Applications of Remote Sensing Technology for Agro-Environmental Issues

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Abstract

The global environment has undergone serious degradation due to continuous industrial development and other human activities associated with the rapid increase of population in recent decades. Such drastic environmental changes threaten agricultural production and the maintenance of ecosystem balance. However, agriculture itself is also one of the causes of these major environmental problems. In other words, environmental changes and agricultural production influence each other markedly.

Environmental problems have a common characteristic in that they occur over large areas and over extended periods of time; in other words, they involve large spatial and temporal scales. As a result, it is difficult for most people to recognize such changes at a certain location from direct observation. Remote sensing is a technology that has the potential of overcoming this shortcoming, because it can provide images over large areas and reduce them to a bird's view, which is suitable for qualitative and quantitative analysis. Moreover, satellite data have been collected for more than a quarter of a century, and they are starting to provide a documentation of chronological changes over longer periods. With continuing advances and innovation in both hardware and software technology, remote sensing has a tremendous potential for the solution of environmental issues. This progress is further enhanced by the recent advances in GIS.

In this paper, remote sensing studies carried out mainly in Japan will be reviewed and the current status and future research will be described.

Introduction

Since mankind appeared in the African continent at the end of the Tertiary period, it took 2 or 3 millions years for the human population to reach 100 million people. But after AD, during several centuries the population doubled. This tendency has accelerated exponentially. In the 18th century, the population increased by 100 million people in almost one century, then the time to reach such an increase was shortened to 10 years in the 1940s, and 500 days at the end of the 20th century.

Such a drastic population increase in recent decades threatens agricultural production and the maintenance of ecosystem balance. For instance, major semi-arid regions are suffering from desertification, tropical forests continue to be destroyed and acid rain is a cause for concern in many industrial countries; on a global scale, ocean and air pollution is on the rise, biodiversity has been decreasing at an alarming rate, the ozone protection layer is being depleted, and there are warning signals that global warming may be taking place caused by the ever-increasing discharges of greenhouse gases and other forms of pollution.

The relation between food production and world population also is far from being reassuring. Expansion of cropland area almost ceased after the 1980s. Much of the fertile arable land has been converted to industrial or residential land, and cropland shifted to hilly sites. Food supply under population increase was mainly

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compensated by the yield improvement supported by agronomic techniques such as fertilizer application, breeding of high-yielding varieties, and spread of farm chemicals including insecticides, fungicides and herbicides. Average yield of crops increased from 1.37 ton/ha in 1961 to 2.76 ton/ha in 1990. As a result, world food production increased 2.21 times compared with 30 years ago. Population increased by 1.75 times during the same period. Apparently, total food production surpasses population increase. But we can not feel easy about it. We must pay attention to the changes of people food habits from carbohydrate to animal protein intake, which accelerates cereal food shortage. Overgrazing, salinization and soil erosion lead to land degradation all over the world. Farm chemicals pollute soil and water. Such unsound agricultural management may adversely affect the earth.

These different environmental problems have a common characteristic in that they occur over such large areas and extended periods that changes cannot be perceived at a certain location from direct observation. Remote sensing is a technique that has the potential of overcoming this shortcoming, because it can produce images over large areas and reduce them to a bird's view, which is suitable for qualitative and quantitative analysis. Moreover, presently, satellite data have been collected for more than a quarter of a century, and they are starting to provide a documentation of some chronological changes over longer periods. Remote sensing method combined with GIS is one of the key technologies for the promotion of agricultural sustainability in harmony with the increase of productivity. Even if it is difficult for production and environment conservation to coexist, this is the main target for the 21st century.

Satellites for earth observation

Landsat series produced by USA started from 1972, providing high spatial and spectral resolution data for more than 25 years. French satellite SPOT has been providing high resolution spatial images since 1986. IRS series launched by India also plays an important role in earth observation. Meteorological satellite NOAA (USA) carries an AVHRR sensor with a low spatial resolution, but the shortest recurrent period. Japanese ADEOS had sent high-quality image data during a short mission time.

