Remote Sensing, a Tool for the Evaluation of Green Vegetation

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Abstract

The Normalized Difference Vegetation Index based on NOAA data can reveal the progression of desertification, deforestation, and drought damage to arable crops as well as chronological changes in cropping patterns on a regional scale.

Landsat/MSS and /TM data which are characterized by high spectral/ground resolutions have contributed to practical agricultural management. Techniques for crop discrimination and crop mapping have made such rapid progress that we can classify crop types with more than 80% of accuracy. Vegetation Indices derived from Landsat/TM are useful for estimating canopy parameters such as biomass, coverage and leaf area.

Plant stress information including water and nutrient deficits, disease attacks and weed infestation has also been acquired from space. Some attempts to estimate the meteorological damage to crops caused by cold wind and flooding have been successful. Therefore it is considered that satellite remote sensing could be a useful tool for the evaluation of green vegetation.

To promote the evaluation of green vegetation precisely, timely and effectively, it is necessary to: 1) develop sensor systems suitable for vegetation science, 2) develop techniques to combine remote sensing data with other sources of information and models, 3) develop a global vegetation monitoring system.

Key words: agro-environment, global monitoring, remote sensing, Vegetation Index

1. Introduction

With the development of sensors combined with effective information systems brought about by advancements in computer technology, new opportunities have opened up in the application of remote sensing techniques to environmental studies. Remote sensing techniques can be used effectively as a tool for monitoring global vegetation changes, and management of agricultural crops on a regional level.

In this paper, I tried to describe how the remote sensing techniques have been applied for the evaluation of natural and cultivated vegetation by reviewing recent reports in this subject. Furthermore, future prospects for developing a more precise and timely observation systems for vegetation monitoring using remote sensing technology are outlined.

2. Satellite derived Vegetation Indices

Based on the fact of vegetation absorbing red (R) wavelengths and reflecting near infrared (NIR) wavelengths, several spectral Vegetation Indices (VI) derived from satelliteborne data have been proposed. VI, including NIR/R;(Ratio, RVI), NIR-R;(Difference, DVI), (NIR-R)/(NIR+R);(Normalized Difference, NDVI) are most popularly used by vegetation scientists. In addition, PVI (Perpendicular Vegetation Index) and K values have been proposed to eliminate background soil effects from vegetation.

In the case of microwave sensors, Polarized Brightness Temperature (PBT) or the Microwave Polarization Difference Index (MPDI) were considered to be useful for the determination of the density of global vegetation (Choudhury, 1989). The principle of these indices is based on the difference between the temperature of vertically and horizontally polarized brightness (ΔT) which decreases with increasing vegetation density (that is, as the canopy water content per unit ground area increases).

3. Monitoring of global vegetation

NOAA/AVHRR and Nimbus/SMMR have been found to be suitable tools for monitoring vegetational changes on a continental scale, because they exhibit low ground resolution, but a high frequency for observation. The Brightness Temperature derived from Nimbus/SMMR at 37 GHz frequency makes it possible to monitor the degradation of aridlands with sparse vegetation. As a result, many scientists have attempted to analyse range degradation around deserts in Africa, Australia and China by this method (for example, Townshend et al., 1989).

Justice et al.(1985) carried out an analysis of the phenology of global vegetation especially for crop growth in the China continent using NOAA/AVHRR data. Monthly changes of NDVI delineated typical cropping patterns including crop calendar and growth conditions in each agricultural district. Likewise, chronological fluctuations of NOAA-NDVI depicted climatic conditions such as previous precipitation in the Sahel, Africa (Henricksen and Durkin, 1986).

Choudhury et al.(1987), Choudhury and Tucker(1987) estimated the monthly biomass changes in the Sahara desert, Senegalese Sahel, Burkina Fasso and Kalahari desert, etc. Generally, NDVI derived from NOAA/AVHRR reflects the amount of chlorophyll in vegetation, while, MPDI from Nimbus/SMMR expresses the soil moisture contents. Therefore the correlation between the two indices is usually high. However, MPDI using a 37 GHz microwave band is superior to NDVI when the vegetation cover is extremely sparse (Becker and Choudhury, 1988).

Recently, remotely sensed data have been used in combination with several types of models or other sources of geographical information such as topographic maps, climatic zoning maps and agricultural yield statistics. Badhwar et al.(1986)proposed a global circulation model of carbon dioxide in which LAI and a vegetation map were derived from satellite data.

