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GISELA – GIS-based evaluation of land use and agriculture market analysis under global warming

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ABSTRACT

One of the important future issues is how agriculture production can meet the future demand increase due to the population and the income growth. Global warming would give both positive and negative impacts on them. Agriculture is often expected to supply biofuels to meet the growing transportation energy demand and the warming control policy. GISELA – GIS-based evaluation for land use and agriculture production model – is developed to evaluate the current and the potential cropland for rice, wheat, maize and soy-beans production under climate changes. We also assess the food and the feed demand based on the historical regional statistics for world into 18 regions. Finally, we assess the future food market integrating the above supply and demand conditions developing a dynamic optimization model, GISELA. Current GISELA findings are as follows: (1) potential cropland in south America will be extensively cultivated, (2) market price of wheat and soy will gradually go up while that of maize is almost stable in medium yield case, and (3) in the low-yield case, all crop prices hike rapidly in the mid of this century.

1. Introduction

Recently, biofuel is expected to play a major role in both energy security and global warming mitigation issues. In 2007, United States promoted maize-based bio ethanol production to mitigate the high oil price as well as to support the agriculture industry. The international crop prices then went up rapidly.

The existing studies on the food supply security issue have mainly focused on whether the future potential food production can meet the increasing demand under the population and the economic growth in developing regions. Dietary pattern changes according to the income growth should then be taken into account for assessing the demand–supply conditions in the international crop market.

Although the food supply per capita has been improved in average which could support all population in the world, however, there exist 800 million people suffering from hunger. It is pointed out that the global warming would cause water resource shortage and extreme climate events which affect the future food production.

The above points suggest that the food supply and demand issues should be discussed comprehensively from multiple points of views.

In this paper, we talk about an optimization model to assess the long term food production potentials based on detailed production conditions using Geographical Information Systems (GIS). The impacts of climate changes are also taken into account.

2. Background of this study

The possibility of food production which meets the food demand under the population and the economic growth has been a central policy issue. We can list up a number of debates between the pessimistic and the optimistic views since the historical Malthus argument. While Lester Brown [19,20] proposed a typical pessimistic view, IFPRI emphasizes a possibility to overcome the hunger in 2020 VISION [8] stressing an importance of world corporation and action. Mitchel [21] points out the production growth of the former central economy countries and concludes that the world will feed the doubling population in the next two decades. Kawashima [18] also concludes that the food supply shortage is unlikely to occur because of the food demand saturation and the assessments of potential cropland including fallow land.

The assessment of the impacts of global warming is still controversial due to the uncertainties in both the spatial distribution of climate change and the possibility of adaptability. The Fourth

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Assessment Report of Intergovernmental Panel of Climate Change [10,11] points out the decrease of yields in the 1–2 °C atmospheric temperature rise in the low latitude area while 1–3 °C atmospheric temperature rise in the middle latitude area may both increase and decrease them. Higher temperature rise would mostly decrease the yields.

Besides the above middle-to-long term food potential production issues, recent market price fluctuation is also worried about. Figs. 1 and 2 exhibit the international prices of major crops and the trends in the world crop supply and demand [22], respectively. The world crop production has mostly followed the world demand while the market prices have heavily fluctuated. Needless to say, such vulnerability of the world crop market affects the daily life of poor people seriously.

These two issues are related with each other. The investment for the expansion of cropland under the market uncertainty would decrease while the marginal productivity of additional cropland would be decreasing. Such lowered investment will make the agriculture system more vulnerable by the insufficient irrigation, fertilizer, storage system, etc. On the contrary, the augmented management and production capability given by the technological progress will strengthen the market robustness which provides stable agriculture policy. Biofuel will be widely utilized under the stable crop market.

When we discuss the food demand–supply issue, it is needed to assess not only the potential supply capability but also the market conditions, especially the market pressure to raise the price.

In this study, we develop a model to assess the crop production and demand potentials under the market behavior model. This model provides a basis to assess the food distribution and biofuel potentials.

3. Outline of this study

Many of existing studies on potential cropland have focused on the certain regions based on detailed data. The long term assessment on the potential global food production under climate changes are provided by IIASA [9], RITE [1] where maximum potential cropland is focused on. IMAGE-2 [26] provides the dynamic changes of crop land under climate changes where the market behavior is not formulated. Global food market has been analyzed by equilibrium models. IFPSIM developed by Ohga [23] is widely used to assess the food market, while the assessments of potential cropland and land use change are not explicitly formulated.

