Journal of Global Environment Engineering, Vol. 3, pp. 1–7, 1997

A MONITORING OF COLD-WEATHER DAMAGE TO RICE CROP THROUGH SATELLITE DATA

Tsuyoshi Tada [1]
Masaki Sawamoto [2]

Abstract

Analyzing NDVI/iNDVI derived from NOAA AVHRR and NDVI observed on ground, the growth profile of rice is observed over its growth cycle under cold-weather damage in 1993. Good relationship between NDVI/iNDVI and rice growth is confirmed. However NDVI of ripening period in 1993 is much higher than average year's value, and there is negative correlation between rice crop and NDVI/iNDVI. A part of biomass production distributed to crop can not be observed through iNDVI, and another part, to leaves and culms, can be observed. It is assumed that the distribution ratio is proportional to the difference between iNDVI of ideal no crop paddy and actual one. Then the crop over the Tohoku district is estimated from iNDVI deficiency.

KEYWORDS: *primary production, rice crop, cold-weather damage, NDVI, iNDVI*

1. Introduction

Activity of plants has close relations with various phenomena considered as global environment problems. Although plants and global environment have great influence on each other, it is difficult to estimate the influence quantitatively. For global analysis of the material cycle, the energy cycle and environmental problems, physiological activity of various plants must be generalized and be included into their models. NPP (Net Primary Production) is used as a generalized index of plant's activity. NPP is defined as the difference between an amount of organic compound produced by green plants (total primary production) and an amount of self consumption for growth and maintenance respiration. In other words NPP is a growth rate of dry weight of plant's body.

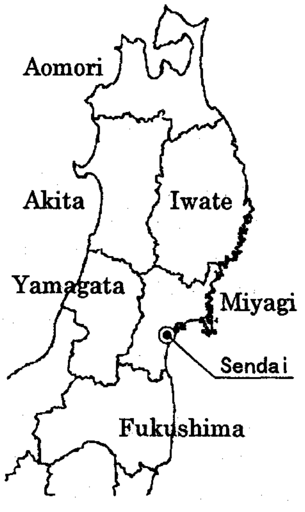

Figure 1. Location of the Tohoku district

1 Graduate Student, Dept. of Civil Eng., Graduate School of Eng., Tohoku University, Aoba-ku, Sendai 980-77, Japan
2 D. Eng., Professor, Dept. of Civil Eng., Graduate School of Eng., Tohoku University, Aoba-ku, Sendai 980-77, Japan

In recent years, some studies have been attempted to estimate NPP through satellite data (Christopher, *et al.*, 1995). NDVI (the normalized difference vegetation index) and iNDVI (the time integral of NDVI) has been widely used for estimation of NPP and they have given good result. It is known that the correlation between iNDVI and NPP is nearly linear function in general concerning matured forest or shrub. However it is not so simple concerning plant under growth, annual plant or paddy and others.

We are concerned with paddy area of the Tohoku district in 1993 when the summer was record-breaking cold weather, and study about correlation between NDVI/iNDVI, growth of paddy and a rice crop. The survey is made on all pixels of satellite images, which are classified into forest, paddy and other landuse through GIS data. We use mean values of three years (from 1989 to 1991) as values of average year.

Forecasting techniques through monitoring of weather and growth conditions have already been established. The purpose of this study is not forecasting of crops but examining how the distribution problem of primary production in a plant affects satellite monitoring techniques.

2. Vegetation Index

2.1 NDVI

NDVI is the abbreviation for "the normalized difference vegetation index". It is derived from NOAA-AVHRR satellite data as follows;

$$\mathrm{NDVI} = \frac{\mathrm{Ch.2} - \mathrm{Ch.1}}{\mathrm{Ch.2} + \mathrm{Ch.1}} \tag{1}$$

Where Ch.1 is radiance value of channel-1, Ch.2 is radiance value of channel-2. The channel-1 of AVHRR sensor can observe radiance of visible red radiation ($0.58 \sim 0.68\mu$m), which is absorbed by photosynthesis activity of leaves. Therefore green plants have low refrectance and be shown as dark area in the channel-1 image. The channel-2 can observe radiance of near-infrared radiation ($0.725 \sim 1.10\mu$m), which is scattered by cell structure of leaves. Therefore green plants have high refrectance and be shown as bright area in the channel-2 image. For reasons mentioned above, the greater difference between channel-1 and 2 radiance means the higher density of leaves and of chlorophyll in a leaf.

