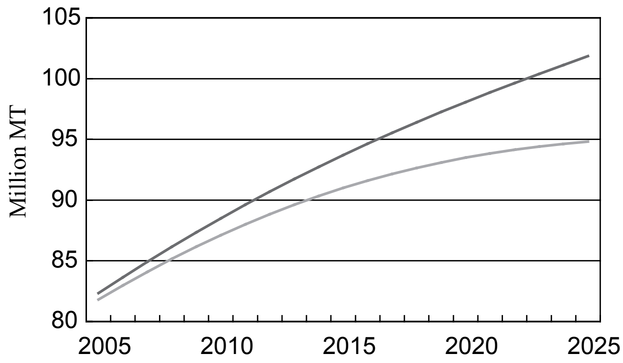

Fig. 6. Production of soybeans in the United States

—: Base line. —: Temp. up.

soybeans in the United States.

The growth rates of production of these crops clearly indicate the differences in impacts of rising temperature across countries and regions. Fig. 7 through Fig. 11 show the growth in production for the five crops in the United States, the European Union, India, China, and the world during the simulation period. The growth rate is measured by the change in production between 2005 and 2025 divided by that in 2005. Fig. 7 shows that if temperature rises, production of rice will sharply decrease in the United States.

Fig. 8 shows that the EU production growth for maize, rice, and soybeans in the case of higher temperatures is greater than that of the baseline. On the other

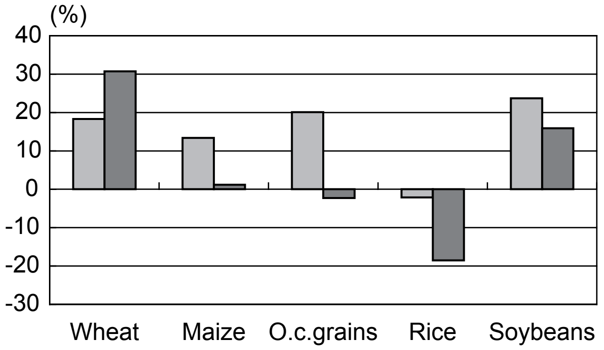

Fig. 7. Growth of crop production in the United States

□ : Base line. ■ : Temp. up.

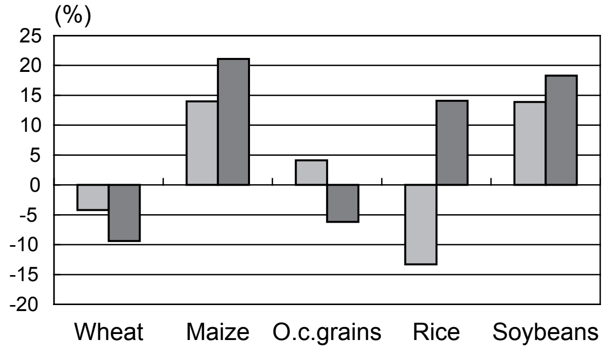

Fig. 8. Growth of crop production in the European Union

□ : Base line. ■ : Temp. up.

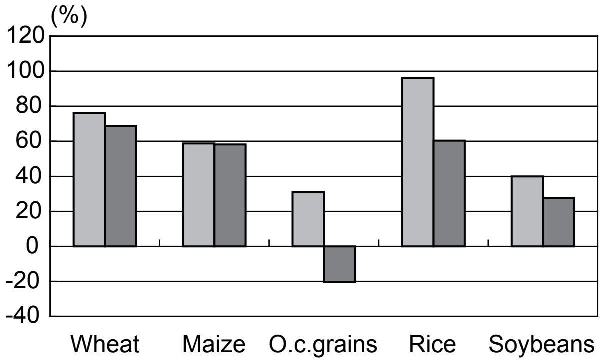

Fig. 9. Growth of crop production in India

□ : Base line. ■ : Temp. up.

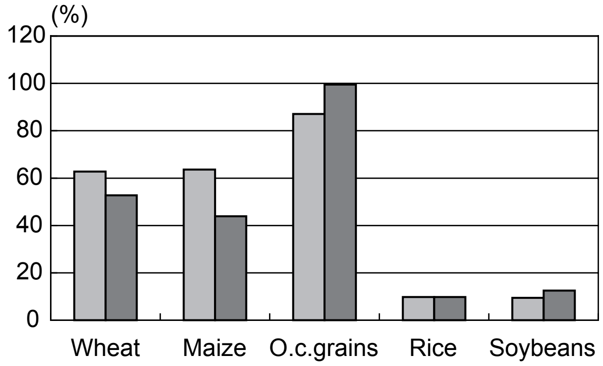

Fig. 10. Growth of crop production in China

□ : Base line. ■ : Temp. up.

