

GISELA – GIS-based Evaluation of Land-use and Agriculture Market Analysis and the Effects of Income Distribution

P R E S E N T A T I O N

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BACKGROUND

Can potential food supply meet the demand under future population growth and global warming?

- then assess the biomass energy supply potential

UNCERTAINTIES on

- Distribution of climate change impacts
- Food demand and market issues
- ❑ Assessment of climate change impacts on potential food production and potential cropland based on 1km mesh GIS data
- ❑ Dynamic equilibrium model on world food market
- ❑ Potential of biomass vs. income distribution (food market accessibility)

Crop market : market vulnerability

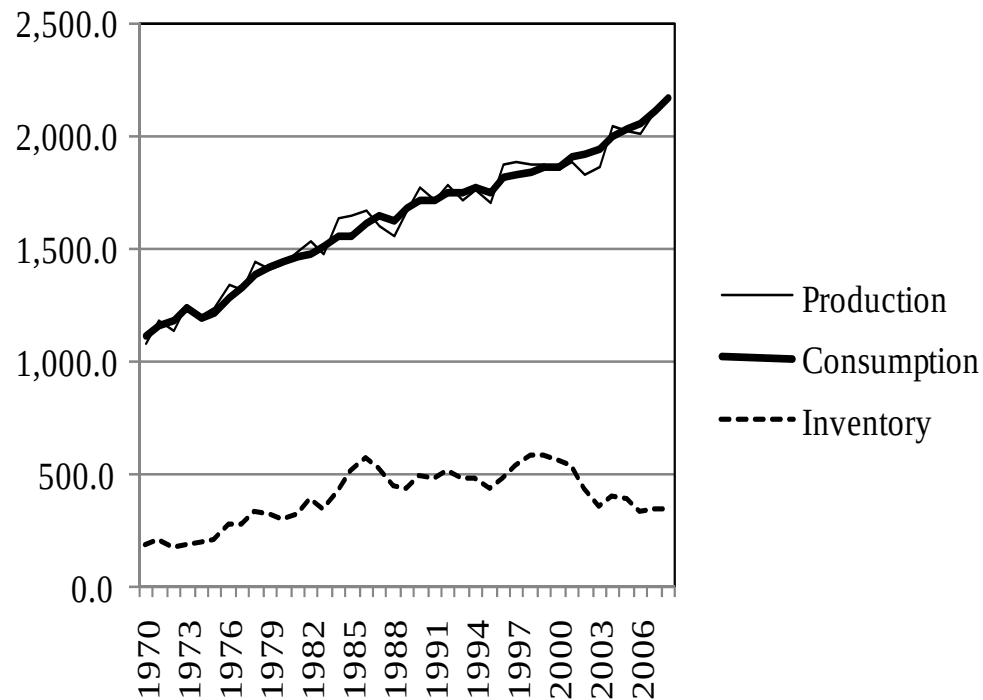


Figure 1 World crop production, demand and inventory (million ton) [MAFF, 2008]

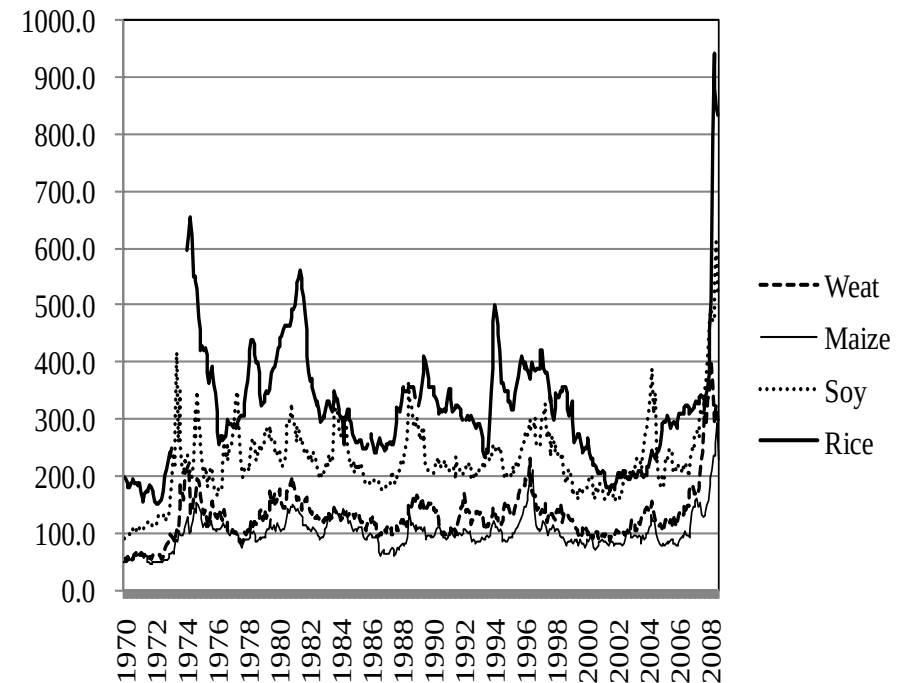


Figure 2 Trends in world crop prices in US dollars per ton [MAFF, 2008]

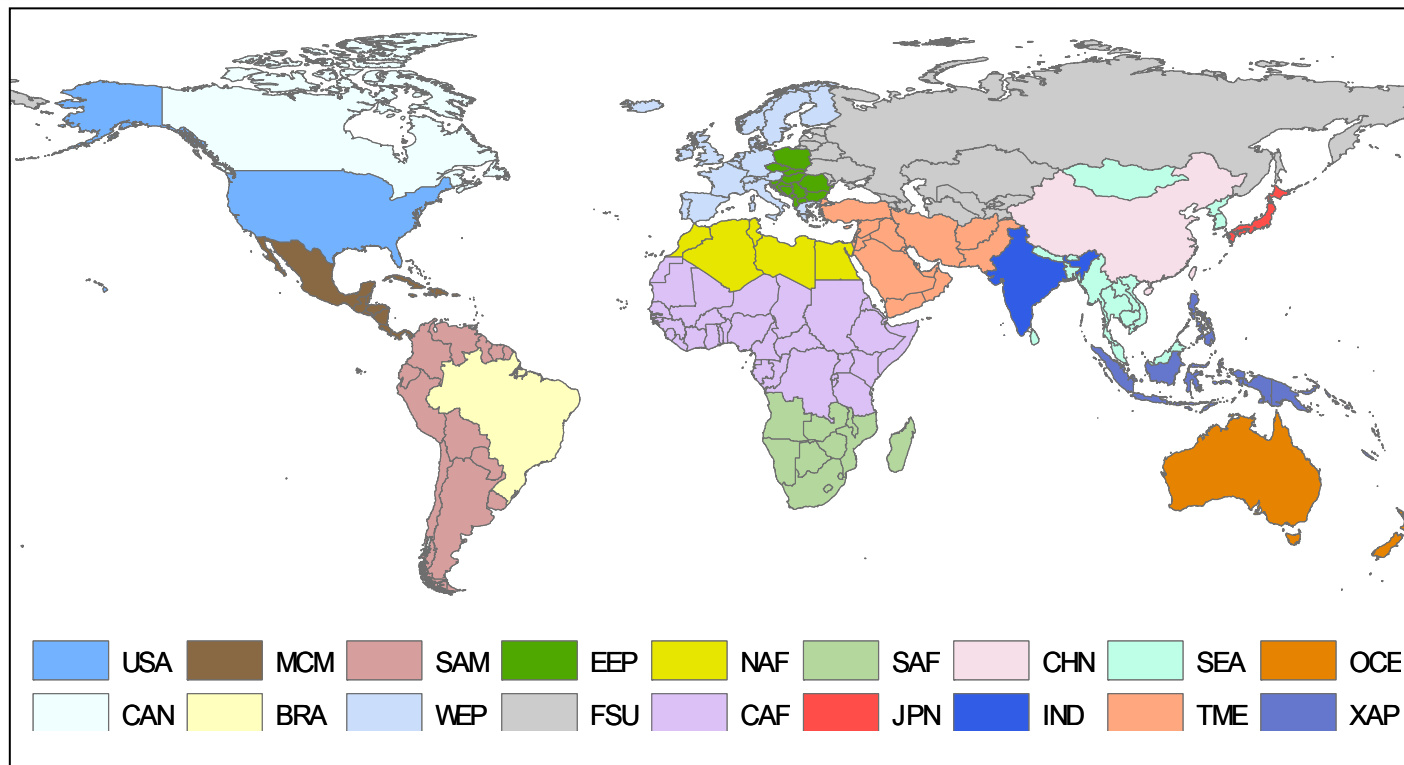
- Crop production has met the world food demand historically.
- Expense for crop might not so high for the world average income class.
- Price fluctuation would mostly affect the low income people seriously.

Our approach

- ❑ Assessment of climate change impacts on potential food production and potential cropland based on 1km mesh GIS data
- ❑ Considering climate change ranges among GCMs
- ❑ Dynamic equilibrium model on world food market
- ❑ Modeling of income distribution

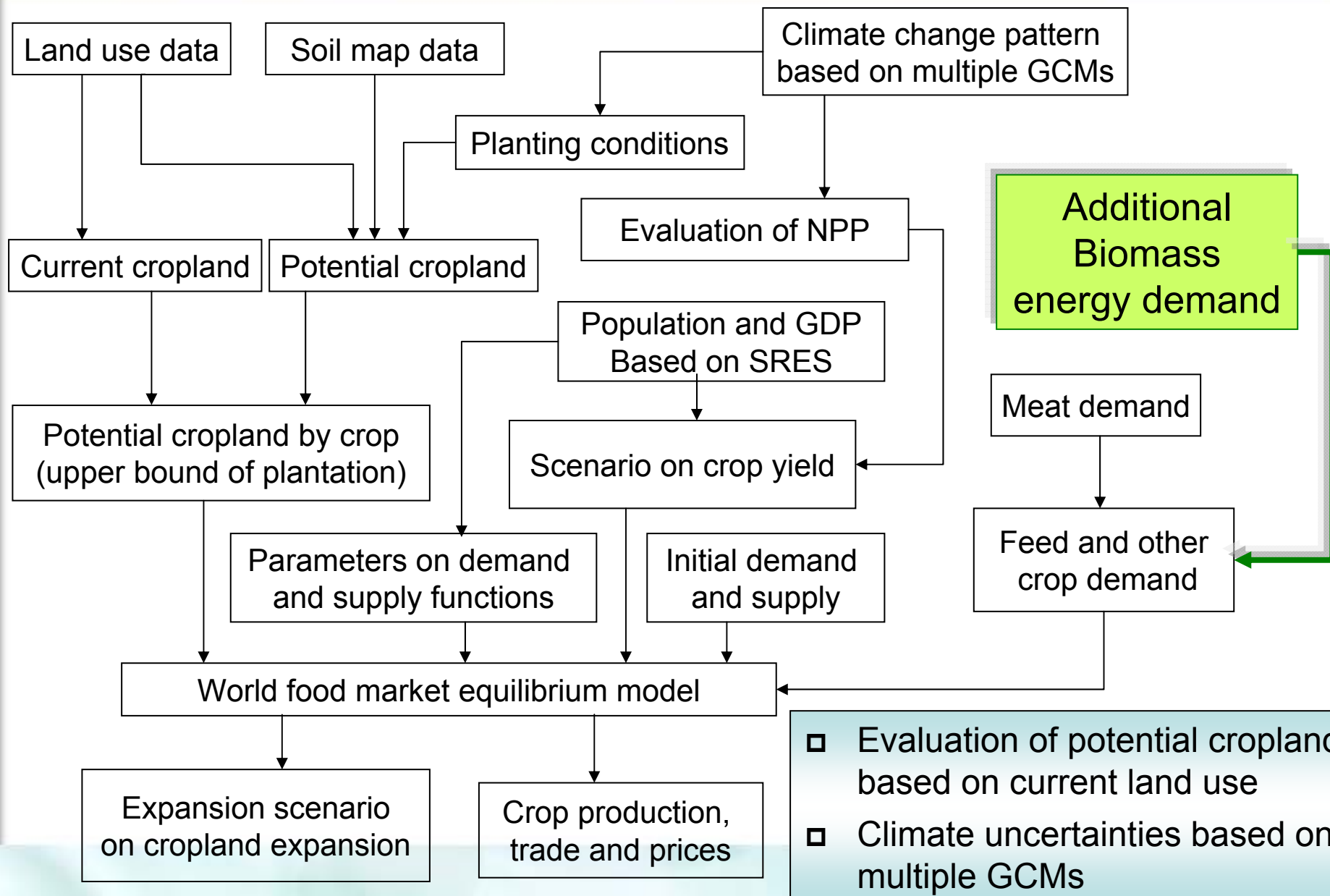
GISELA – GIS-based Evaluation of Land use and Agriculture market

