Monitoring of crop yields and CO_2 fixation by a photosynthetic-sterility model using satellites and meteorological data in Asia

Daijiro Kaneko[1]

[1] Matsue National College of Technology, www.matsue-ct.ac.jp Email kand@ce.matsue-ct.ac.jp

Abstract

This study is intended to develop a model for estimating CO_2 fixation in the carbon cycle and for monitoring grain yields using a photosynthetic-sterility model, which integrates solar radiation and air temperature effects on photosynthesis, along with grain-filling from heading to ripening. Grain production monitoring would support orderly crisis management to maintain food security in Asia, which is facing climate fluctuation through this century of global warming. A decision-tree method classifies the distribution of crop fields in Asia using MODIS fundamental land-cover and SPOT VEGETATION data, which include the Normalized Vegetation index (NDVI) and Land Surface Water Index (LSWI). This study provides daily distributions of the photosynthesis rate, which is the CO_2 fixation in Asian areas combined with the land-cover distribution, the Japanese geostationary meteorological satellite (GMS), and meteorological re-analysis data by National Centers for Environmental Prediction (NCEP). The method is based on routine observation data, enabling automated monitoring of crop yields.

Media summary

This paper is intended to develop a photosynthetic-sterility model for monitoring crop yield and CO_2 fixation in Asia using satellites and meteorological data.

Key Words

Monitoring, crop yield, photosynthesis, CO_2 fixation, remote sensing

Introduction

This research aims to develop a crop monitoring model for Southeast Asia by using remotely sensed and meteorological data. The author has reported a crop production index CPI to monitor grain production by developing a photosynthesis-based crop production index which takes into account the effect of temperature on the photosynthesis rate (PSN) and on sterility during grain filling, from heading to ripening. The CPI index depends on the solar radiation, temperature effects, and the vegetation biomass available from remotely sensed and meteorological data. In view of the climate change and the expansion of perturbation range in annual rainfall due to the global warming in the Asian countries, it is important to oversee the quantity of grain in production at an early stage. The very poor Japanese harvests in 1993 and 2003 were caused by low temperature and shortage of sunshine; this happens about every ten years in Japan. The climate conditions in rice production are the same in Japan and the Korean Peninsula. Orderly crisis management in crop production minimizes the resulting social, economic and political tensions in Asian politics. The present report presents distributions of photosynthesis amounts (CO_2 fixation) in Asia and proposes a crop yield index (CYI) by improving the photosynthesis model and the normalized unit, CPI_U, which was previously developed using the crop situation index (CSI). The author is expanding the monitoring methods using CPI_U and CYI by the application of the indices to crop fields in Japan and China. Land/cover and grain fields' classification are examined in Southeast Asia using terra MODIS and SPOT VEGETATION data. This paper describes modeling of the photosynthesis response functions of the two indices of CPI and CYI along with the crop field classification in Southeast Asia using Terra MODIS fundamental land-use and phonological data from SPOT VEGETATION.

Method for monitoring crop production

The author defined the PSN using eq. (1a) shown below, with a Michaelis-Menten type of radiation response function f_{rad_mm} that is proper for wheat and maize, and another type of radiation response function f_{rad_pc} proposed by Prioul-Chartier, which properly fits the curve of the PSN for paddy rice.

$$PSN = f_{rad} \cdot f_{Syn}(T_c) \cdot \beta_s \cdot eLAI \quad (1a)$$

For wheat and maize, the following is used.

$$f_{rad\_mm} = \frac{a_{mm} \cdot PAR}{b_{mm} + PAR} \quad (1b)$$

For paddy fields, with applicability also for vegetation of forest and grass, the following is used.

$$f_{rad\_pc} = \frac{a_{pc} \cdot PAR + PSN_{\max} - \sqrt{(a_{pc} \cdot PAR + PSN_{\max})^2 - 4m \cdot a_{pc} \cdot PSN_{\max} PAR}}{2m} \quad (1c)$$

In those equations, PSN is the photosynthesis rate (gCO_2 m^{-2} day^{-1}), PAR is the photo-synthetically active radiation (MJ m^{-2}), β_s is the stomatal opening, a_{mm} and b_{mm} are Michaelis-Menten constants, T_c is the canopy temperature (°C), $eLAI$ is the effective leaf area index, f_{ster} is the sterility response function for the air temperature, a_{pc} is the Prioul-Chartier constant, PSN_{max} is the maximum PSN, and m is the curve convexity constant.