Since all the above-mentioned satellites are equipped with optical sensors, in the case of cloudy weather, the earth surface condition cannot be detected due to the cloud cover. Microwave is longer than optical wavelength and it can penetrate cloud layers. ERS (ESA), JERS (Japan) and RADARSAT (Canada) are equipped with microwave sensors called SAR (Synthetic Aperture Radar). L band SAR of JERS is suitable for the detection of topographic conditions, while C band SAR of ERS and RADARSAT can detect plant organs such as trunks and branches. Several earth observation satellites with special missions will be launched by the millennium. TRMM (Tropical Rainfall Measurement Mission) was launched in 1997, to elucidate the mechanisms of energy balance on a global scale by a joint project between NASDA and NASA. ADEOS-2 has a mission to monitor global environment changes by using new sensors such as microradio-meter and global imager. ALOS will be launched early in the 2lst century, and will enable high resolution land observation for mapping, disaster monitoring, and resources exploration.

Some commercial satellites will be launched in this century. They are characterized by a super fine spatial resolution of 1 to 4 m, a high spectral resolution, and the shortest recurrent time (1-3 days). Actually, recently launched IKONOS has 3 visible and 1 near IR bands, a spatial resolution of 1 to 4 meter, and a recurrent period of 1 to 3 days. With continuous advances and innovations in both sensors and platforms, hardware and software technology, remote sensing has a tremendous potential for the solution of environmental issues.

Resolution required for satellite sensors differs depending on the target. Some agricultural phenomena need a fine spatial resolution (Table 1). In order to obtain information about crop diagnosis and yield estimation, fine spatial resolution and relatively frequent observations are needed. On the contrary, rough resolution and long-term intervals are suitable for the monitoring of soil humus contents and plant succession.

Table 1 Required resolution and recurrent frequency in agriculture

Agricultural phenomena	Expected spatial resolution	Required time interval
Landslide	10m - 100m	10min - 1wk
Forest fire	100m - 1km	30min - 1wk
Flooding	100m - 1km	1 hr - 1wk
Grasshopper outbreaks	100m - 1km	1 d - 1wk
Plant diseases	20m - 200m	3 d - 1wk
Soil moisture	50m - 1km	3 d - 2wk
Crop diagnosis	10m - 100m	1wk - 1mon
Grassland management	100m - 1km	2wk - 1mon
Yield estimate	10m - 100m	2wk - 2mon
Crop acreage	20m - 100m	2mon - 6mon
Land use changes	50m - 500m	3mon - 1yr
Desertification	100m - 1km	6mon - 1yr
Deforestation	100m - 500m	lyr - 3yr
Plant succession	100m - 1km	3yr - 30yr
Soil humus content	100m - 500m	5yr - 20yr

(after Akiyama, 1990)

Quantification of natural resources

Many attempts have been made to quantify the agricultural environment and resources using remote sensing technology in Japan. Here, the major topics are briefly reviewed .

1 Soil

Soil condition is one of the most important factors for agricultural production. Soil type (*e.g.* Fukuhara *et al.*, 1979), soil water content (Hatanaka, 1992), soil organic materials (Okamoto *et al.*, 1990) were analyzed and a specific relation between the spectral features and soil properties was detected. Such a wide and accurate estimation in each field provides important information for precise farming.

2 Water

Miyama and Ogawa (1992) estimated the water resources from quantifying snowfall depth in a catchment during winter. This estimation will be useful for the planning of water utilization of river basin in spring. Estimation of water depth is rather difficult, but recent satellite sensors like TRMM can measure the extent of rainfall directly using a microwave imager.

3 Heat

Minor differences in topography produce a large difference in the heat regime in local areas. Such differences lead to suitable crop and quality in agricultural products. Differences between day and night temperatures also play important role in the taste of fruits and quality of tea. Heat distribution map can be constructed from IR bands of satellites (Kawashima and Hayashi, 1988). Attempts at monitoring day and night temperatures were made using NOAA/AVHRR data by several researchers.

4 Vegetation

Biomass estimation and its distribution pattern were investigated for the natural vegetation and cultivated plants including crops and trees by many researchers. Some results will be introduced in the following chapters.