Outline ···Regions, Crops and Scenarios

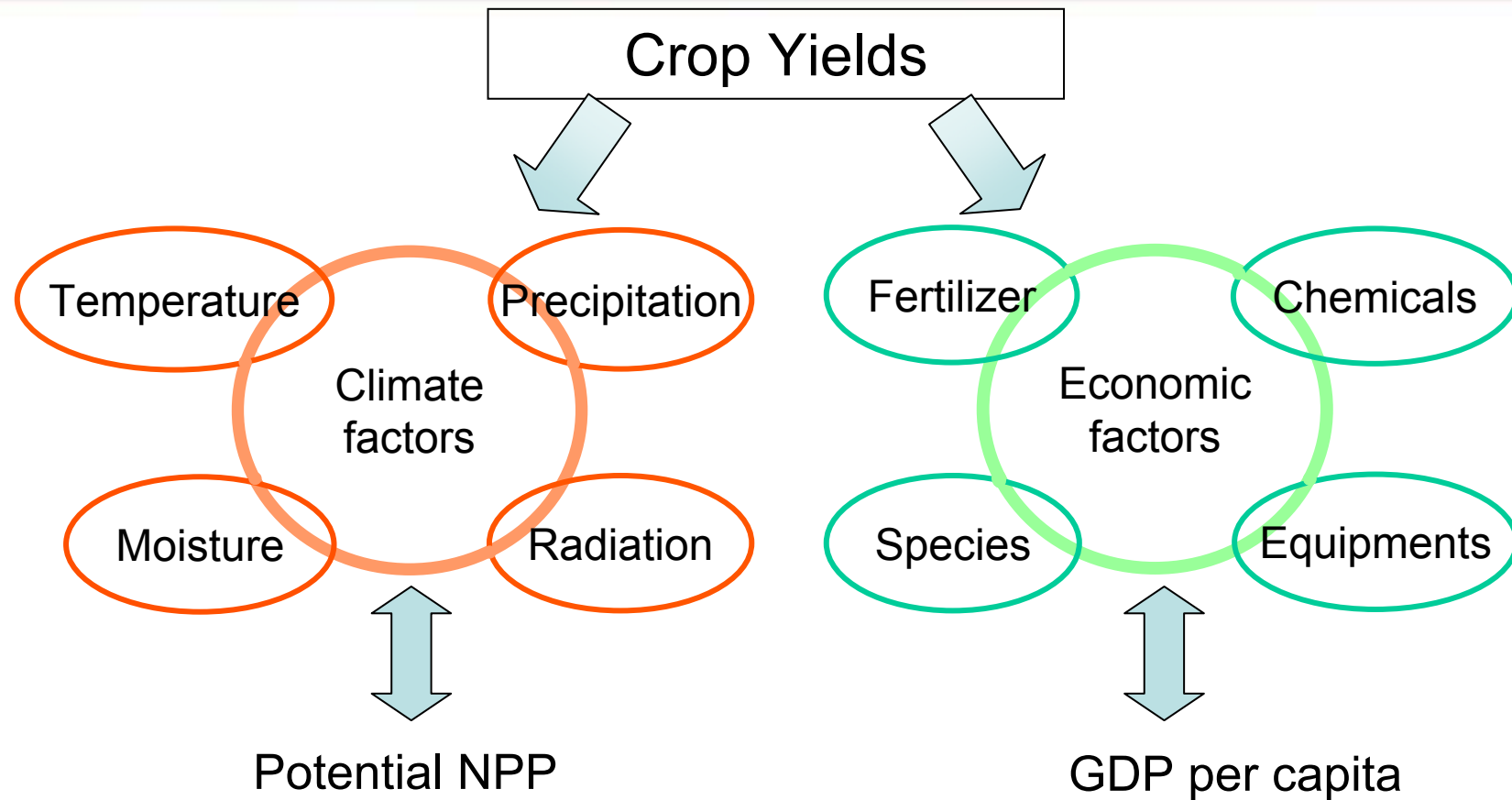


- ❑ World 18 regions
- ❑ Maize, rice, wheat and soy beans
- ❑ Time horizon -- 2000 - 2080
- ❑ Four SRES scenarios on economic and social driving forces
- ❑ Currently A1B climate scenario is adopted

Outline of GISELA Model



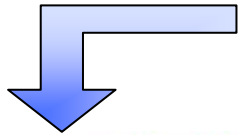
Scenario on Crop Yields



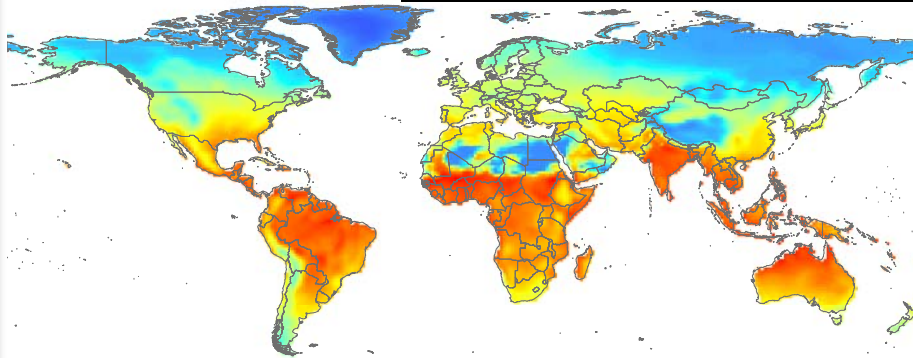
Scenarios on future yields by region and crop

Assessment of NPP based on GCMs

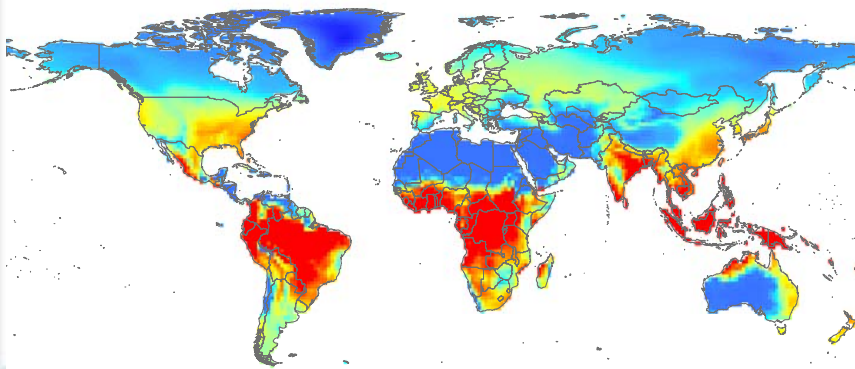
Chikugo NPP
model



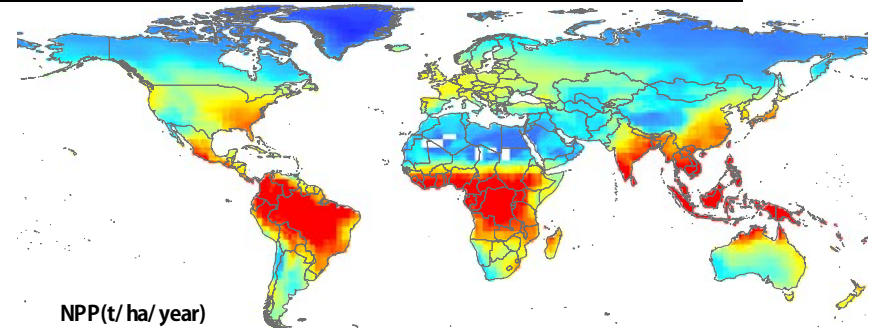
GCM	Institution	Resolution
CNRM-CM3	Centre National de Recherches Meteorologiques	2.8°
MIROC3.2(HI)	National Institute for Environmental Studies	1.1°
MIROC3.3(ME)	National Institute for Environmental Studies	2.8°
MPI-ECHAM5	Max-Planck-Institut for Meteorology	1.9°
MRI-CGCM2.3.2	Meteorological Research Institute	2.8°
NCAR-CCSM3.0	National Centre for Atmospheric Research	1.4°



NPP in 2050 by MIROC-HI



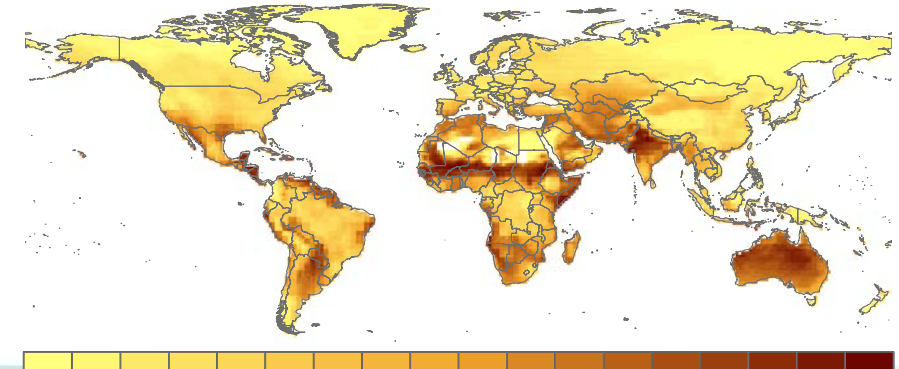
NPP in 205 by ECHAM-5



NPP(t/ ha/ year)

0 30

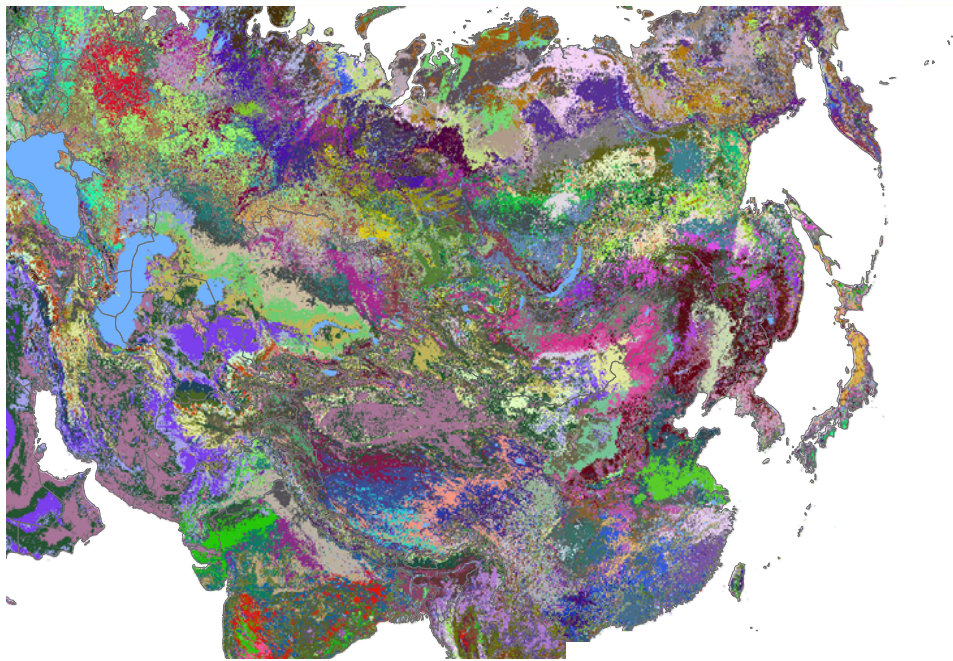
Mean value of NPP (middle NPP) in 2050



0 12

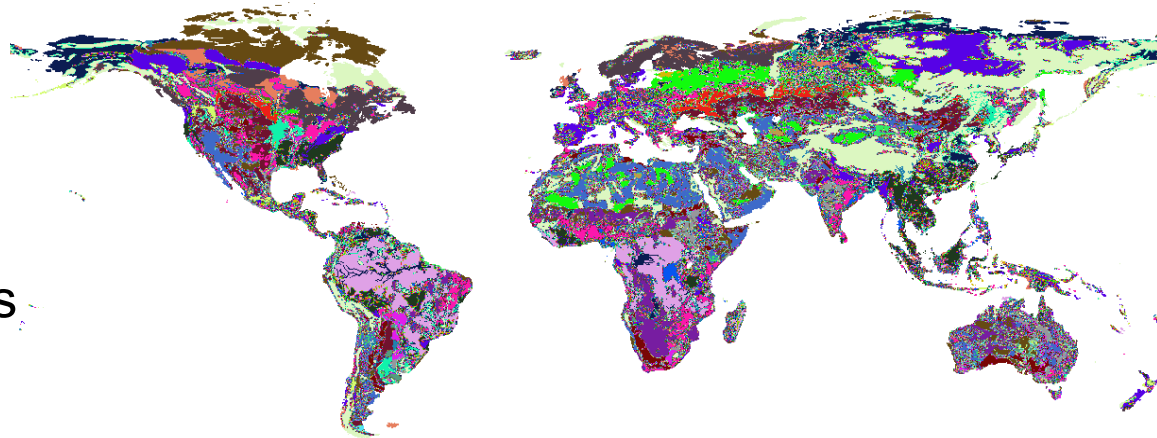
S.D. of NPP in 2050

Soil Map (FAO/UNESCO) and Land Use Data (USGS)