The correlation between NDVI ,LAI (leaf area index), and APAR (absorbed photosynthesically active radiation) has been reported (Sellers, 1985; Sellers, 1987). There are some agricultural applications (Maselli *et al.*, 1993; Benedetti, *et al.*, 1993).

NOAA-AVHRR data can be obtained twice a day. However there are very few scenes that are fair weather all over the district. Therefore it is necessary to compose a cloud-free image from some raw images in a period. In this study we compose monthly images by maximum value composite technique. Here are temporal NDVI profile of paddy and forest area in the Miyagi prefecture (**Figure 2** and **Figure 3**).

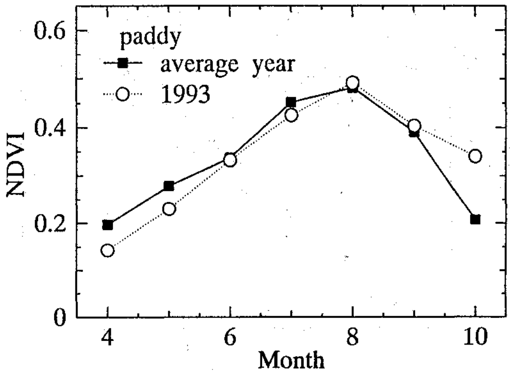

Figure 2. NDVI of paddy area in the Miyagi prefecture

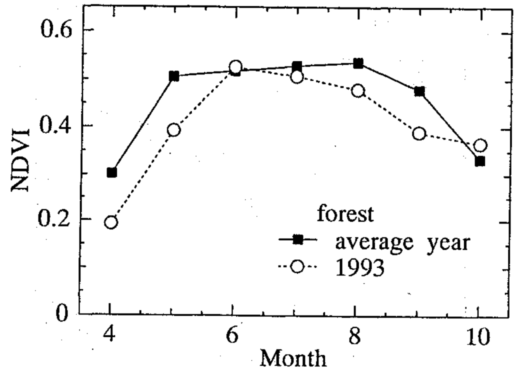

Figure 3. NDVI of forest area in the Miyagi prefecture

We have observed spectral refrectance also on the ground in paddy field near the Sendai City with portable photo meter. Here is a figure, which shows NDVI calculated from spectral refrectance in the bands equivalent to AVHRR sensor (**Figure 4** and **Figure 5**).

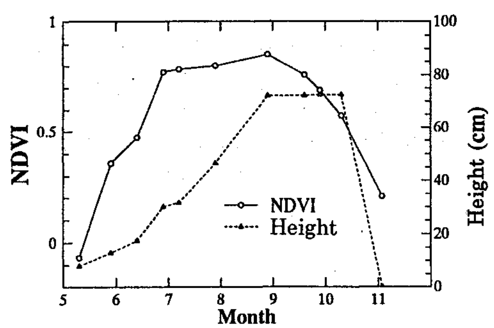

Figure 4. NDVI of paddy field observed on the ground (1993)

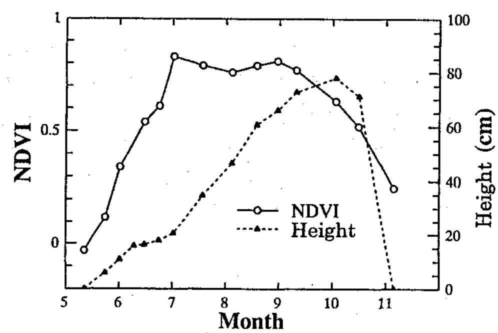

Figure 5. NDVI of paddy field observed on the ground (1996)

2.2 iNDVI

iNDVI is the abbreviation for "the time integral NDVI". It is derived from a multi-temporal NDVI data set as follows;

$$\text{iNDVI} = \Sigma(\text{NDVI}_i \times d_i) \tag{2}$$

where NDVI_i is typical NDVI value in ith period, d_i is days of ith period. It is known that there is a positive correlation between NDVI and the photosynthesical reaction rate of chloroplast. Therefore it is expected that there is a correlation between iNDVI and the amount of energy absorbed by plants in a growth period. Some studies have investigated the relationship between iNDVI and NPP and have reported it is nearly linear function (Mino, *et al.*, 1993). In this study iNDVI of nth month is defined as the integrated NDVI from April first to the last day of nth month. Here are temporal iNDVI profile of paddy and forest area in the Miyagi prefecture(**Figure 6** and **Figure 7**).

