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Estimation of Net Primary Production in Japan under Nitrogen-Limited Scenario Using BGGC Model

Tomohiro HAJIMA*, Yo SHIMIZU*, Yoshitaka FUJITA*, and Kenji OMASA*

*Department of Biological and Environmental Engineering, Graduate School of Agricultural and Life Sciences, The University of Tokyo, Tokyo, 113-8657 Japan

Abstract

The Bio-Geographical and GeoChemical model (BGGC) is a process-based mathematical model that can be used to assess future impacts of climate change on the distribution and functioning of terrestrial ecosystems. This model can simulate the cycling and fluxes of carbon and nitrogen in vegetation, soils and exchanges with atmosphere, as well as estimate potential distribution of natural vegetations. One of the strengths of the BGGC model is to estimate net primary production (NPP) under scenarios where nitrogen is limiting. This is accomplished by a material cycling module that can simulate processes of vegetation competition due to nitrogen limitation. The objective of this study was to use BGGC model under various climate change scenarios to test its applicability in evaluating changes in NPP with limiting nitrogen availability across the diverse geographical regions of Japan.

Results of simulation showed that nitrogen interacts with elevated CO_2 and temperature, decreasing NPP with increasing nitrogen limitations. The terrestrial ecosystem was generally predicted to be a net sink for carbon but it could be over-estimated without the nitrogen limiting the photosynthesis.

Key words: BGGC model, Climate change, Nitrogen uptake, NPP

1. Introduction

The third assessment report of Intergovemental Panel on Climate Change (IPCC) reported that global warming will cause an increase of surface air temperature of about 1.4 to 5.8 °C from 1990 to 2100 (IPCC, 2001). Increases in the atmospheric concentration of CO_2 and temperature could affect terrestrial ecosystems in many ways, including changes in their spatial distribution as well as carbon and nutrient cycling. However, it is difficult to estimate these changes by a simple causal relation because the change of material cycling in ecosystem and spatial distribution of vegetation involves a complicated physiological processes like respiration, photosynthesis, phenology as well as physical factors in the surface air and soil. Consequently, we used a comprehensive, mechanistic ecosystem model constructed with those physiological and physical processes deemed important in understanding the impact of global warming.

In the estimation of vegetation, some process-based bio-geographical models like BIOME3 (Haxeltine and Prentice, 1996) have been constructed. Ishigami *et al.* (2002) improved BIOME3 for estimating the distribution of potential natural vegetation in Japan and assessed the climate change on potential natural vegetation and net primary production (NPP). Potential natural vegetation is defined as the climax vegetation under the stable climate condition, and thus it does not include the transient vegetation or the secondary vegetation. NPP, which is defined as the net flux of carbon from the atmosphere into green plants per unit time, is a basic index to grasp the function of ecosystem as the source of CO_2. In bio-geographical model BIOME3, however, the prediction of the distribution of NPP and vegetation in the global warming have some problems with regards to the increases in CO_2 concentration and temperature that cause the direct increase in NPP. This is because the rate of nitrogen-limited net photosynthesis is not modelled explicitly.

Bio-Geographical and GeoChmical model (BGGC) has been constructed by coupling bio-geographical model with bio-geochemical model to consider the influence of nitrogen content of canopy. Hence, the objective of this study is to use BGGC model to test its applicability in evaluating changes in NPP with limiting nitrogen availability. This also aims to estimate NPP across the whole geographical region of Japan under climate change scenarios.

2. Materials and Methods

2.1 Model features

BGGC consists of two main components: (i) a competition submodel, which is mainly derived from BIOME3 (Haxeltine and Prentice, 1996; Ishigami *et al.*, 2002). and (ii) a soil material cycling submodel, which is the Soil Organic Matter model of bio-geochemical model 'CENTURY4' (Parton *et al.*, 1993). By combining these two models, it was made

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Table 1. Processes represented in BGGC, the approach taken, and the sources.