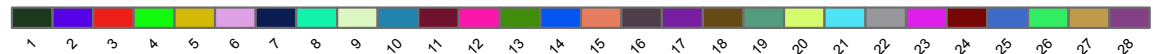


Land use data (1km×1km)
USGS GLCC-Version2

Soil map
FAO/UNESCO Soil units



土壤分類



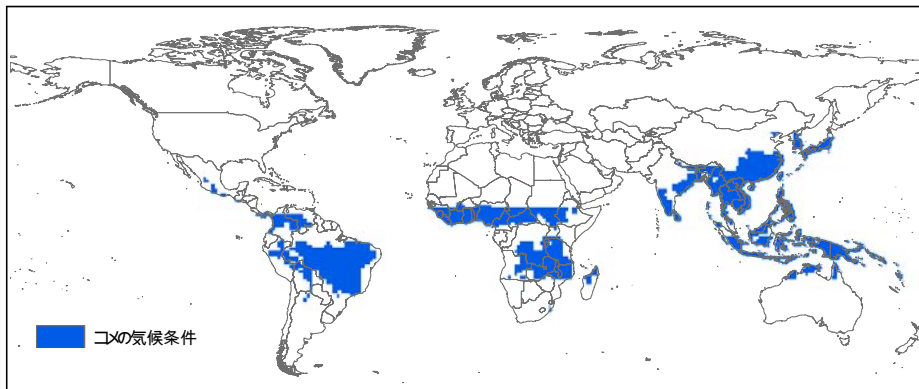
Estimation of Potential Cropland

Climate Condition

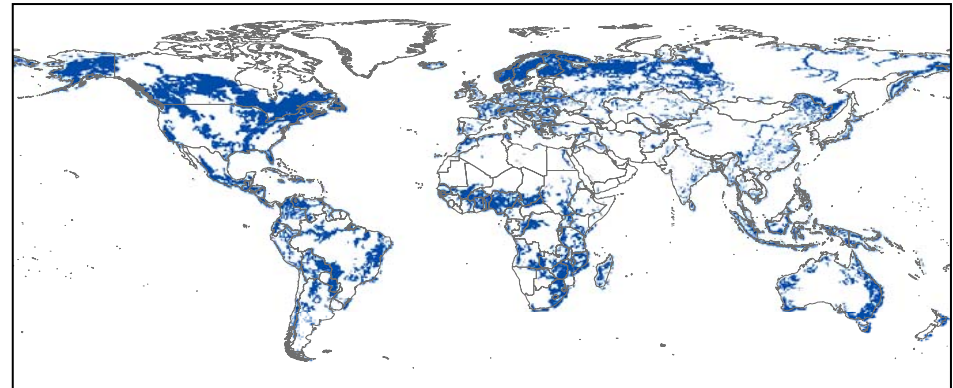
Crop	Cummulative temperature	Cummulative precipitation
Maize	1500-3000 (°C)	500-700 (mm)
Rice	2500-3800 (°C)	600- (mm)
Wheat	1300-2500 (°C)	100-1500 (mm)
Soy bean	2000-3200 (°C)	450-750 (mm)

Soil and Land use

- ❑ Land use data (pasture, tropical forest and other forest)
- ❑ Soil category



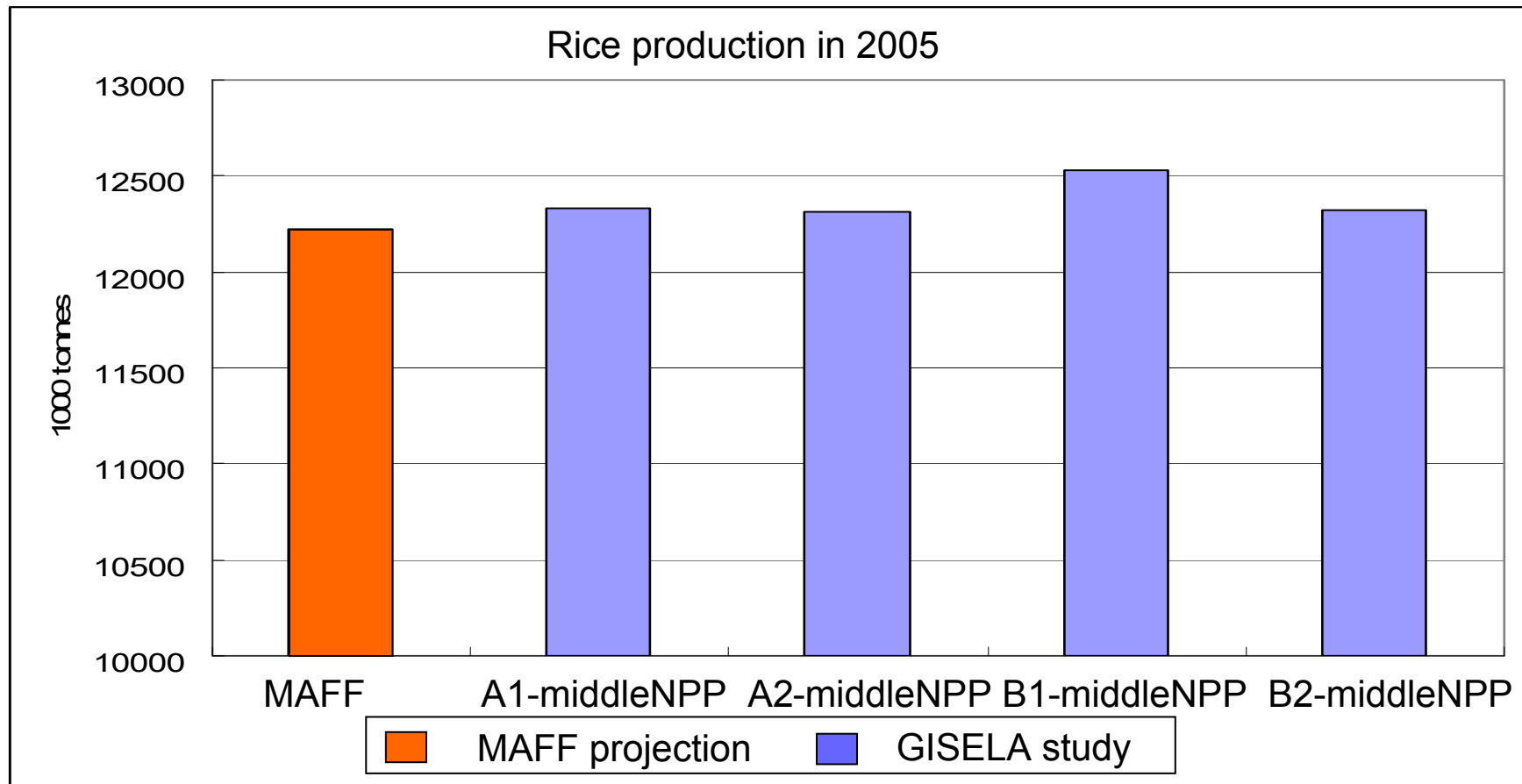
Possible rice plantation area
based on climate conditions
(rice)



Possible rice plantation area
based on soil map and land
use category (rice)

Potential cropland

Comparison with other Studies



Rice production projection in Japan in 2005
by Ministry of Agriculture, Forestry and Fishery Japan and GISELA study

GISELA procedure generates very similar projection in rice production to MAFF with around 1% error.

Crop Demand Estimation

Crop Demand for Food and Feed



Food demand is represented by demand function and calculated endogenously by the market equilibrium model.

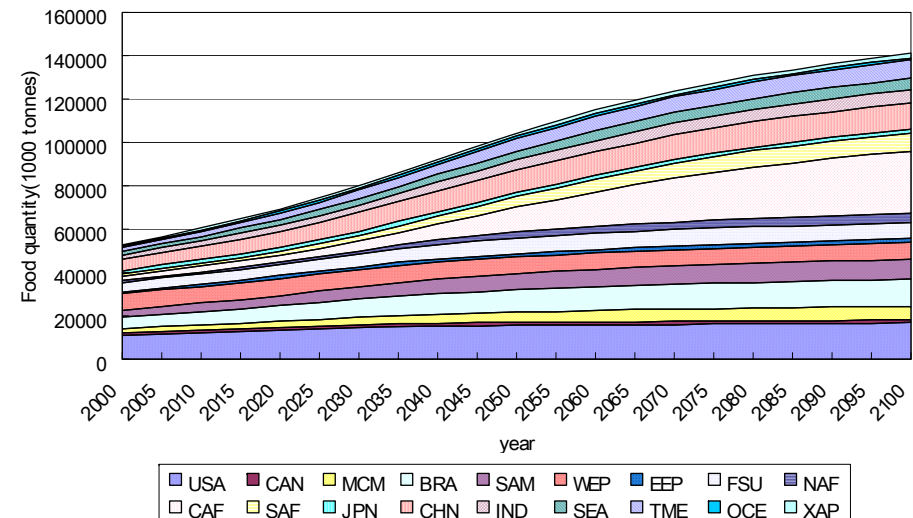
$$D(i, k, t) = R(i, k, t) - X(i, k, t) + M(i, k, t) - NF(i, k, t)$$

$$D(i, k, t) = A \cdot MDP(i, k, t)^{-\mu(i, k)} Y(k, t)^{\sigma(i, k)}$$

$R(i, k, t)$: production $X(i, k, t)$: export
 $M(i, k, t)$: import $NF(i, k, t)$: feed demand
 $MDP(i, k, t)$: domestic market price
 $Y(k, t)$: GDP-PPP
 μ : demand price elasticity
 σ : demand income elasticity



Feed demand is calculated based on the meat demand projection.