The unit of the photosynthesis model is the carbon dioxide fixation rate (gCO_2 m^{-2} day^{-1}), which fits the objectives for carbon circulation on the earth in this era of climate change and recent price increases of petroleum and coal. The unit is also compatible with increased biomass demand for use in carbon-neutral energy production and for ethanol production. The author improved the model by adopting the Prioul-Chartier type of photosynthesis rate function, which has characteristics of the limit of the maximum photosynthesis rate on the grain case of paddy rice. Integration of the photosynthesis rate over the interval from sowing t_s to harvest t_h defines the crop production index unit CPI_U as taking the following form:

$$CPI_U = F_{Ster}(T_c) \cdot \int_{t_s}^{t_h} PSN_U \cdot dt \quad (2)$$

$$F_{Ster} = \int_{t_f}^{tr} f_{Ster}(T_c) \cdot dt \quad (3)$$

The CPI_U equation (2) involves the heading term expressed via equation (3), which is of time-integrated shape so as to account for the effect of temperature on flowering, pollination, and ripening.

Data used for modeling

The photosynthesis rate (CO_2 fixation) PSN for carbon cycle and biomass energy as well as the crop production index (CPI) for grains require daily solar radiation and air temperature data because these vary

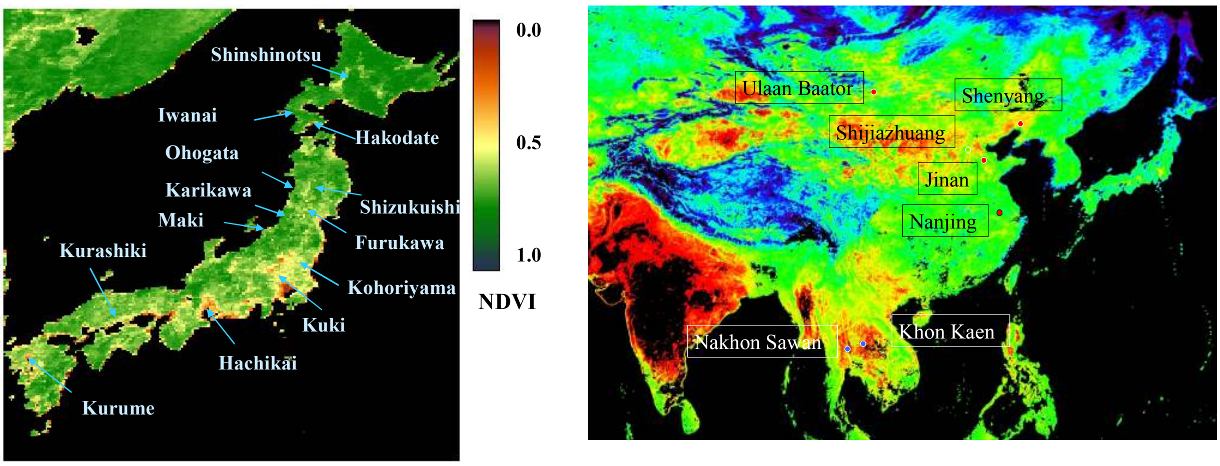

Figure 1. Distribution of NDVI and monitoring sites in Japan for validation of this crop yield model and distribution of principal monitoring sites over the NDVI derived from SPOT VEGETATION in Southeast Asia.

widely from day to day. The ultimate aim of monitoring the quantity of crop production in Southeast Asia demands daily data for solar radiation and air temperatures across large regions. A useful source of the necessary meteorological data is the world weather data network, which currently gives daily weather reports of data around the world in real time. However, these data are point data at meteorological observation sites. The author intends to introduce weather prediction reanalysis data supplied by the National Center for Environmental Prediction (NCEP) in the USA, which includes the horizontal distribution of surface meteorological data on a world scale. The ground air temperature data at test sites are supplied by the Japanese Meteorological Agency from Automated Meteorological Data Acquisition System (AMeDAS) points at ten sites out of more than 1000 observation points that are distributed in the Japanese agricultural regions.