Management of agricultural production

1 Crop area and yield estimation

1) Paddy area estimation using optical and microwave sensors

Owing to the policy of rice reduction implemented by the government, the planting area of rice is decreasing year by year in Japan. Therefore, every year, we need to determine the actual planted acreage as soon as possible. Already Okamoto and Fukuhara (1996) developed an accurate method of estimation of the area using Landsat/TM, which is effective to acquire cloud-free data sets at the early stage after rice transplanting. Ogawa (1999) has developed a practical method for estimation, which was adopted in a feasibility study at the Statistics and Information Department, Ministry of Agriculture, Forestry and Fisheries. He investigated the seasonal changes of the backscattering coefficient of several land cover types, including rice fields using RADARSAT/SAR data. The SAR data enable to acquire data sets regardless of the weather conditions at short time intervals by changing the sensor direction (called pointing function). The results showed that the backscatter of paddy is low during the flooding season while it increases as rice grows until it is fully covered with canopy. This method enables to distinguish paddy fields from other types of land cover precisely and timely. The method aims first at selecting the paddy field candidates using past Landsat/TM data set, then at detecting planted paddy fields from candidates using RADARSAT/SAR data. The paddy field areas were estimated in two selected regions in Japan during the early growing season with a very high precision of about 98.5 % and 101 % accuracy compared to the official statistical values.

2) Construction of crop map using multitemporal Landsat images

Okano *et al.* (1993) constructed a crop map using multitemporal Landsat data in the Tokachi plain, Hokkaido to investigate the relationship between soil organic matter content, planting ratio, and crop order. Crops including sugar beet, potato, and wheat could be distinguished with a 95 % accuracy. Cropping order differed depending on the soil organic matter content.

3) Crop yield prediction

Crop yield prediction is rather difficult for several reasons. Firstly, crop discrimination must be conducted with a high accuracy in advance, then, the suitable period for yield analysis is limited, and it may be affected by natural disasters in the harvest season. Mubekti *et al.* (1991) predicted rice yield using Landsat /TM data just before harvest in the Ishikari plain, Hokkaido. Multiple regression model predicted yield with a high value of the coefficient of determination (R^2=0.953). Yield of wheat was estimated by Shiga (1993), and the coefficient was comparatively low (R^2=0.66 - 0.79).

2 Grassland renovation using multi-temporal satellite data

In order to maintain a high production and good feeding value, grass renovation accompanied by plowing and seeding must be carried out in pastures at several year intervals. The changes in grass production years after grassland renovation are a good index of grassland production. By extracting newly renovated grassland from Landsat/TM image every year from 1985 to 1994, Mino and Saito (1996) compiled a grass-renovation year map in the Konsen district in Hokkaido, a main dairy farming area. At the same time, the backscattering behavior of ERS-1/SAR in the improved grassland gave a very high backscattering coefficient because renovated grasslands show a high surface roughness and high soil moisture content (Mino *et al.*, 1998). In dairy farming areas, where optical data are often hindered, development of monitoring method using microwave sensor is more suitable.

3 Discrimination of fields with crops affected by diseases

Clubroot of cabbage is one of the most serious soilborne diseases in Japan, which is widespread and tends to be more severe in areas where cabbage is intensively cultivated. It is usually most severe in topsoils rich in organic matter and seldom occurs in areas with clay-rich subsoils. Torigoe *et al.* (1993) attempted to determine the relationship between the soil properties and extent of clubroot disease incidence in cabbage fields in Tsumakoi-mura, Gunma Prefecture using Sojuzkarta KFA 1000 (COSMOS) satellite imagery. The image data were converted from analog to digital by a drum scanner. The near infrared reflectance was a better indicator for delineating five soil series, indicating differences in the soil color, organic matter content, and water regime among the five soil series. Using these results, three drainage classes for each soil series were identified and they provided useful information for the assessment of the incidence of clubroot disease.

They also enabled to discriminate cabbage fields for the detection of clubroot disease damage using three Landsat/TM images acquired during the growing season in 1986 (Torigoe *et al.*, 1992). The cabbage fields with disease were further divided into several classes based on NDVI (Normalized Difference Vegetation Index) values depending on the extent of disease development.

4 Crop damage by natural disasters

Crop damage caused by natural disasters in Japan is limited to cold wind and drought in summer, flooding and strong wind after typhoons, ash fall by volcanic eruption. Usually, the area scale is not very large except for the damage caused by cold wind.