Beef demand projection (SRES-B2)

Relationship of crop price categories

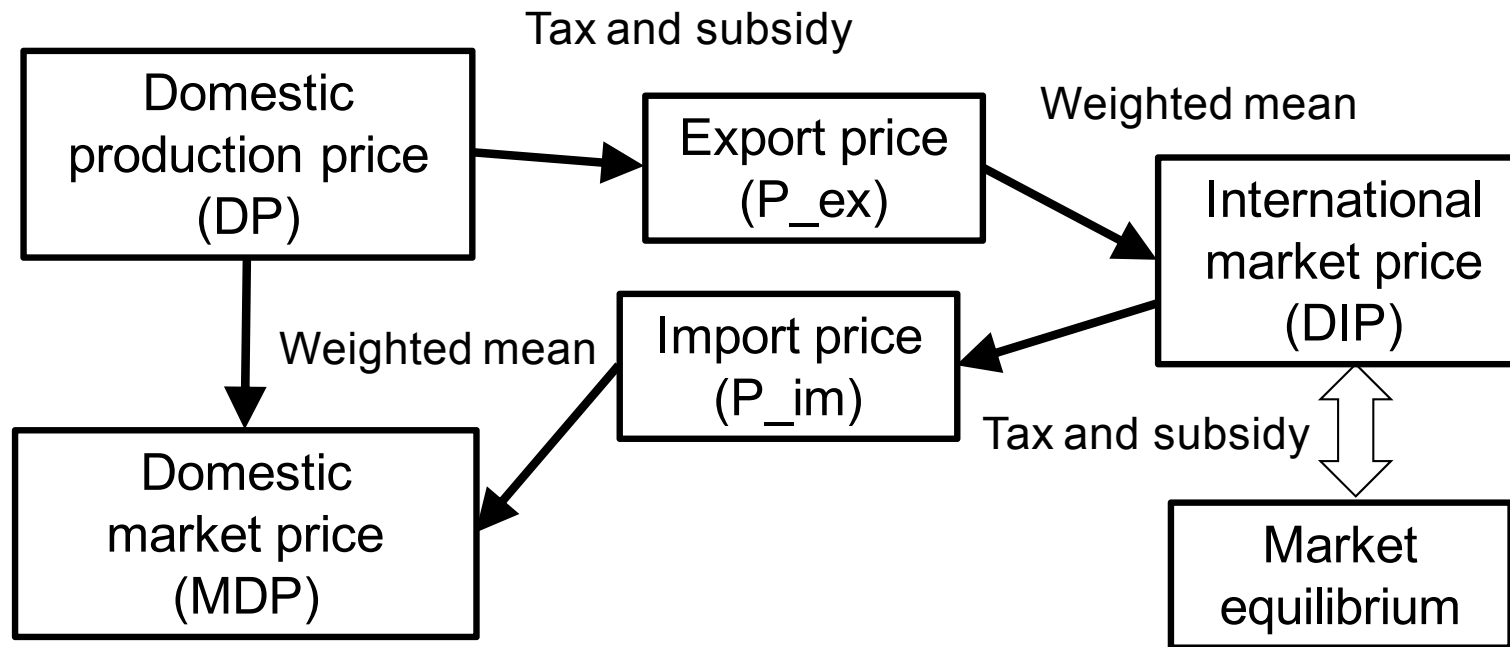
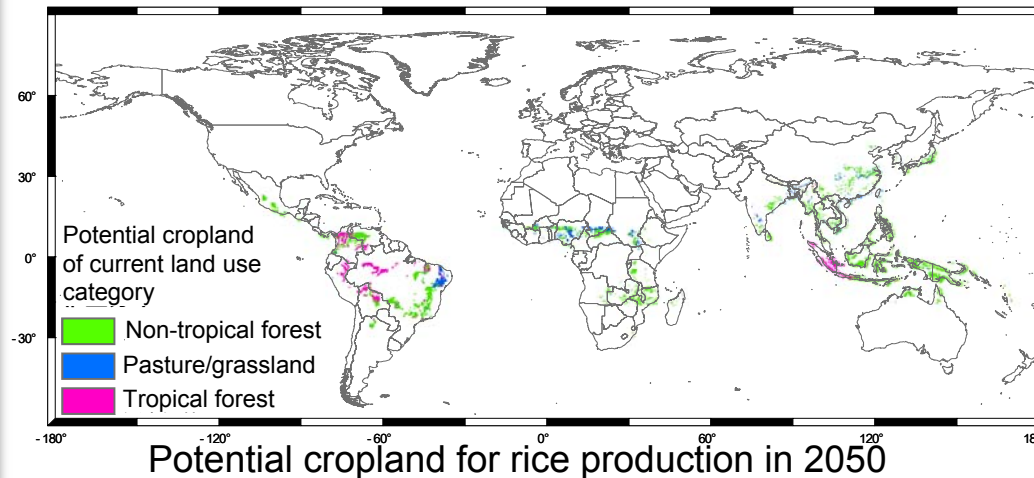


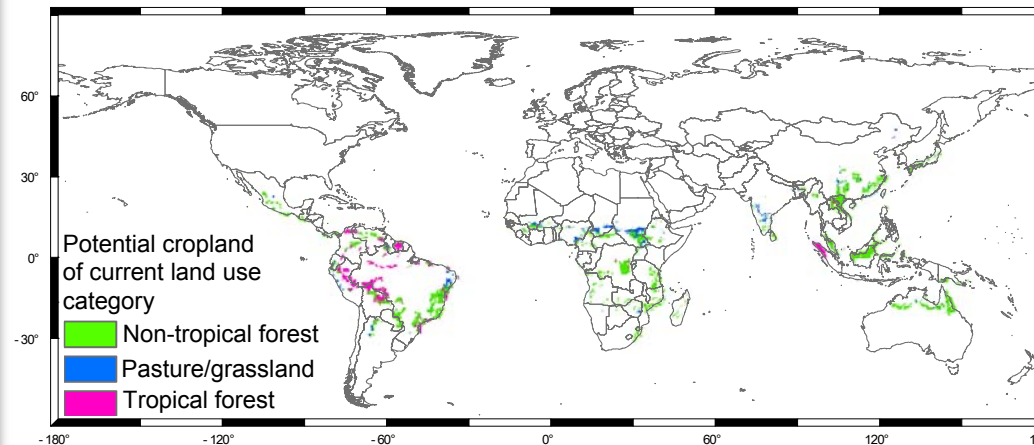
Figure 5 Relationships among price categories

Result (2) Potential Cropland Area in Middle NPP case



Potential cropland for rice production by current land use category in 2050

	Non tropical forest (Kha)	Pasture/ grassland (Kha)	Tropical forest (Kha)	Historical area (kha) in 2000
Africa	71451.7	27227.8	5206.7	25573.8
Eurasia	27145.7	902.7	5264.7	49262.4
North America	0.0	0.0	0.0	30404.3
Oceania	16521.8	299.5	4331.3	6168.2
South America	21422.6	3850.4	39374.3	26652.7
World	130447.0	32168.2	53774.0	138061.4

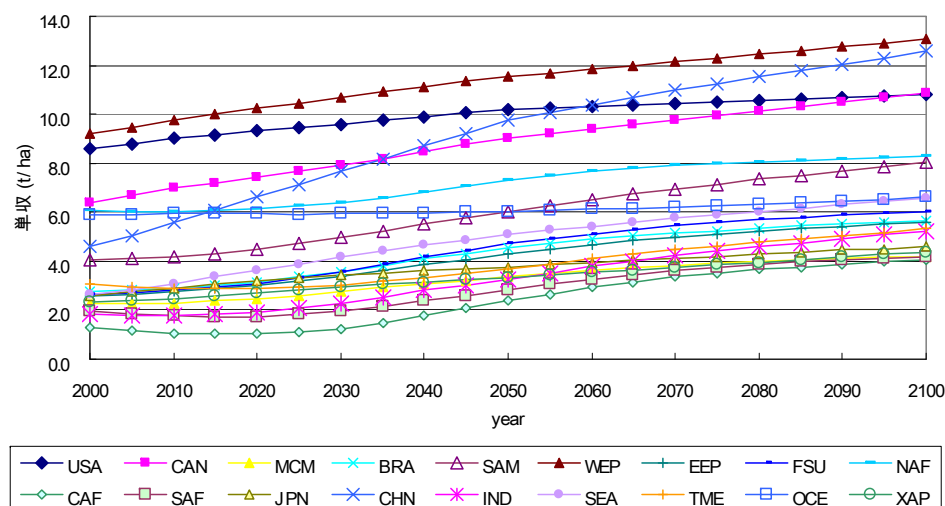


Potential cropland for maize production by current land use category in 2050

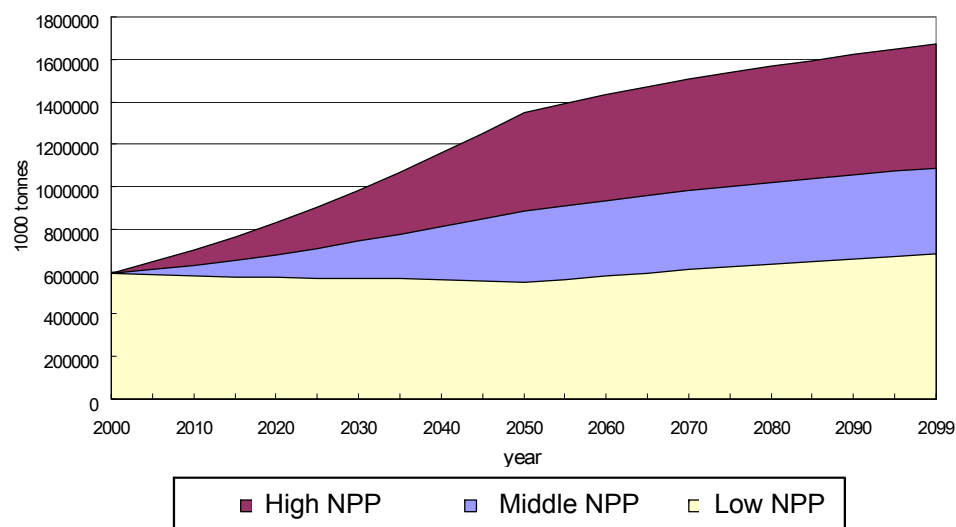
	Non tropical forest (Kha)	Pasture/ grassland (Kha)	Tropical forest (Kha)	Historical area (kha) in 2000
Africa	48101.9	25419.6	265.8	7599.1
Eurasia	12706.4	1272.5	1798.5	122647.8
North America	0.0	0.0	0.0	1230.4
Oceania	23885.9	279.4	4341.7	15988.3
South America	28832.1	3479.4	27839.3	6379.7
World	112592.1	30436.9	34123.4	153845.3

Potential cropland seems to be large. However most of them can be found in forest area.

Results (1) Crop Yield and Production Projection (Maize)



Maize yield projection (SRES B2)



Potential maize production projection
(Cropland area in 2000)

Yields Growth Rates (%) 2000 based

	A1	A2	B1	B2
USA	34.9	26.2	27.8	25.7
CAN	79.2	62.4	72.9	70.5
MCM	142.6	57.5	96.7	85.6
BRA	157.0	71.1	110.5	106.6
SAM	140.1	73.3	101.7	99.3
WEP	54.5	45.0	45.6	42.0
EEP	179.7	118.8	131.6	119.0
FSU	175.1	78.3	154.8	128.1
NAF	59.1	28.3	71.5	36.3
CAF	356.2	147.6	293.6	223.4
SAF	193.1	84.8	159.9	114.2
JPN	143.2	110.4	115.1	78.5
CHN	231.6	132.9	197.2	173.3
IND	242.5	91.6	201.3	187.8
SEA	270.2	125.0	174.3	147.5
TME	130.1	49.7	104.8	74.2
OCE	27.1	11.7	19.5	12.8
XAP	199.6	61.7	98.3	86.5

- Yields grow highly on developing regions.
- Potential production in low NPP case is almost similar to that in 2000.