The Japanese Ministry of Agriculture, Forestry, and Fisheries provides grain statistical information, which includes crop situation index for the paddy rice at ten sites for modeling and monitoring those paddy provinces. This crop situation index is the ratio of crop production in the year in question to the mean annual production for the ten most recent years.

The satellite NDVI data used in the CPI index are the four-minute mesh set of vegetation index data derived from the NOAA Advanced Very High Resolution Radiometer (AVHRR) by Tateishi and NDVI derived from SPOT VEGETATION in Southeast Asia. Figure 1 shows the distribution of vegetation index NDVI in Southeast Asia including Japan derived by SPOT VEGETATION. The further satellite data for the CPI index is global solar irradiance, obtained via the Japanese Geostationary Meteorological Satellite (GMS) over SE_Asia, including Japan.

Results of the crop production indices

The crop production index CPI_U has incorporated the main factors related to grain production, and is applicable to significant climate changes and abnormal weather conditions because of its basis in photosynthesis. Figure 2 shows the daily variation of Crop Yield Index CYI, which expresses yield unit of (t/ha) on cumulated effects of daily meteorological conditions. The CYI and CSI indices are powerful for crop production monitoring and early warning of poor harvests. Figure 3 shows preliminary results for the CPI index for five regions from northern to southern China. For precise evaluation of crop production in China, the CPI_U requires normal production averaged annually. Figure 4 depicts a precise distribution of grain fields in Southeast Asia. A decision-tree method using NDVI and LSWI phenology can divide the MODIS crop field into four classes of grain fields in the North China and Hindustan plains. This distribution is used for computing the distribution of photosynthesis and crop yields in Southeast Asia**.** Classified data of the distribution of Land-use enables computation of the distribution of crop yield as well as CO_2 fixation and CH_4 emission for studies related to global warming and carbon cycles on the earth. Figure 5 shows a distribution of photosynthesis rate (CO_2 fixation) in grain fields of spring wheat, winter wheat, and paddy fields in Southeast Asia on 1 August 2001. Dark areas in the west imply outside

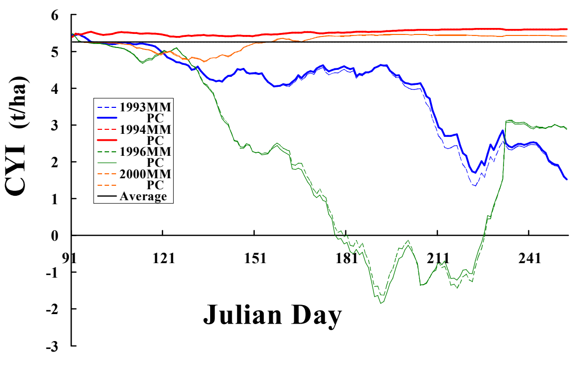

Figure 2. Relation between estimated Crop Yield Index CYI and Julian day for early monitoring of rice yields in Japan.

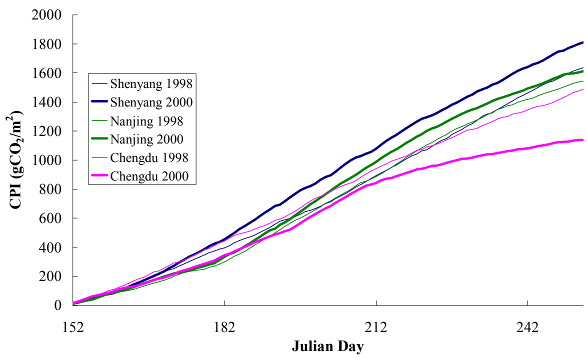

Figure 3. Seasonal variation of the crop production index CPI in five regions from northern to southern China.