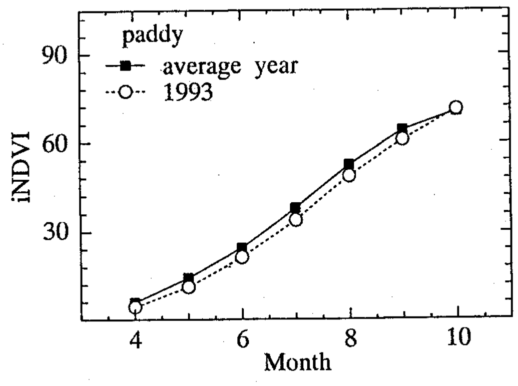

Figure 6. iNDVI of paddy area in the Miyagi prefecture

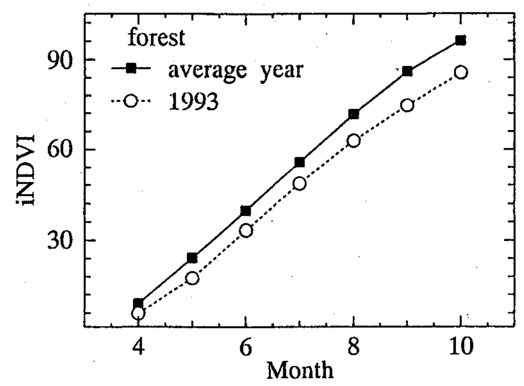

Figure 7. iNDVI of forest area in the Miyagi prefecture

3. NDVI Profile in Growth Stage

3.1 Cold-weather Damage in 1993

In general the cause of a poor rice crop under cold weather falls into three categories. The first is a delay of growth. The second is a disability of ripening, which is due to a serious damage before heading (forming of ears). This damage is called sterility. The last is a defect of ripening, which is due to bad weather in the latter half of a ripening period. In 1993, the first and the second type damages occurred. Specially the second was the main reason of the record-breaking poor rice crop.

3.2 Growth Period

The Tohoku district was covered with the Okhotsk high atmospheric pressure and it was very cold in July and August of 1993. As the figures (**Figure 2** and **Figure 6**), it is shown that the growth was slightly delayed in growth period (from May to August). However the deficiency of NDVI and iNDVI was much smaller than the recorded deficiency of crop.

Tohoku regional agricultural administration offices estimates next crop through weather and field conditions, and reports it as yield index every month. This index means the ratio of estimated crop to average year's one. The yield index before August shows that the damage for a growth period was not so serious. Observed NDVI and iNDVI reflect the condition correctly (**Table** 1). Since paddy area is always managed very carefully, the cold weather did more serious damage to forest area.

Table 1. iNDVI and yield index at August, 1993 (percentage for average year)

prefecture	Aomori	Iwate	Akita	Miyagi	Yamagata	Fukushima	Average
iNDVI (paddy)	91	94	86	92	84	83	89
yield index	85	91	94	90	94	91	92

3.3 Ripening Period

It is known that iNDVI is proportional to NPP in general (Running, *et al.*, 1988). In a similar way, it is expected that iNDVI has a positive correlation to rice crop. However, the relationship between NDVI/iNDVI and crop was not clear in October. On the contrary, a negative correlation was shown (**Table 2**). This table shows the following curious tendencies.

Table 2. NDVI/iNDVI and yield index at October, 1993 (percentage for average year)

prefecture	Aomori	Iwate	Akita	Miyagi	Yamagata	Fukushima	Average
NDVI (forest)	103	98	99	110	105	99	101
NDVI (paddy)	133	130	117	164	130	129	133
iNDVI (forest)	90	90	88	89	83	82	87
iNDVI (paddy)	97	99	93	101	92	89	95
yield index	28	30	83	37	79	61	56

All over the Tohoku district in 1993, NDVI was higher than average year. Deficiency of iNDVI in paddy area was only about 5% and forest's iNDVI deficiency was more than paddy's one. The more serious crop damage shows the higher iNDVI. The reason for these tendencies is that much green leaves remained after heading, although most of leaves ought to be golden.

When paddy gets serious damage in a reproductive period before heading, sterility rate increases, and yield capacity is limited. Although weather takes a turn for the better in a ripening period, paddy can not form ears no longer. Regional agricultural administration offices report that cold weather in June 1993 did such irreparable damage to paddy fields.