Result (3) Crop production (maize and rice)

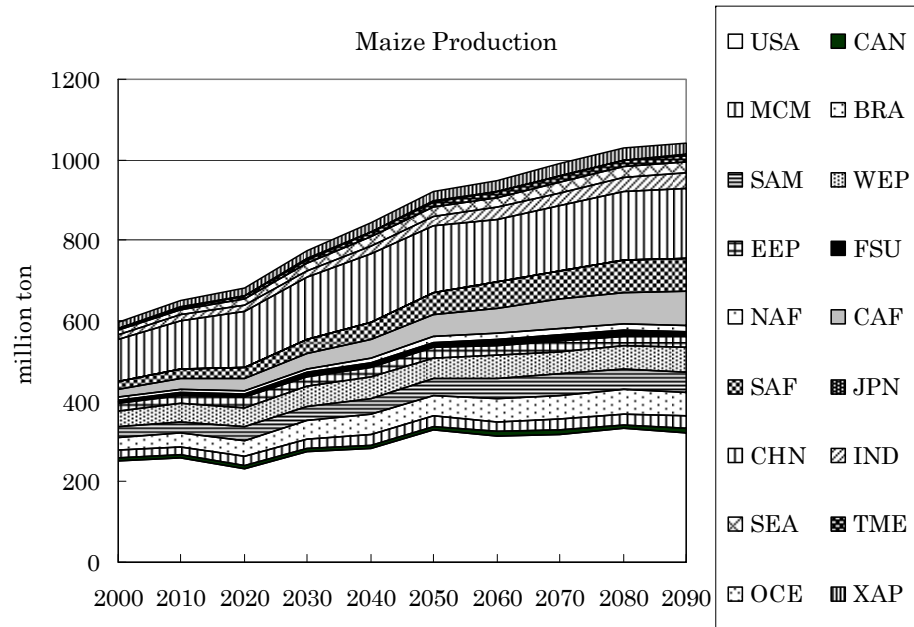


Figure 6 Maize production profile in mid-yield case

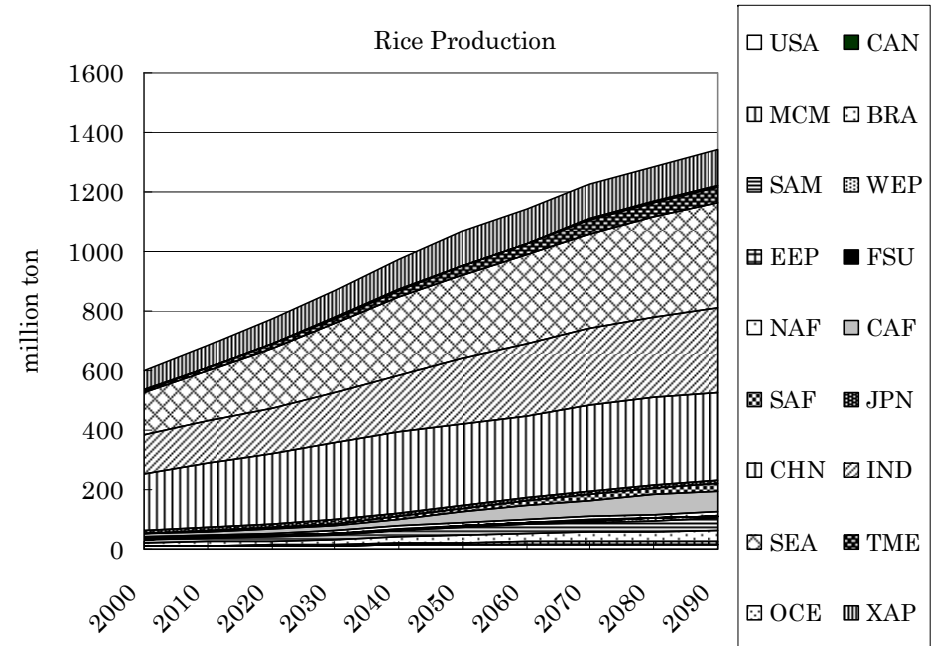


Figure 7 Rice production profile in mid-yield case

Results (4) International crop prices

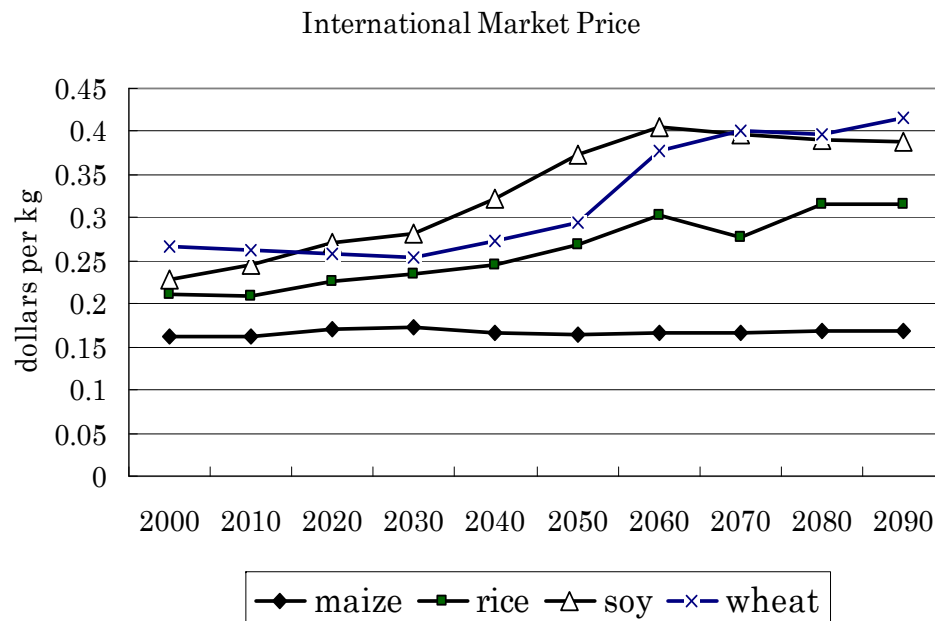
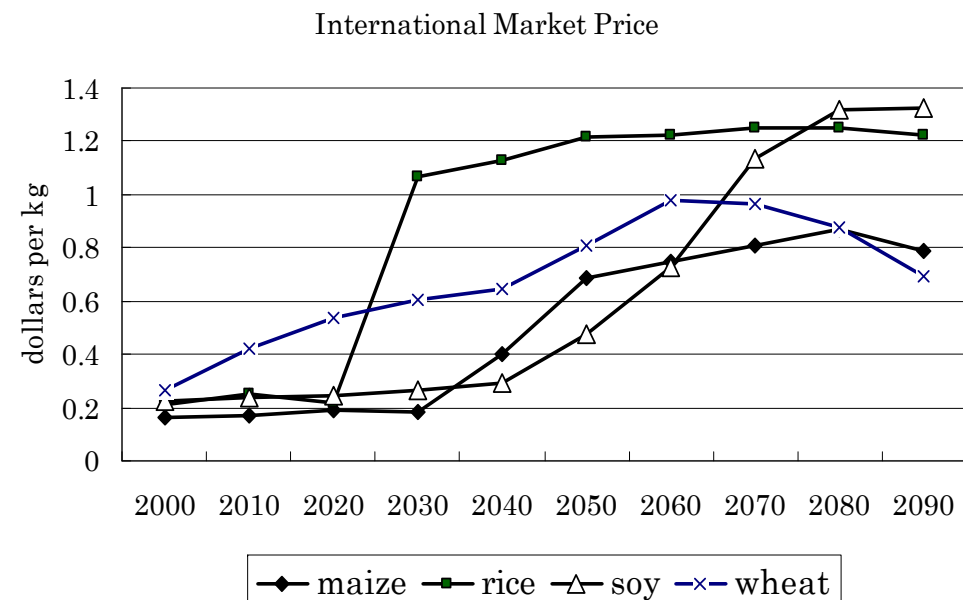
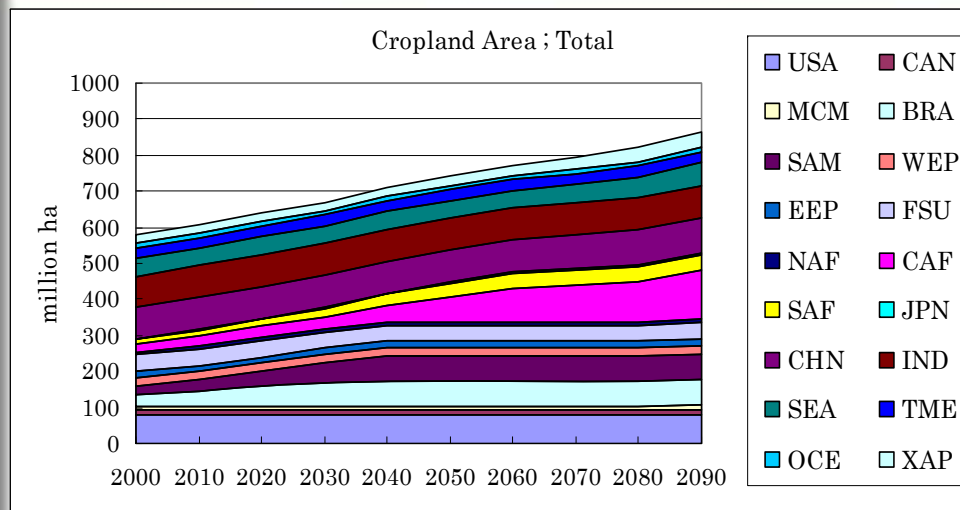


Figure 8 International market prices in mid-yield case; in US dollars per kg

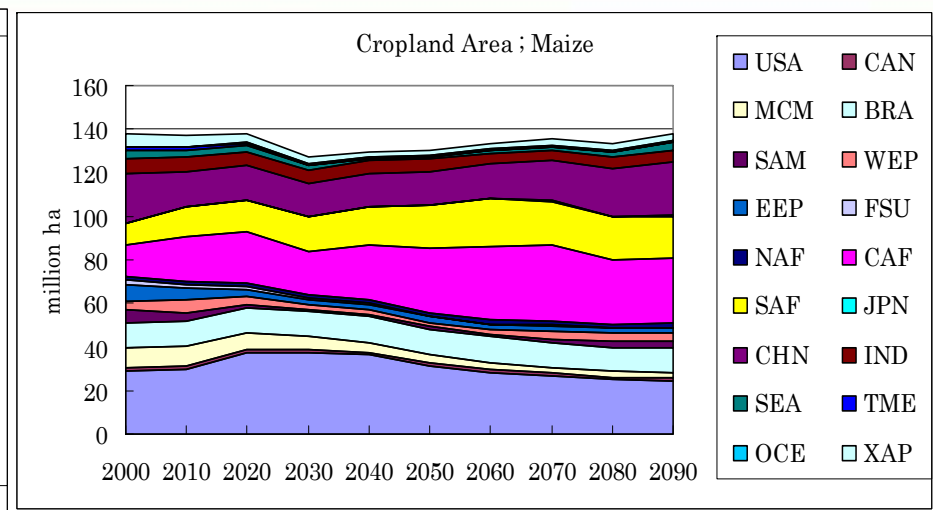
Figure 9 International market prices in low-yield case; in US dollars per kg



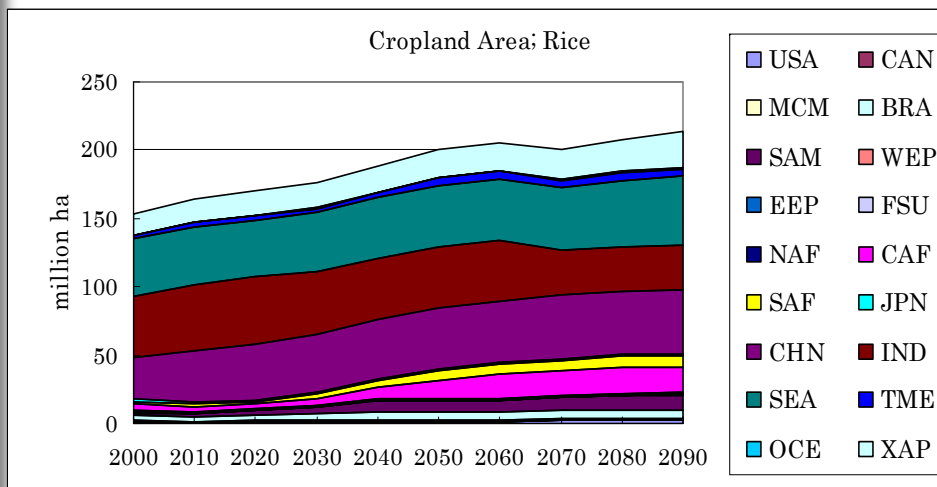
Results (5) Cropland Expansion



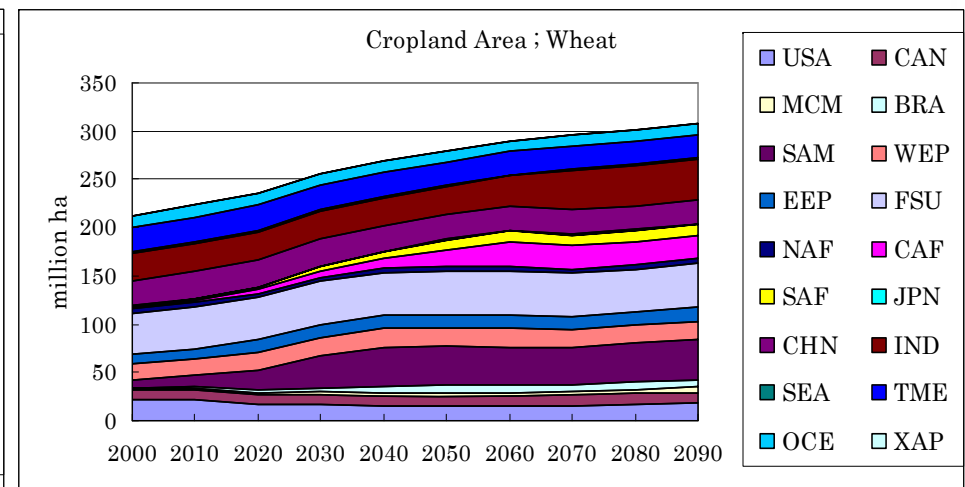
Cropland expansion ;total (SRES-B2:middle NPP)