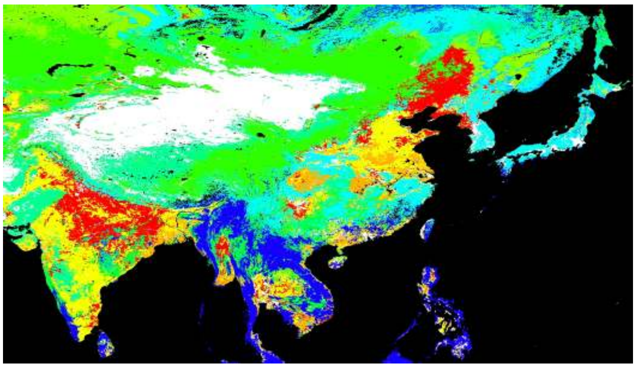

Figure 4. The precise distribution of grain fields in Southeast Asia by a decision-tree method using the MODIS land cover data.

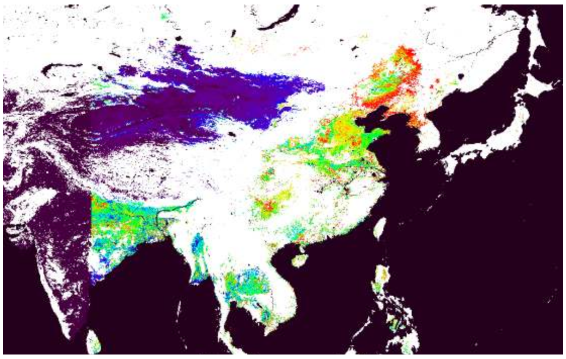

Figure 5. Distribution of photosynthesis rate in grain fields of spring wheat, winter wheat and paddy fields in Southeast Asia.

coverage of the solar irradiance derived from the Japanese GMS.
The author intends to apply the method first to FAO/USDA grain statistics and produce a database for NDVI and Land-cover/Land-use data for Southeast Asia using SPOT VEGETATION and MODIS data, as well as surface air temperature.

Conclusion

This report presents a remote sensing method for monitoring photosynthesis rate (CO_2 fixation) in the fields related to the carbon cycle, biomass energy, and grain production from early stages of crop growth to the harvest period in Southeast Asia. The author describes the distribution of photosynthesis rate in Southeast Asia and sterility based crop production index (CPI) and crop yield index (CYI), which incorporate data related to solar radiation, air temperature, and NDVI as a factor representing vegetation biomass. The two indices incorporate mechanisms of temperature influences such as effects of temperature on photosynthesis by grain plant leaves, low-temperature effects of sterility, cool summer damage attributable to delayed growth, and high-temperature injury. These latter factors are especially important during the heading period of crops. Vegetation types examined in this study include principal grain plants such as paddy, wheat, and maize, in addition to forest and grass areas related to the carbon cycle. The next steps in development of this research are water stress modeling and the computation of CPI and CYI distributions in Southeast Asia using crop field classification. The method is based on routinely collected observation and prediction data, allowing automated monitoring of crop production at arbitrarily chosen sites.

References

Kaneko, D, Ohnishi, M, Ishiyama, T, and Tateishi, R. 2004. Proposal of a photosynthesis type of crop yield index for monitoring crop production in China and India in the era of water resource restriction, 4th International Crop Science Congress, 4p, Brisbane, Australia.
http://www.cropscience.org.au/icsc2004/poster/2/8/252_daijir.htm#TopOfPage

Kaneko, D.: Crop yield monitoring based on a photosynthetic sterility model using NDVI and daily meteorological data, The International Society for Optical Engineering, Proceedings of SPIE, Remote Sensing for Agriculture, Ecosystems, and HydrologyⅨ, 14th SPIE EUROPE International Symposium on Remote Sensing, Firenze, Italy, 6742, F67420, 1-12, 2007.

Rasmussen, MS. 1998. Developing simple, operational, consistent NDVI-vegetation models by applying environ-mental and climatic information: Part II. Crop yield assessment, International Journal of Remote Sensing, 19(1), 119-137.

Xiao, X, Boles, S, Frolking, S, Li, C, Babu, Y, Salas, W, and Moore, B. 2006. Mapping paddy rice agriculture in Southeast Asia using multi-temporal MODIS images, Remote Sensing of Environment, 100, 95-113.