On the other hand, Reiners et al.(1989) estimated the distribution and dynamics of nitrogen in a sagebrush steppe combining Landsat/TM image and a system simulation model from the view point of biogeochemistry.

Table 1: Comparison of crop discrimination results using satellite data

Country/ District	Satellite /Sensor	Main Crops	Accuracy	Author /Year
USA/ Corn belt	Landsat /MSS	Corn, Soybean	83.9%	Batista et al. /1985
USA/ Wisconsin	Landsat /MSS	Alfalfa, Corn, Oats	89.8%	Lo et al. /1986
Hungary/ 	Landsat /MSS	Corn, Alfalfa, Sunflower etc.	90%	Csillag /1986
Argentina/ Buenos Aires	Landsat /MSS-TM	Corn, Soybean Sorghum etc.	80%	Badhwar et al. /1987
USA/ NY State	Landsat /TM	3 Vegetables, 4 Crops	90% < 75% <	Williams et al. /1987
Japan/ Tokachi	Landsat /TM	7 Crops	90.1%	Fukuhara et al. /1988
Hungary/ Kiskore	SPOT/XS Landsat/TM	Wheat, Alfalfa Soybean	85-88% 87-91%	Buttner et al. /1989
UK/ East Anglia	SPOT /HRV	10 Vegetation, 4 Vegetation	71% 88%	Jewell /1989

4. Practical management of regional agriculture

Two decades have passed since Landsat-1 was launched by NASA in 1972. Several kinds of satellites are orbiting at present and useful technologies for the extraction of agro-environmental information on a regional level have been developed. As a result, the following information can be obtained by space-borne sensors with high spectral/ground resolutions such as Landsat/MSS, /TM and SPOT/HRV; 1) crop inventory and planting acreage estimation, 2) biomass, leaf area and yield estimation, 3) crop stress detection, and 4) agro-environmental survey including soil, vegetation and atmosphere.

4.1 Crop discrimination and planting acreage estimation

In 1974, in the Large Area Crop Inventory Experiment (LACIE), a joint undertaking of NASA, USDA and NOAA, satellite remote sensing technology was applied on an experimental basis to forecast harvests in major wheat producing areas of the world using Landsat/MSS data. As a result, a 1977 real-time forecast of Soviet wheat production indicated that the system could operate and could be applied to other areas and other crops (MacDonald and Hall, 1980). This project was followed by AgRISTARS which focused on crop condition assessment from space (AgRISTARS, 1983).

Many attempts of crop discrimination and planting acreage estimation have been made world-wide for a variety of crops using Landsat/MSS, Landsat/TM and SPOT/HRV

data. Recent studies and classification accuracies are summarized in Table 1.

4.2 Biomass, leaf area and yield estimation

Vegetation reflects near-infrared(IR) wavelengths, and absorbs red ones. Using these characteristics, several spectral vegetation indices have been proposed to estimate vegetational information including biomass, yield and leaf area.

In the grasslands of the northern part of Tochigi Prefecture, estimation of the first cutting yield of pasture grass was made using Landsat/MSS data collected on May 22, 1979. Land-use classification was used in an attempt to extract pastures and meadows. Then multiple regression analysis was performed to estimate the yield of the first cutting in each pasture plot (Akiyama et al., 1985).

4.3 Crop stress information

Plants experience various kinds of stress during growth processes, including stress caused by atmospheric factors, rhizospheric factors, or biotic stresses caused by a variety of organisms. If farmers could detect various crop stresses in the early stages of infections or nutrient deficiencies before visible symptoms appear, the yield and quality of agricultural products might increase.

Water deficit can be clearly detected by near-IR and mid-IR wavelength reflectances which indicates thermal changes caused by stomatal movement. For crop stress caused by soil-borne diseases, the same bands can be used as they enable the detection of the wilting of leaves (Torigoe et al., 1992).

Stresses due to meteorological factors sometimes do not appear early. Spikelet sterility is often caused by low temperature during the flowering stage of rice plants in the northern part of Japan. Usually, ears die-off along with ripening, while the sterile ones remain green at harvest time. Band 5 of Landsat/MSS clearly separated the damaged areas from non-damaged ones (Miyama et al., 1983).

As plant damage caused by flooding is highly correlated with the turbidity of water, Yamagata and Akiyama (1988) estimated rice yields under flooding. The effects of these meteorological phenomena can be observed by satellite sensors, and maps describing the damage to crop yields can be constructed.