Cropland expansion for Maize production (SRES-B2:middle NPP)



Cropland expansion for Rice production (SRES-B2:middle NPP)



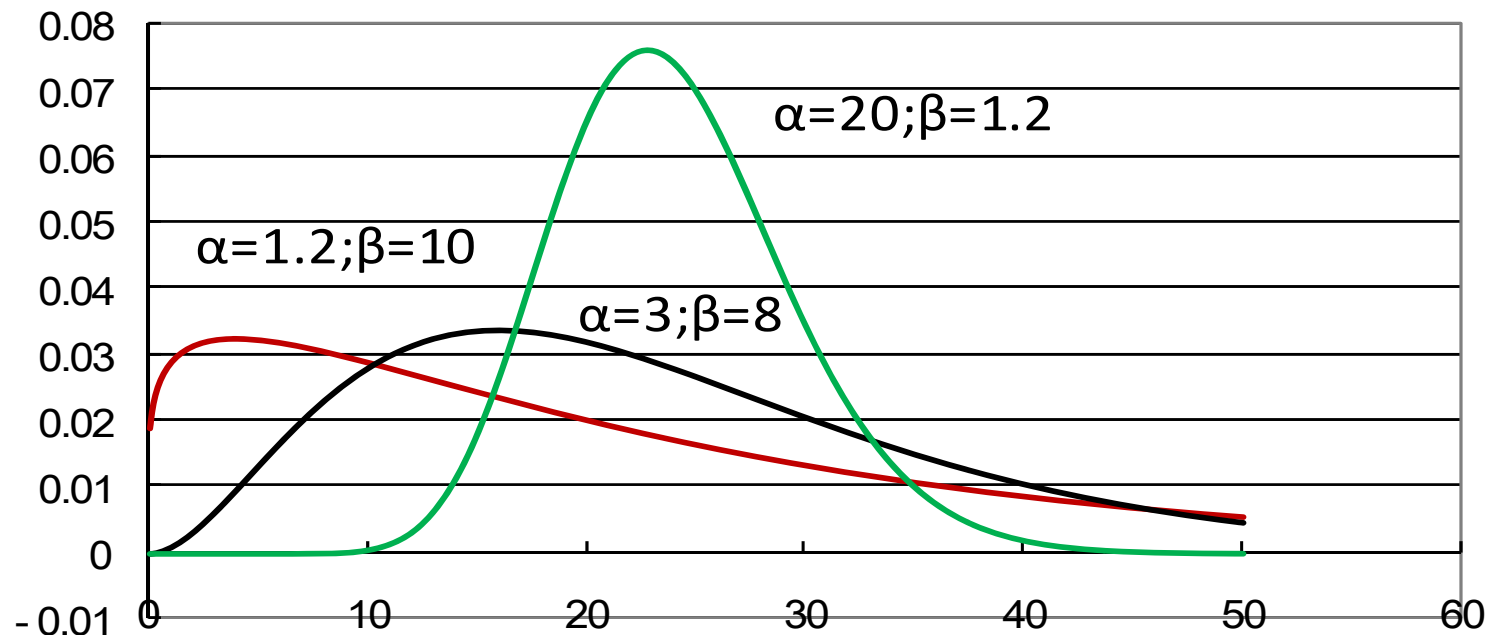
Cropland expansion for Wheat production (SRES-B2:middle NPP)

Results (6) Potential Cropland Cultivation

Mid-yield case		USA	CAN	MCM	BRA	SAM	WEP
	2050	0.0%	0.0%	0.0%	30.7%	33.7%	0.0%
	2090	0.0%	0.0%	3.5%	55.3%	56.3%	0.0%
		EEP	FSU	NAF	CAF	SAF	JPN
	2050	0.0%	0.0%	0.0%	0.0%	2.7%	0.0%
	2090	35.5%	0.0%	0.0%	26.1%	13.5%	0.0%
		CHN	IND	SEA	TME	OCE	XAP
	2050	11.6%	0.0%	0.4%	0.0%	0.0%	0.0%
	2090	81.0%	67.8%	53.1%	0.0%	2.3%	17.1%
Low-yield case		USA	CAN	MCM	BRA	SAM	WEP
	2050	0.0%	0.0%	0.0%	18.5%	0.0%	0.0%
	2090	0.0%	0.0%	14.0%	55.3%	56.3%	0.0%
		EEP	FSU	NAF	CAF	SAF	JPN
	2050	0.0%	0.0%	0.0%	2.0%	2.7%	0.0%
	2090	72.1%	0.0%	0.0%	68.3%	62.3%	0.0%
		CHN	IND	SEA	TME	OCE	XAP
	2050	12.7%	0.0%	1.9%	0.0%	0.0%	0.0%
	2090	79.1%	67.8%	74.1%	0.0%	3.7%	75.0%
High-yield case		USA	CAN	MCM	BRA	SAM	WEP
	2050	0.0%	0.0%	0.0%	38.9%	56.3%	0.0%
	2090	0.0%	0.0%	0.0%	55.3%	56.3%	0.0%
		EEP	FSU	NAF	CAF	SAF	JPN
	2050	0.0%	0.0%	0.0%	0.0%	0.4%	0.0%
	2090	0.0%	0.0%	0.0%	2.5%	1.9%	0.0%
		CHN	IND	SEA	TME	OCE	XAP
	2050	11.6%	0.0%	0.0%	0.0%	0.0%	0.0%
	2090	81.0%	0.0%	8.4%	0.0%	2.1%	8.1%

Modeling of Income Distribution

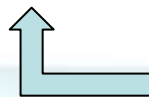
Gini coefficient does not represent the poverty.



Applying Gamma Distribution

$$f(x, \alpha, \beta) = \frac{1}{\beta^\alpha \Gamma(\alpha)} x^{\alpha-1} e^{-\frac{x}{\beta}}$$

$\alpha\beta$: mean value $\alpha\beta^2$: variance.



Income quintile data (World Bank)

Examples of Gamma Distribution

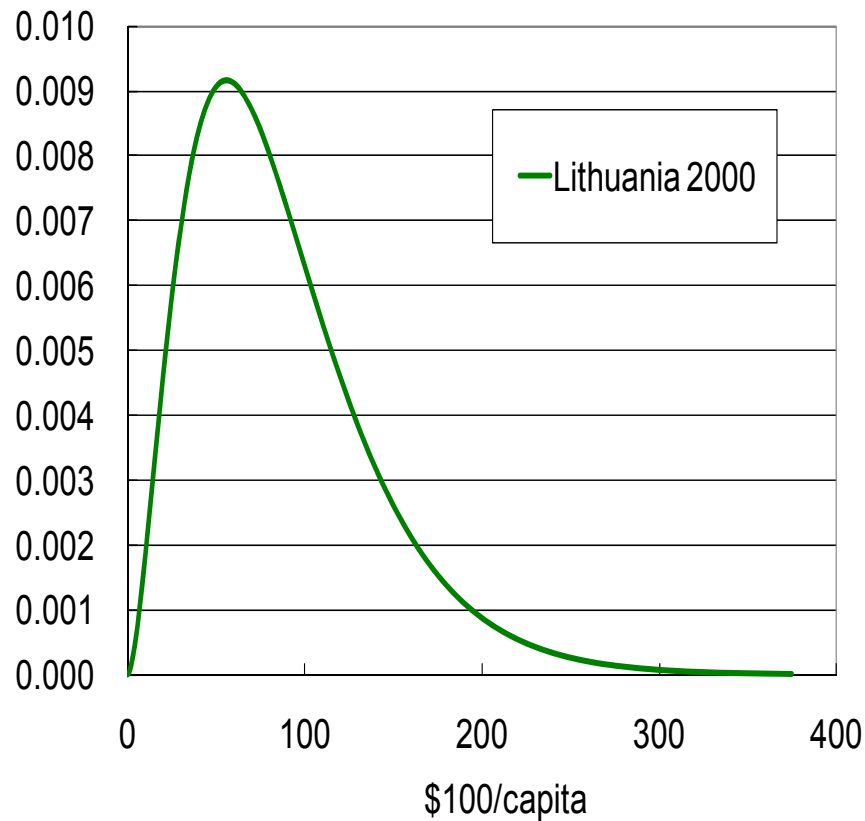


Figure 11 Gamma distribution
(Lithuania,2000)
 $\alpha : 2.8$ $\beta : 11.6$ $R^2 : 0.97$
Gini coeff. 31.9

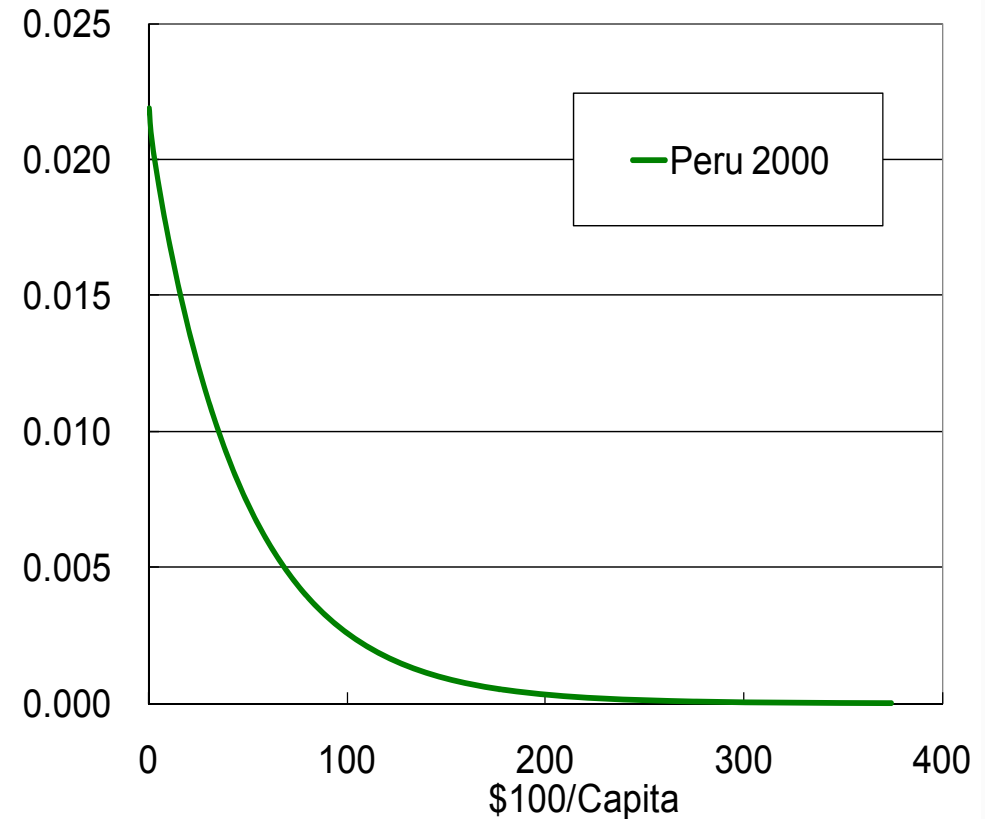
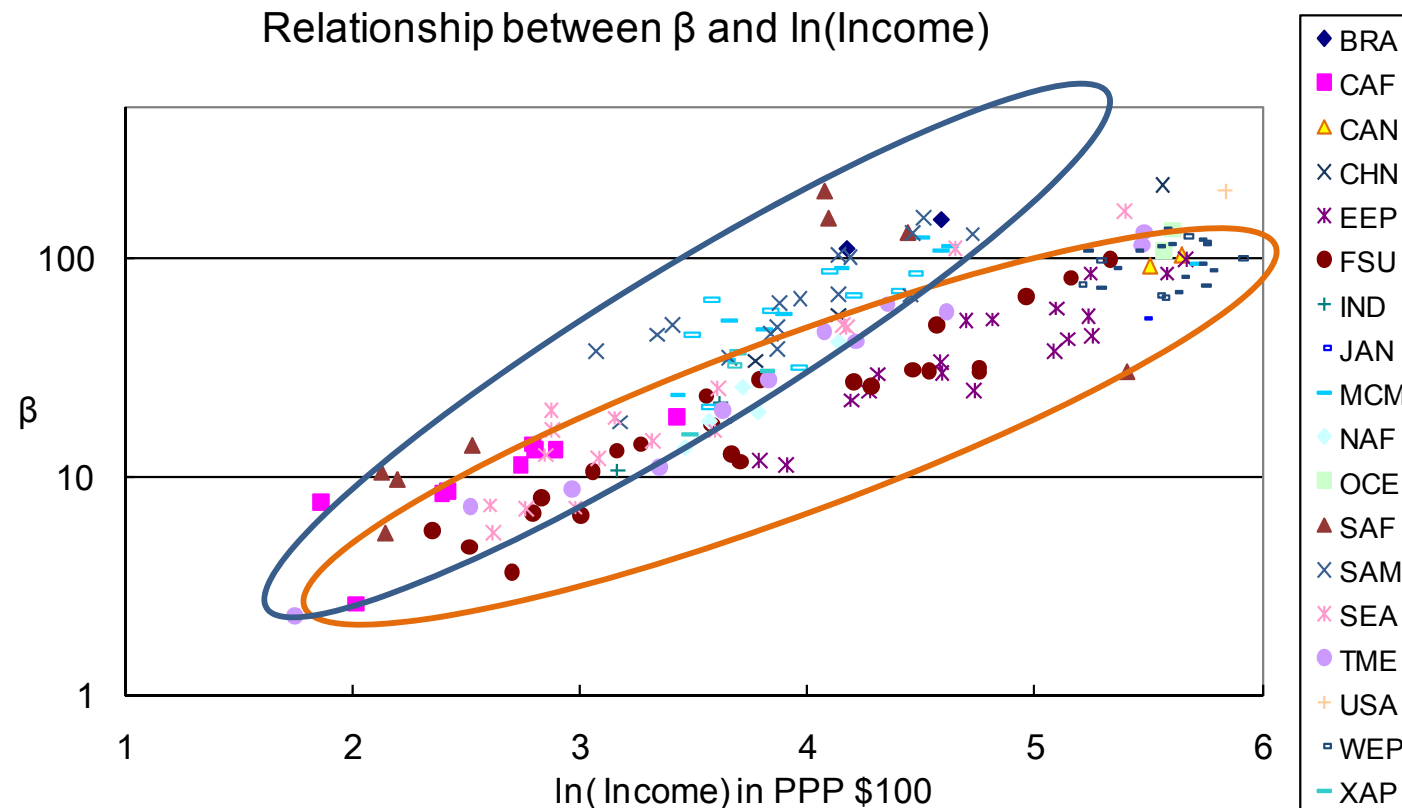