We develop a long term food supply and demand model considering the long term climate change. In this paper, the short term price fluctuations affected by financial market and other speculative dealings are not described. The market vulnerability will be suggested by the equilibrium price changes and the required development of potential cropland.

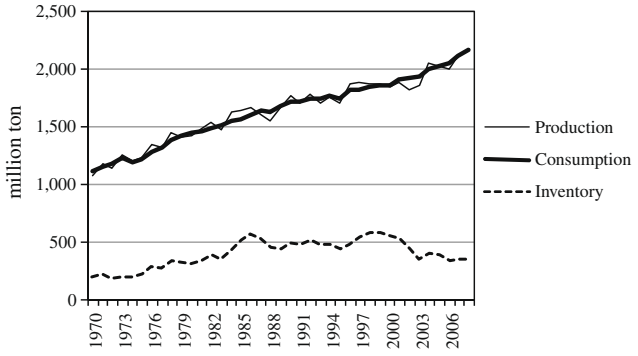

Fig. 1. World crop production, demand and inventory in million tons [22].

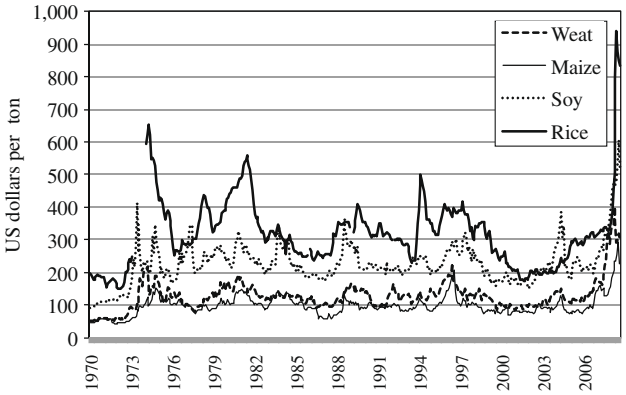

Fig. 2. Trends in world crop prices in US dollars per ton [22].

In this paper, we consider four major crops, i.e., maize, rice, soy and wheat. We apply Geographical Information System (GIS) to analyze the relationship between climate changes and the potential production by crop. Potential cropland by crop is estimated based on the detailed land use data given by USGS [28], soil map given by FAO [5], growing conditions on temperature and water availability. Reflecting the uncertainties of climate models, we compare the six Atmosphere–Ocean General Circulation Model (AOGCM) studies and estimate the pessimistic yield case and optimistic yield case besides the base case. The potential cropland area generated by the above gives the upper limit of the cultivation. We then develop a dynamic optimization model to see the market behavior. Under the given world population and economic growth scenario, the model generates equilibrium market prices and demand by crop by maximizing the summation of discounted consumer's surplus. Feed demand is given exogenously.

The outline of this study is shown in Fig. 3. The boxes with bold line and italic characters are the exogenous data and the boxes connected with the market equilibrium model by both-side arrow represent endogenous variables. Other boxes are the estimated parameters. Land use data and climate change simulations provide potential cropland by crop and region. The demand functions of crops by region are given based on the Business-as-Usual (BAU) GDP and population scenario and statistically estimated parameters. We employed the IPCC-SRES-B2 scenario [16] for the reference GDP and population scenario. The model is named GISELA – GIS-based evaluation of land use and agriculture market.

4. Structure of GISELA model

4.1. Definition of region group

The block of the market equilibrium model of GISELA aggregates the world into eighteen regions shown in Table 1 while it deals with USGS 1 km grid data to assess the potential cropland. We assume the reference population and GDP scenario according to the IPCC-SRES-B2 scenario.

4.2. Estimation procedure of potential cropland

Potential crop production is a product of the potential cropland and the yield. The estimation procedure of the former is as follows: the current land use data is provided by USGS GLCC-Version2. We extracted the number of grids classified as maize, rice, soy and wheat production area. We calculate the ratio of number of grids to the FAO cropland statistics in 2000 as conversion coefficient. Next, we extract the pasture/grassland area, the tropical forest area and other forest area. According to Tivy [27] and FAO Soil Map [5],