Process	Approach	Sources
Competition	Canopy plot model (maximizing the NPP for each PFT)	Haxeltine and Prentice (1996)
Photosynthesis	A function of light, CO_2, Nitrogen, temperature	Haxeltine and Prentice (1996), Anten *et al*.(1995)
Maintenance and growth respiration	Leaf: scaled to Vmax, sapwood: a function of carbon content, root: a function of litter, growth: steady rate of photosynthate	Farquhar *et al*.(1980), Haxeltine and Prentice (1996), Ryan (1991)
Stomatal conductance	Not represented	
Evapotranspiration	Minimum of a soil-supply and a plant-demand	Monteith (1995), Prentice *et al*.(1993)
Tree mass and height	Not represented	
Decomposition	Soil Organic Matter model from Century	Parton *et al*. (1993)

possible to calculate the photosynthetic rate considering the nutrition condition in the soil. An overview of the processes considered, and the modelling approaches used, are shown in Table 1.

The essential logic of this model is almost same as the BIOME3. First, BGGC selects a subset consisting of some plant functional types (PFTs) in a particular grid cell on the basis of some ecophysiological constraints. Second, the maximum sustainable leaf area index (LAI) and NPP for each PFT was calculated on the basis of simulating the photosynthesis and respiration under the climatic and soil condition in the grid. In this process, the simplified Farquhar photosynthesis model (Farquhar *et al.*, 1980; Haxeltine and Prentice, 1996) was used to calculate the daily photosynthetic rate. In BGGC model, the nitrogen-photosynthesis model (Anten *et a.l*, 1995) was newly added to its photosynthetic process and the effect of nitrogen on the photosynthesis was considered. Lastly, the PFT with the highest NPP was selected as the dominant plant type in the grid. The output of PFT was classified into biome types and the optimal NPP was obtained.

2.2 Climate inputs

IPCC developed a set of scenarios (Special Report on Emissions Scenarios, SRES) about the future emission of greenhouse gases. These scenarios were grouped into 4 types (A1, A2, B1, B2) according to some storylines differentiated in two main dimensions: the balance between economic and environmental concerns, and the heterogeneity of regional development patterns. These scenarios are used as inputs to several General Circulation Models (GCMs), which generate the future climatic datasets. In this research, the climate datasets from CSIRO-Mk2 model for the scenario of A2 and B2 were used as climate inputs.

However, these outputs from GCMs have rough spatial resolution, therefore, when using these outputs as the off-line input of bio-geographical or bio-geochemical models like BGGC, it was necessary to improve the resolution. Yokozawa *et al.* (2003) statistically interpolated the GCMs data (based on the IS92a emission scenario) to 10 x 10 sq. km grid data. This study used the same method to GCMs data based on SRES scenarios from which a grid of 4,691 for Japan was obtained.

Table 2 shows the climatic data and atmospheric CO_2 concentration used as inputs in this study, respectively.

2.3 Simulation

In this paper, in order to directly evaluate the effect of nitrogen on photosynthesis processes, the soil material circulation module was temporarily separated from BGGC (except for soil water circulation module) and a set of initial parameters concerned with canopy nitrogen and its photosynthesis capacity was given to each PFT. These parameters were tuned to adjust the current potential natural vegetation estimated by BGGC to the results of BIOME3.

3. Results and Discussion

Figure 1 shows the distribution of the ratio of NPP estimated for 2080 (A2 scenario, input CO_2 concentration is 713 ppm) to NPP for current climate condition. The ratio averages was 1.35 and maximal / minimum values ratio showed 2.04 / 0.90. In the distribution of the ratio, the high ratio can be observed in higher latitude and in higher elevation area.

For evaluating the effect of nitrogen on NPP

Table 2. CO_2 concentration and changes in averages of each climate data between GCM experiment data to Normals. Changes in temperature is represented as the difference and changes in precipitation and radiation is the ratio of GCM to Normals. CO_2 concentration used for 2000 is 367 ppm.

Scenario	A2 Scenario		B2 Scenario	
Year	2050	2080	2050	2080
CO_2 (ppm)	537	713	476	570
Temperature (℃)	2.08	3.54	2.07	2.73
Precipitation	1.11	1.09	1.06	1.08
Radiation	1.10	1.13	1.12	1.14

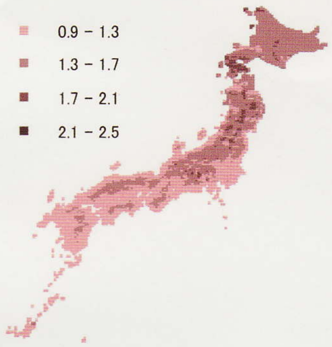

Fig. 1. Distribution of the ratio of NPP estimated for 2080 (A2 scenario, input CO_2 concentration is 713 ppm) to NPP for current climate condition.