1) Cold wind damage on rice

In the northern part of Japan, rice experiences damage due to low temperature and insufficient radiation during the summer. Miyama *et al.* (1983) analyzed Landsat/MSS data acquired on September 19 in 1980 to construct a map with the geographic distribution of cold weather damage in the Ishikari plain of Hokkaido. Multiple regression model using MSS band 5 and band 6 was selected, in which the correlation coefficient (R) with yield was 0.91. Results of Landsat data analysis provided accurate information, which enabled to take measures to prevent the damage, including techniques of water management, position of windbreaks and nutrient control under cold weather conditions.

2) Flooding after typhoons

A typhoon hit the Kanto district on 4 August, 1986, bringing about floods in several areas. Many paddy fields in the northern Kanto district were inundated with flood water. Yamagata and Akiyama (1988) analyzed two Landsat/TM images, immediately after the typhoon and one month after flooding, to estimate rice yield damage (Figs. 1 and 2). Regression model was highly correlated with rice yield. Especially, owing to the close relationship between the flood water turbidity and the actual rice yield decrease, it was shown that rice yield can be estimated based on the image acquired immediately after the flood.

Monitoring of agro-environment

1 Land evaluation for agricultural development

It is generally recognized that the methodology for land evaluation had been developed in accordance with the progress of Geographic Information Systems. The method aims at constructing an evaluation map by integrating several thematic maps derived from remote sensing image analysis and existing various spatial data. At the onset of this study, Akiyama *et al.* (1987) determined suitable land for agriculture in Sumatra Island. Saito *et al.* (1991) also developed an evaluation method for land productivity in Thailand. Yamamoto *et al.* (1995) introduced neural networks into GIS to obtain accurate criteria for the construction of a land evaluation model, which was applied to grassland development in Tochigi prefecture in Japan.

In recent years, the need to quantify the function of agricultural land has become increasingly important in Japan. Attempts have been made to quantify the multiple functions of such land, for example the impact of the cultivation of paddy rice on soil conservation, landscape maintenance or capacity for water purification. Remote sensing by satellite is a powerful tool for such an evaluation.

2 Outflow of red soil sedimentation in coral reef

Among the various types of soils occurring in the Okinawa area, red soil is easily washed away by rain on a bare surface. Okamoto *et al.* (1992) developed a method of evaluating the distribution of red soil washed onto coral reefs using multitemporal Landsat/TM data. This method is based on the reflection spectral characteristics arising from the difference in the mineral composition of red soil and of white sand of the coral reef. Furthermore, they adopted the method for monitoring red soil outflow, and they analyzed the relationship between land use changes and the amount of red soil accumulation. In this study (Okamoto *et al.*, 1998), they were able to estimate the amount of red soil accumulation quantitatively in each of the five river basins in Okinawa Island.

3 Conservation and utilization of steppe in Inner Mongolia

Desertification is both a local and a global challenge. China is one of the countries facing the most serious desertification problems in the world. A preliminary assessment of desertification in 1997 showed that the total area of affected land covers approximately 2.62 million km^2, accounting for 27.3 % of the total territory of China, and it is estimated that 400 million people are suffering from the impact of desertification. The annual increase of the spread of desertification by wind erosion in the whole country amounts to approximately 2,460 km^2 (Wang, 1999).

As a result of chronological image analysis in Xilin gol steppe, Inner Mongolia using Landsat data over 20 years since 1979, it was revealed that areas with productive meadow steppe and typical steppe are decreasing, while areas with degraded dry steppe are increasing in this district (Akiyama *et al.*, 1999; Fukuo *et al.*, 1999). Areas of cultivated land and fallow land are also increasing (Fig. 3). Changes of biomass and botanical composition are related to the spectral reflectance of both satellite and portable spectro-radiometer. Land