4.4 Soil surveys and land evaluation

Many scientists have attempted to classify the soil types using satellite data. Contents of organic matter and moisture in soil are one of the most important sources of information for farmers. Fukuhara et al.(1980) were able to determine differences in the soil moisture contents using Landsat/MSS data in the Tokachi district. In the same area, Hatanaka et al.(1989) classified organic matter contents in soil using band 3 reflectance data of Landsat/TM obtained in May, when the surface of the upland fields was almost bare in this time of the year. The classification results were plotted on a 1/50,000 scale map, and used by the officers of the agricultural extension services (Okamoto et al., 1990).

On the other hand, it is necessary for developing countries to select land suitable for agricultural development using satellite data. Several thematic maps relating to biomass, soil moisture and present land-use can be constructed. When these thematic maps derived

from satellite data are superposed on existing meshed topographic or geographic maps, value-added information concerning the productivity of land can be obtained (Akiyama et al., 1987, Saito et al., 1991).

5. Perspectives for vegetation monitoring

In conclusion, to evaluate green vegetation more precisely, timely and effectively, the following recommendations can be made.

5.1 Development of sensor systems suitable for vegetation science

For the comprehensive monitoring of global green vegetation, the development of sensor systems suitable for vegetational observation is required. In the Earth Observing Programs (NASA, 1984), more than ten satellites will be launched in the 1990's. Some of them will be equipped with microwave sensors, which will not be hindered by cloud cover. Since in most of the tropical forest zones of the world, vegetation is covered by thick clouds throughout the year, it is difficult to carry out monitoring periodically using optical sensors such as Landsat/TM. In the future sensors, wavelength ranges for observation will be expanded including microwave and UV ranges. Also spectral and spatial resolutions should be adopted to vegetation sciences. In addition, appropriate intervals of observation should be arranged.

Table 2 and Fig.1 show the temporal and spatial scales required to monitor the changes in vegetational phenomena (Akiyama, 1991).

5.2 Development of multi-stage sensing combined with models and AI

The low resolution/frequent revisit systems of NOAA and Nimbus are suitable for monitoring vegetation resources on a global scale. They can depict phenological changes in the cropping patterns on a continental scale, chronological fluctuations of desertification and progression of deforestation on a national level.

As the Landsat and SPOT sensors are characterized by high spectral/spatial resolutions, they can be applied to the practical management of agriculture. These sensors are suitable for crop inventory and planting acreage estimation, biomass and yield forecast, crop stress detection and agro-environmental surveys including soil and vegetation.

Use of low altitude platform/sensor systems such as aircraft MSS, balloon photos and ground-based platform/spectrometers can provide more precise and timely crop diagnosis information including plant phenology, disease and insect damage, succession, water and element deficits.

Therefore, the application of multi-stage sensing coupled with appropriate models, database and AI is important. Acquired information will be analysed systematically and through the addition of Geographic Information, future conditions of green vegetation will be predicted (Akiyama and Shibayama, 1992).

Table 2: Space and time scales required for vegetational and agricultural monitoring
(Revised from Akiyama, 1991)

Phenomena	Temporal scale	Spatial scale
A Landslide	10min - 1w	50m - 500m
B Wildfire	30min - 1w	100m - 1km
C Flooding	30min - 3d	100m - 1km
D Desert locust outbreaks	1d - 1w	100m - 5km
E Disease incidence	3d - 1w	50m - 1km
F Soil moisture	3d - 2w	50m - 5km
G Crop diagnosis	1w - 1mon	10m - 100m
H Grassland management	1w - 1mon	50m - 1km
I Global vegetation	1w - 1mon	500m - 10km
J Global yield estimate	2w - 2mon	50m - 500m
K Crop inventory	1mon - 3mon	20m - 100m
L Desertification	1mon - 1y	100m - 5km
M Agricultural land-use	2mon - 10y	50m - 500m
N Forestry management	1y - 3y	100m - 5km
O Deforestation	1y - 5y	50m - 1km
P Succession	3y - 30y	100m - 1km
Q Humus content	5y - 20y	50m - 1km

Figure 1: Spatial and temporal scales of present satellite sensors and phenomena occurring in vegetation monitoring

Letters in the figure indicate the phenomena listed in Table 2. Right-angled areas can be measured by the satellite.

5.3 International cooperation for global vegetation monitoring

International technical cooperation has been implemented for sensor/platform development. In order to evaluate global green vegetation more timely and precisely, interdisciplinary collaboration and international cooperation including developing countries will be important.

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