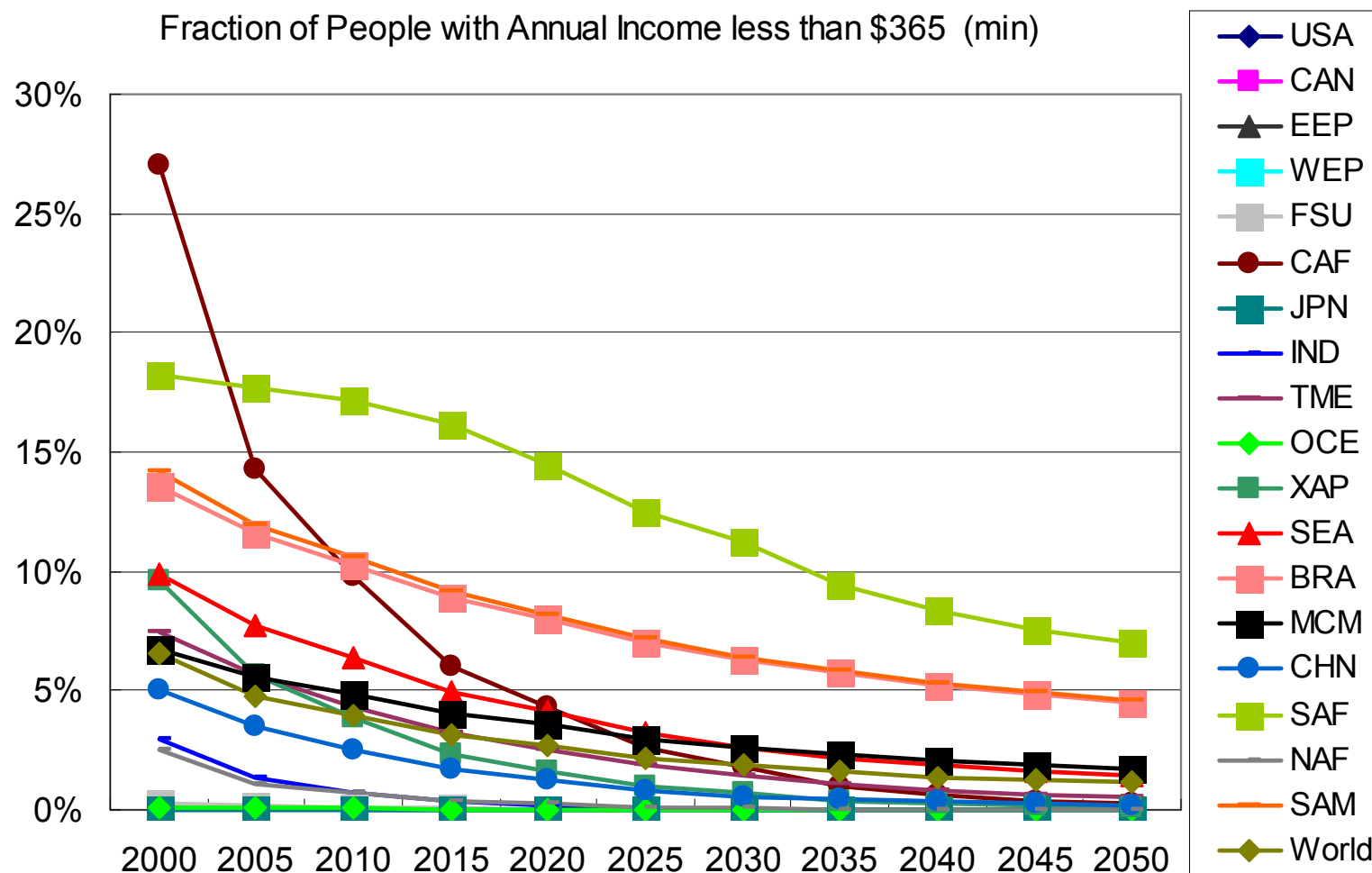
Figure 12 Gamma distribution
(Peru,2000)
 $\alpha : 0.98$ $\beta : 21.0$ $R^2 : 0.95$
Gini coeff. 49.8

Distribution of Gamma Parameters

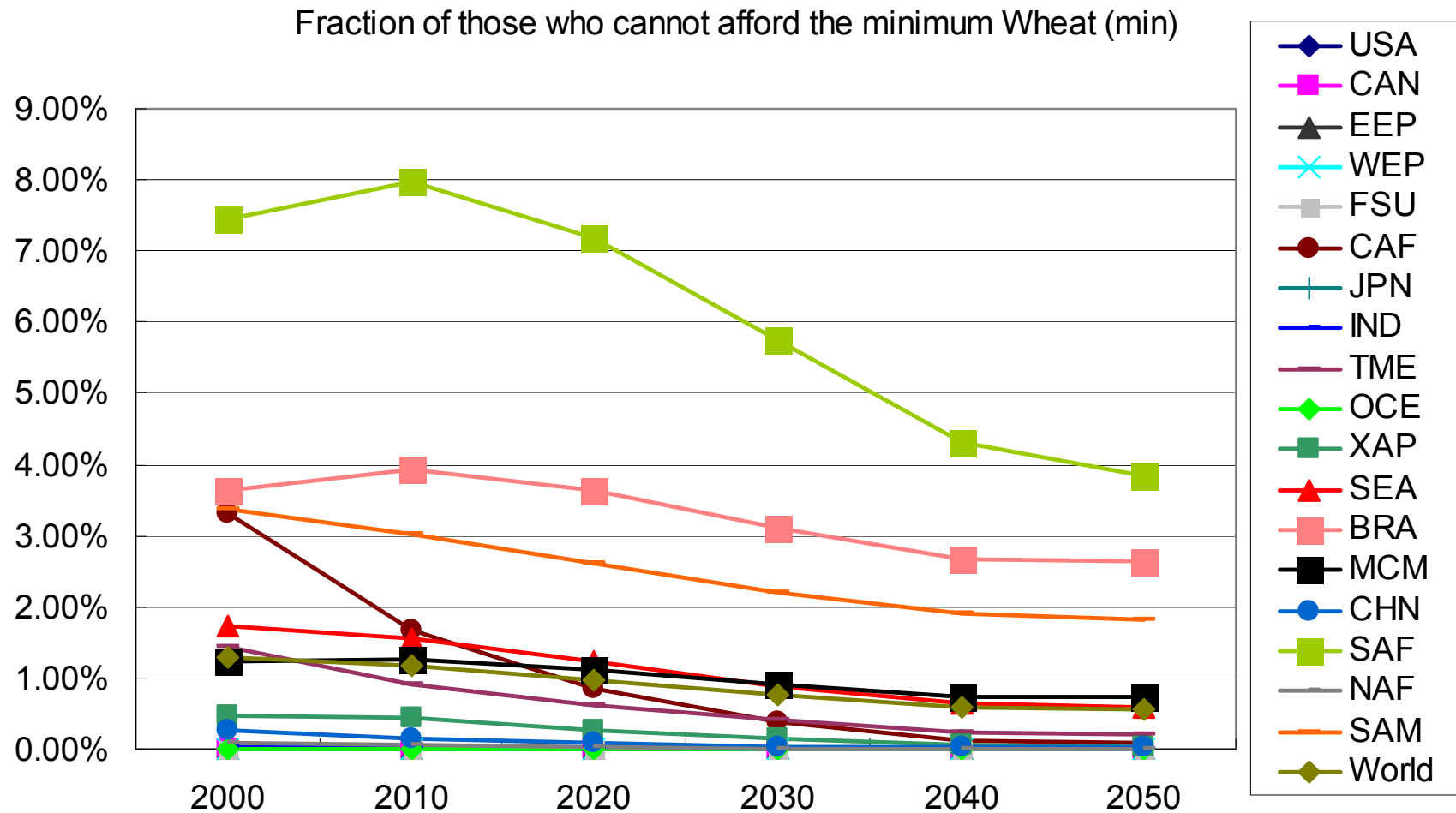


	Group-1 (in blue circle)	Group-2 (in orange circle)
B	-0.049 (0.153)	-0.264 (1.856)
A	0.982 (12.1)	0.865 (27.5)
R2	0.668	0.891
regions	BRA,CHN,MCM,NAF,SAF,SAM,SEA,XAP	CAF,CAN,EEP,FSU,IND,JP,N,OCE,TME,USA,WEP