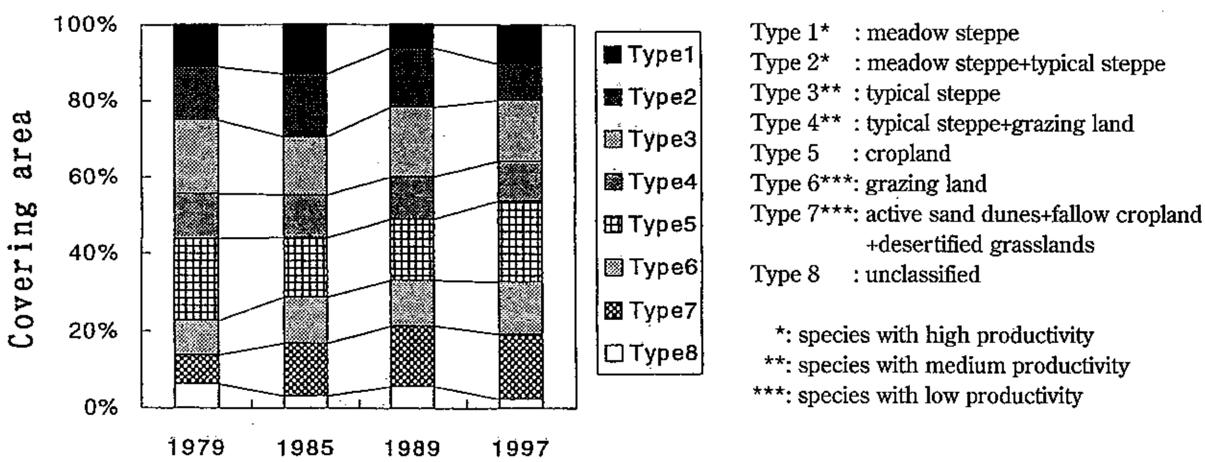

Fig. 3 Chronological changes of steppe vegetation in Xilin gol, Inner Mongolia during 20 years (Fukuo *et al.*, 1999)

degradation process was correlated with the botanical composition as well as biomass decline. We aim at identifying effective spectral indices for the detection of grassland condition.

Perspectives for the use of remote sensing for agro-environmental issues

Use of remote sensing for agro-environmental issues may be summarized as follows; Firstly, to evaluate past and present conditions accurately and timely, remote sensing is an effective technique for describing spatial and periodical changes. Next, to determine the causes of phenomena quantitatively, remote sensing is useful. When combined with appropriate models and GIS, remote sensing data acquire an additional value for predicting future conditions. Finally, for the development of countermeasures, remote sensing can be used for monitoring and evaluation of the conditions.

In order to support such approaches, accumulation of long-term data is essential. Sensor development is important to enhance spatial, spectral and temporal resolution, and to enable all-weather observation. Contributions from computer science are significant and valuable in both software and hardware systems. In addition, new concepts and methodology should be continuously introduced.

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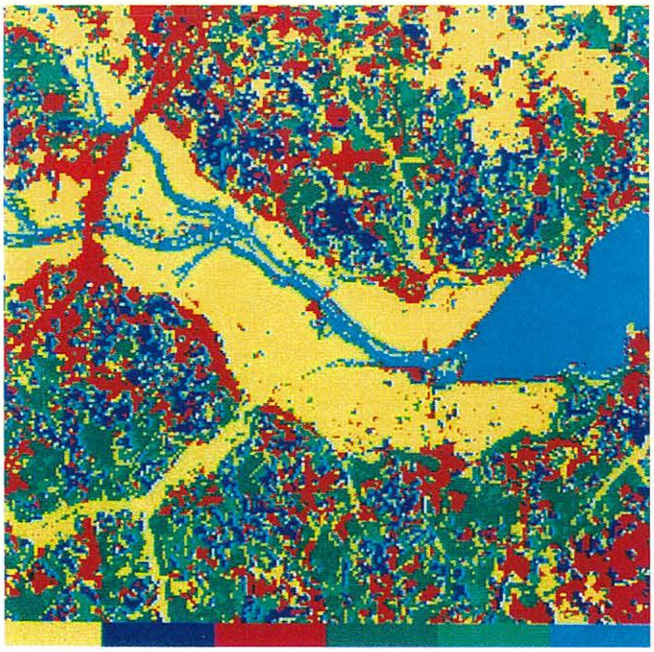

Fig. 1 Land cover classification in the Lake Hinuma area, Ibaraki prefecture (Yamagata & Akiyama, 1988)

Yellow; paddy fields, Blue; upland fields, Red; residential area, Green; forest, Light blue; water
Landsat/TM image acquired September 7, 1986 (Path/Row; 107/35)

Fig. 2 Estimated yield distribution map after inundation of paddy fields in the Lake Hinuma area (Yamagata & Akiyama, 1988)

Yield rank, A; more than 4.5t/ha, B; 4.0-4.5t/ha
. . . . H; 1.0-1.5t/ha, I; less than 1t/ha
Landsat/TM image acquired August 6, 1986 (Path/Row; 107/35)