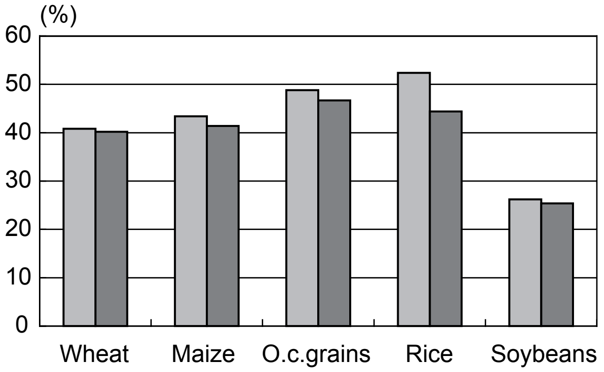

Fig. 11. Growth of global crop production

□ : Base line. ■ : Temp. up.

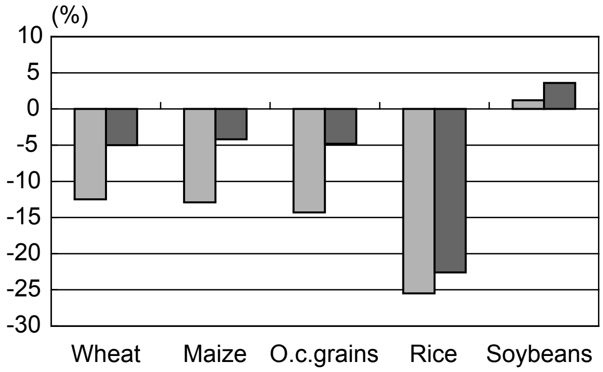

Fig. 12. Rates of price changes in the world

□ : Base line. ■ : Temp. up.

hand, the production of wheat and other coarse grains will be decreased by higher temperatures. In this simulation, the farm price of the European Union is the summation of the trade price, marketing margin, and per-unit subsidy, following the same approach used for other countries and regions, the EU prices of wheat, other coarse grains, and rice were fixed in the original model. Thus, changes in the EU production in the higher temperature scenario reflect changes in both the EU yields and prices.

Fig. 9 shows that if temperature rises in India, the productions of all crops will decrease. In particular, production of other coarse grains and rice will sharply decrease in the case of higher temperatures. Fig. 10 shows the growth rate of production in China. Rising temperatures lead to an increase in the production of other coarse grains and soybeans while it leads to a decrease of production of wheat and maize.

Finally, Fig. 11 shows the growth of global crop production. As shown from Fig. 7 to Fig. 10, differences in the growth rates of production between baseline and the higher temperature scenario can be quite large for a given crop in a given country or region, however, the difference in world total production is not large except in the case of rice. World trade will absorb most of the shocks of higher temperatures. Rice production will be affected more than other crops by the climate change largely because of the sharp drop in rice yields and production in the United States and South Asian countries.

Fig. 12 shows rates of price changes in the world. By reducing crop production, the rising temperature scenario leads to higher prices than those of the baseline. These price changes offset the impact of lower production on farmer's profit; however, higher prices depress the welfare of poor and vulnerable people in households that are net purchasers of food.

Conclusions

In many cases, the yields of crops have increasing trends and the non-stationarity of the data is a problem for estimating yield functions. In the case of non-stationary data for yields, these data are first differenced. Estimation results show that crop production in some countries or regions will be reduced greatly by rising temperature. Crop production of the United States, the European Union, and South Asian countries could suffer severe damage from global warming. The results of simulation using the world food model show that the changes of production resulting from higher temperatures are quite different for each crop in each country or region. However, world total production for most crops other than rice is not severely affected. The production of rice will be affected because of the large reduction of yields in the United States and South Asian countries.

These results are based on the mid-term simulation where available cropping regions and the parameters of the supply and demand model are fixed. To obtain more accurate simulation results, it is very likely that a different long-term supply and demand model is required. Furthermore, higher temperature will increase demands for chemical inputs such as herbicide and pesticide, then, a model which includes agricultural input markets is also required. While the scenario is quite simple (temperature measured in degrees Celsius increases 0.05% per year for all countries or about 0.2ºC over the 20 years), the drastic changes of crop production in some countries is remarkable. The countries which suffer severe damage by higher temperature may need to consider changes in cropping patterns and practices.

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