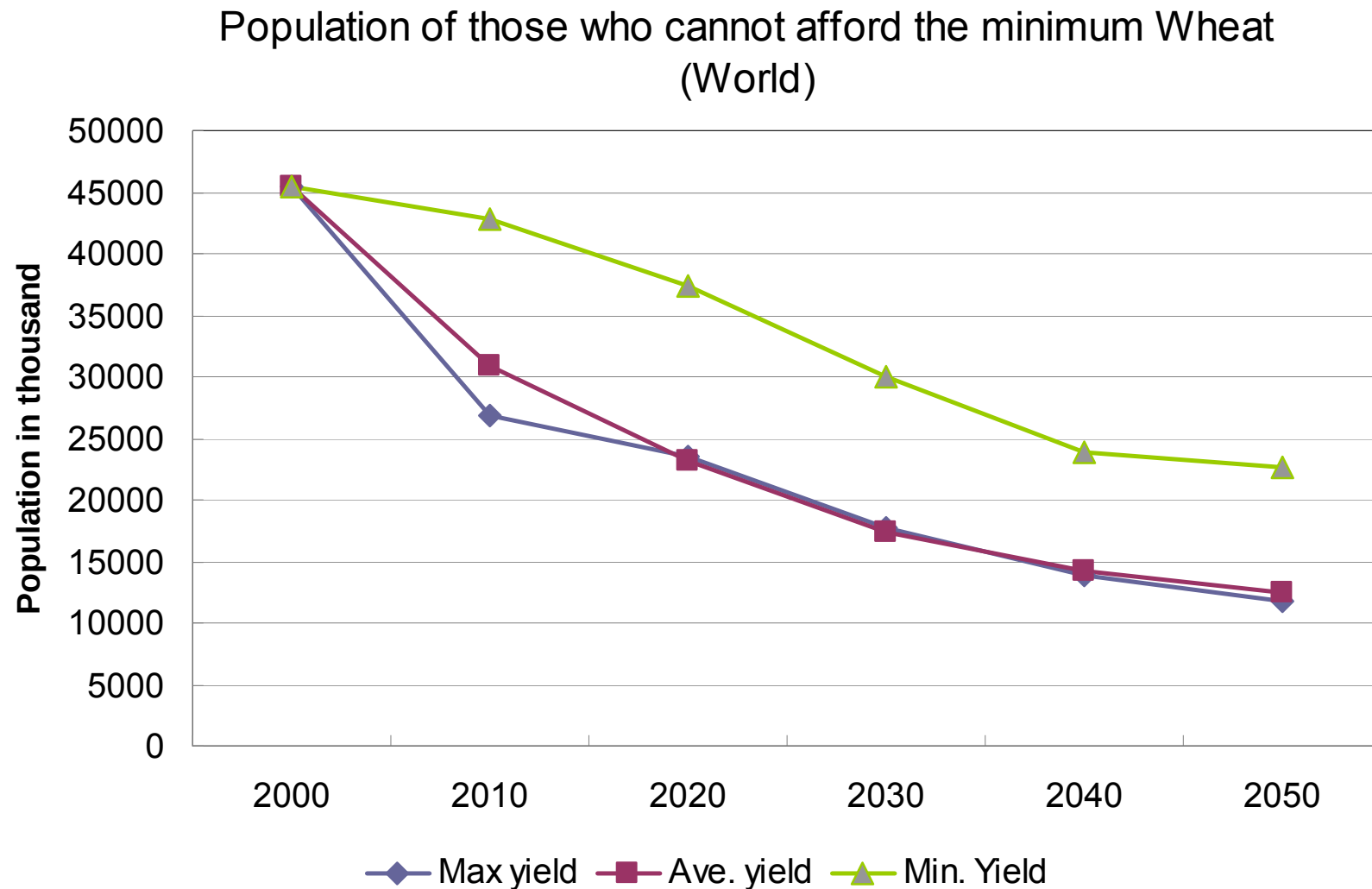
Fraction of the absolute poor population by region (annual income less than \$365)



Fraction of those who cannot afford the minimum wheat requirement in minimum yield case



Comparison of population of those who cannot afford the minimum wheat requirement

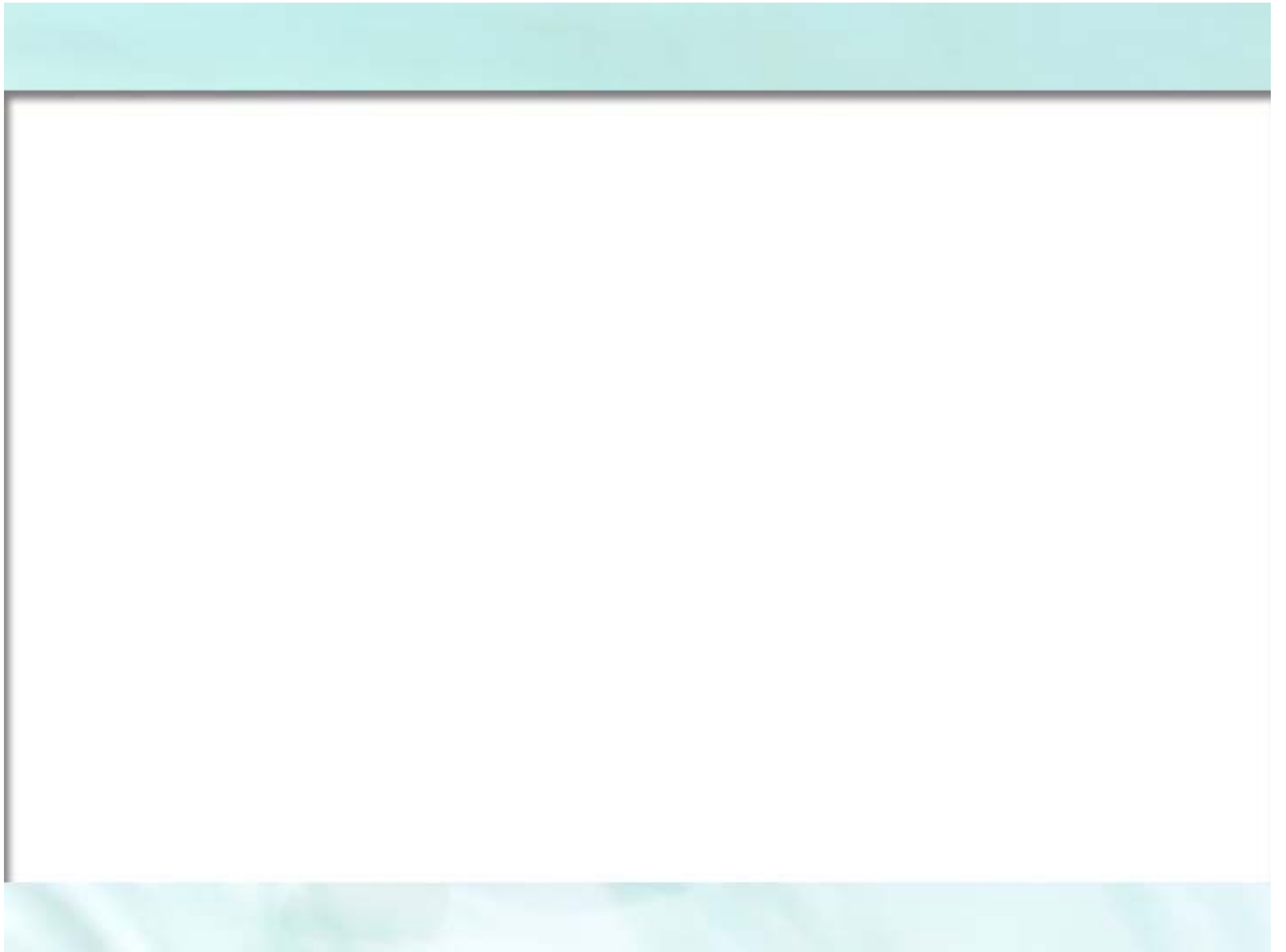


SUMMARY and CONCLUSION

- ❑ Estimation of potential cropland based on detailed land use and GIS.
- ❑ Evaluation of uncertainty on climate changes based on multi GCMs and SRES scenarios.
- ❑ Development of world crop market equilibrium model
- ❑ GISELA simulations suggest the need for the cultivation of potential cropland in current forest area in spite of the yield growth in developing regions.

SUMMARY and CONCLUSION (2)

- ❑ Market price of wheat will go up due to the meat demand growth in developing regions.
- ❑ The poverty and hunger problem may still remain in the middle of this century even if total crop production could meet the world food demand.
- ❑ Potential of biomass energy should be evaluated considering the food market and the social structure, *if it conflicts with the food production*.
- ❑ Food accessibility under climate change and the market vulnerability for low income people would be a key of global sustainability.



Formulation of Market Equilibrium Model

$$D(i,k,t) = R(i,k,t) - X(i,k,t) + M(i,k,t) - NF(i,k,t)$$

$$\sum_k D(i,k,t) = \sum_k R(i,k,t)$$

$$R(t,k,i) = YLD(t,k,i) \cdot LAND(t,k,i)$$

$$\sum_i LAND(t,k,i) \leq LAND_UP(t,k)$$

i : crop type k : region t : period

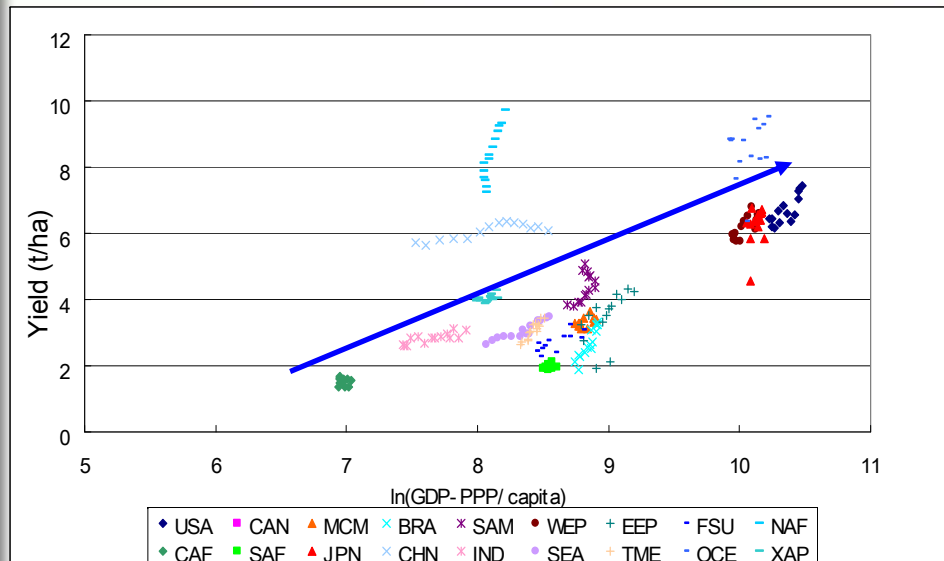
$D(i,k,t)$: food demand $R(i,k,t)$: production

$X(i,k,t)$: export $M(i,k,t)$: import $NF(i,k,t)$: feed demand

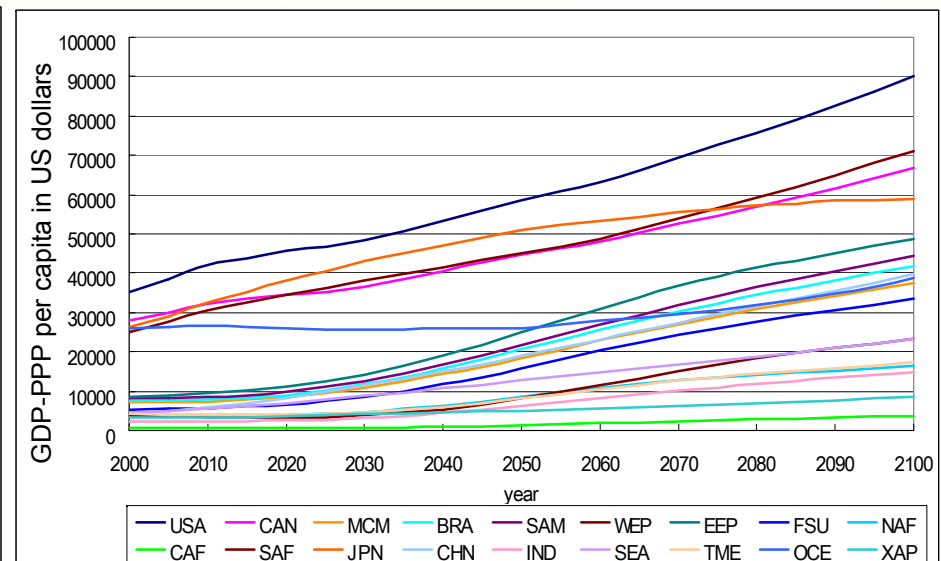
YLD : crop yield $LAND(t,k,i)$: cropland area

$LAND_UP(t,k)$: upper limit of potential cropland

Relationship between economic factor and yield



Historical rice yields vs
 $\ln(\text{GDP-PPP/capita})$



GDP-PPP per capita scenario
(SRES B2)

- Regression analysis between GDP-PPP per capita and crop yields with regional dummy variables
- GDP and population values follow SRES-A1, A2, B1 and B2 scenarios.
- Assume upper limit on crop yields.