estimation, the results of NPP estimated by BGGC model and the existing bio-geographical model 'BIOME3' were compared under each scenario (Fig. 2). In BGGC model, the difference of input climate data sets between A2 and B2 scenario caused a little difference to the result of estimated NPP values. But the results of NPP as simulated by BIOME3 showed larger difference between these two scenarios. Much more difference can be observed in the increasing rate of NPP between the results of BGGC and BIOME3. These results mean that an elevated CO_2 concentration and an increased of temperature have a direct influence on the estimation of NPP in BIOME3.

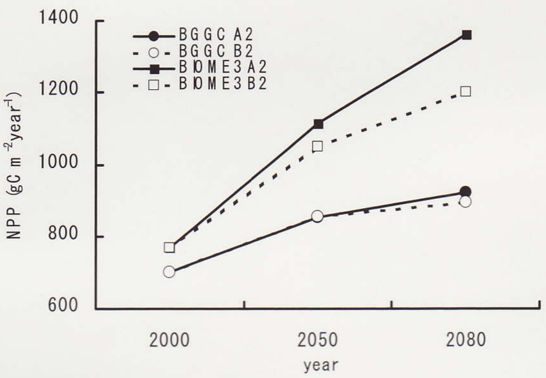

Fig. 2. Comparing the averages of NPP estimated by BGGC model with bio-geographical model 'BIOME3' for each scenario

In this study, although the variation of soil nitrogen content according to the climate change was not considered, the significant effect of nitrogen on estimating NPP was evident. Nitrogen interacts with elevated CO_2 and temperature, decreasing NPP with increasing nitrogen limitations. The terrestrial ecosystem was generally predicted to be a net sink for carbon but it could be over-estimated without the nitrogen limiting the photosynthesis.

References

Anten, N .P .R., Schieving, F. and Werger, M. J. A., 1995: Patterns of light and nitrogen distribution in relation to whole canopy carbon gain in C3 and C4 mono- and dicotyledonous species. *Oecologia.*, **101,** 504-513.

Farquhar, G. D., Caemmerer, S. and Berry, J. A., 1980: A biochemical model of photosynthetic CO_2 assimilation in leaves of C3 species. *Planta.*, **149,** 78-90.

Haxeltine, A. and Prentice, I. C., 1996: A general model for the light-use efficiency of primary production. *Funct. Ecol.,* **10,** 551-561.

Haxeltine, A. and Prentice, I. C., 1996: BIOME3: An equilibrium terrestrial biosphere model based on ecophysiological constraints, resource availability, and competition among plant functional types. *Glob. Biogeochem. Cycles.*, **10,** 693-709.

IPCC, 2001: *Climate Change 2001 The scientific basis: Contribution of Working Group 1 to the third assessment report of the intergovernmental panel on climate change*. Cambridge University Press.

Ishigami, Y., Shimizu, Y. and Omasa, K., 2002: Estimation of potential natural vegetation distribution in Japan using a process model. *J. Agric. Meteol.*, **58**, 123-133.

Monteith, J. L., 1995: Accommodation between transpiring vegetation and the convective boundary layer, *J. Hydrol.*, **166**, 251-263.

Parton, W. J., Scurlock, J. M. O., Ojima, D. S., Gilmanov, T. G., Scholes, R. J., Schimel, D. S., Kirchner, T., Menaut, J. C., Seastedt, T., Moya, E. G., Kamnalrut, A. and Kirchner, J.I., 1993: Observation and modeling of biomass and soil organic matter dynamics for the grassland biome world-wide. *Glob Biogeochem. Cycles.*, **7,** 785-809.

Prentice, I. C., Sykes, M. T. and Cramer, W., 1993: A simulation model for the transient effects of climate change on forest landscapes, *Ecol. Modell.*, **65**, 51-70.

Ryan, M. G., 1991: Effects of climate change on plant respiration, *Ecol. Appl.*, **1**, 157-167.

Yokozawa, M., Goto, S., Hyashi, Y. and Seino, H., 2003: Mesh climate change data for evaluating climate change impacts in Japan under gradually increasing atmospheric CO_2 concentration. *J. Agricul. Meteol.*, **59,** 117-130.