It seems reasonable to suppose that paddy produced NPP as much as average year in ripening period because of the good weather and high NDVI. The third type damage was not reported in 1993. Productions in ripening period were distributed not to ears but to leaves and culms, which have chlorophyll and maintain high NDVI after a heading period.

4. Estimation of Crop

Part of primary production after heading is distributed to reproductive growth and is stored in ears as rice crop. This part does not appear in NDVI. Another part is distributed to leaves and culms. This shows NDVI equivalent to the distributed production. Therefore the crop, part of primary production which does not appear in NDVI/iNDVI, can be estimated as a deficiency of iNDVI.

Suppose an occasion that paddy does not form ears at all. All productions after a heading period are distributed to leaves and clum. Then paddy field maintains photosynthesical activity and the NDVI of a heading period throughout a ripening period. The iNDVI in the above occasion may be estimated as follows;

$$\mathrm{iNDVI_{leaf}} = \mathrm{iNDVI_{IX}} + \mathrm{NDVI_{IX}} \times 31 \quad (3)$$

where $\mathrm{iNDVI_{leaf}}$ is estimated iNDVI from April to October without ears, $\mathrm{iNDVI_{IX}}$ is observed iNDVI from April to September, $\mathrm{NDVI_{IX}}$ is observed NDVI in September which is substituted for NDVI in a ripening period without ears. This substitution is an assumption and not valid. Then the production distributed to ears can be estimated.

$$\mathrm{iNDVI_{crop}} = \mathrm{iNDVI_{leaf}} - \mathrm{iNDVI_{X}} \quad (4)$$

where $iNDVI_{crop}$ is iNDVI corresponds to the crop, $iNDVI_X$ is observed iNDVI from April to October. Using the above equations, crops are estimated at all pixels of satellite data. Then paddy pixels are picked and summarized up through GIS data. Here are a figure which shows an idea of this estimation and a table shows estimated crops in 1993 which are converted into ratios for average year (**Figure 8**, **Table 3**).

Table 3. Estimated crop and actual yield index in 1993 (percentage for average year)

prefecture	Aomori	Iwate	Akita	Miyagi	Yamagata	Fukushima	Average
estimated crop	64	58	94	34	59	11	55
yield index	28	30	83	37	79	61	56

It is safe to say that the cold-weather damage of rice crop in 1993 can be shown on the whole. Average of the whole district has good accuracy. The reason why crop in the Fukushima prefecture is under estimated is that the prefecture was partly covered with cloud which can not be completely removed by monthly composite. The reason for over estimation of the Aomori and Iwate prefecture needs detail consideration. We can see a tendency that over estimation occurs in northern area and under estimation occurs in southern area. Therefore it is likely that time lag of harvest between each area is a reason of such errors.

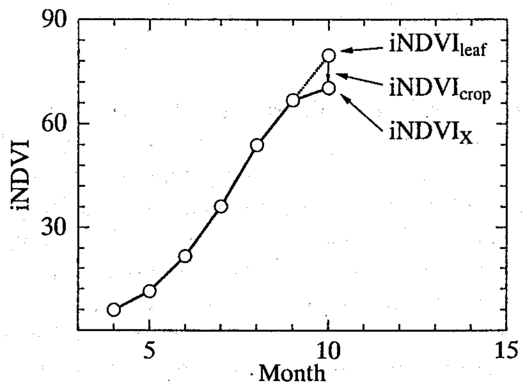

Figure 8. Idea of the estimation method

5. Conclusion

There have been some studies which report the positive correlation between NDVI/iNDVI and a crop, however the following result was obtained. Under cold-weather damage, paddy field's NDVI in ripening period is higher than average year's value, and iNDVI has negative correlation with a rice crop. Deficiency of iNDVI corresponds to the primary production distributed to ears as a crop.

NDVI and iNDVI show an ability of production, and at the same time, show a part of stored production. The former increases the latter of a next period, and the increasement of the latter is added to the former again. This cycle is controlled by a photosynthesical ability and a distribution ratio of production. We will develop a method for monitoring of distribution mechanism and for quantitative estimation.

Two assumptions have not been examined. The first is that $iNDVI_{leaf}$ can be estimated by equation(3). The second is that NDVI shows NPP directly. It is reported that plant under stress shows high NDVI and low photosynthesical activity at the same time (Gorward, *et al.*, 1987). If NPP in heading period is not sufficient for ripening, the high NDVI in ripening period may reflect delay of ripening. We have to validate these problems.

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