Agricultural Weather Hazard Maps in Hokkaido, Japan,
Developed from Satellite Data

Chiharu OKANO* and Michikazu FUKUHARA**
(*Center for Environmental Remote Sensing, Chiba Univ., 1-33 Yayoi, Inage, Chiba 263, Japan)
(**National Institute of Agro-Environmental Sciences, 3-1-1 Kannondai, Tsukuba, Ibaraki 305 Japan)

Abstract

The cool and wet summer of 1993 in Tokachi district, Hokkaido, Japan, resulted in damage to sugar beet and caused an overall reduction in yield. Landsat TM and Mos-1/MESSR images were analyzed for detecting the location and extent of the damaged area. Data for the period of July to September 1993 (a low-yield year), were compared to data for August 1991 (a bumper year).

Yield estimation equations for 1991 and 1993 derived from Landsat/TM data taken on August 29, 1991 and those on July 8, 1993 corresponded with actual yield. Results showed severe damage in the fields with low soil organic matter. The change in KVI (vegetation index) values was small in July, medium in August and medium in September. No damaged fields were found in the area with higher soil organic matter. In these areas the KVI value was medium in July, high in August and low in September.

The relationships among the extent of the damage, the changes of KVI, and soil organic matter content suggested that the production drop was partly due to leaching of fertilizer by high precipitation in addition to damage from the cool and wet summer.

key words: remote sensing, agricultural weather hazard, vegetation index

1. Introduction

Unusual weather in the summer of 1993 was detrimental to crop yield. In the Tokachi plain, Hokkaido, Japan, the observed daylight duration in June of 1993 was 68 hours. This figure was approximately half the duration for that month during a normal year. The observed precipitation was seven times larger than that of a normal year. These factors caused an overall reduction in sugar beet yield. The final yield of sugar beet was at least 10% less than the yield during a normal year. A field survey of the damage was conducted. It was known that the degree of damage from the cool and wet summer varied within a region and within fields. However, details of the damage over a large area were not understood. In this study, yield maps of the 1991 (bumper year) and the 1993 (low-yield year) were created using satellite imagery to investigate the cause of the damage.

2. Study site and data

The study was conducted in the Tokachi plain, in the western portion of Hokkaido (Fig.1). This is an important agricultural region in Japan.

A field of sugar beet was surveyed by Nippon Beet Sugar Mfg. Co., Ltd. Ground truth data for root yield of sugar beet was collected by an agricultural benefit society. Landsat TM data and Mos-1 MESSER data were acquired in the 1991 (bumper year) and the 1993 (low-yield year). Landsat TM data from August 29, 1991, and July 8 and August 25, 1993 were selected.
Mos-1/MESSR data of August 16, September 1 and September 19, 1993 were also selected.

A map of soil organic matter content for the Tokachi plain was developed by Fukuhara et. al. from Landsat TM data which was used as soil environmental data. The soil data was reorganized for high, middle and low organic matter content.

3. Procedures

(1) The six images were rectified to 1:50,000 topographic maps for 1991 and 1993. The study area was extracted from the rectified imagery to analyze a series during different seasons.

(2) The position of sugar beet fields on the TM data was determined using ground truth data. The center pixel of the sugar beet fields was extracted as polygonal data to exclude boundary pixels containing mixed information.

(3) It is necessary to standardize satellite data when it will be compared with the data derived from a different sensor. The CCT average for the polygon data was calculated for each site, then converted into the radiance value using function 1 and function 2.

function 1 (for MESSR data)
\[ Q_s = V_s (K_s \cdot R_s) \]
\[ Q_s: \text{radiance value (mV \cdot cm}^{-2} \cdot \text{Str}^{-1}) \]
\[ V_s: \text{CCT count} \]
\[ K_s, R_s: \text{constant} (\text{Table 1}) \]

function 2 (for TM data)
\[ Q_s = V_s (D_{max} (R_{max} \cdot R_{min}) + R_{min}) \]
\[ Q_s: \text{radiance value (mV \cdot cm}^{-2} \cdot \text{Str}^{-1}) \]
\[ V_s: \text{CCT count} \]
\[ D_{max} = 255 \]
\[ R_{max}, R_{min}: \text{constant} (\text{Table 2}) \]

<table>
<thead>
<tr>
<th>Band 1</th>
<th>Band 2</th>
<th>Band 3</th>
<th>Band 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rs</td>
<td>590/2.3</td>
<td>610/1.9</td>
<td>620/1.6</td>
</tr>
<tr>
<td>Ks</td>
<td>383/670</td>
<td>383/670</td>
<td>63/670</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Band 1</th>
<th>Band 2</th>
<th>Band 3</th>
<th>Band 4</th>
<th>Band 5</th>
<th>Band 6</th>
<th>Band 7</th>
</tr>
</thead>
<tbody>
<tr>
<td>R_{min}</td>
<td>-0.0099</td>
<td>-0.0227</td>
<td>-0.0083</td>
<td>-0.0194</td>
<td>-0.00799</td>
<td>0.1534</td>
</tr>
<tr>
<td>R_{max}</td>
<td>1.004</td>
<td>2.404</td>
<td>1.41</td>
<td>2.66</td>
<td>0.5873</td>
<td>1.896</td>
</tr>
</tbody>
</table>

(4) The KVI (vegetation index) value of the polygon data was calculated from the radiance value in the red and infrared bands of TM data and MESSR data obtained for the dates referenced above. A growing pattern map was also created using the KVI values.

(5) Regression analysis was executed on the root yield and KVI values, then yield maps were developed.

(6) The estimated root yield was recalculated for a 250m grid average for each year. Finally, a map of the decrease in root yield for 1993 as compared with the yield for 1991 was developed.

4. Results and discussion

4-1. Changes in the KVI value for 1993

The KVI value has changed with growth stage shift from July to September in 1993. The KVI value on July 8 was in the range of 0.46~1.00 and there was a large difference on each field. Grower C's KVI value was the lowest. It was suggested that this field was damaged by high precipitation which was observed in the southern part of Tokachi plain at the beginning of June.
Afterwards, the difference of KVI was decreasing among six growers' fields in August 16, and there was not any difference among them in August 25. Because the aged leaves wither at the end of the growth stage, the KVI value decreased in September.

However, the KVI value for September 19 was higher than for September 1 on grower A's and B's fields because of secondary growth of beet top. The changes of KVI values corresponded to variation of sugar beet top weight.

![Fig. 2 Changes of KVI value of each sugar beet grower's fields from July 8 to September 19 in 1993](image)

4-2 Estimation of root yield

Regression analysis was executed on root yield at the time of harvest and KVI values were derived from 5 satellite images. Correlation coefficients for July 8 were the highest during the growing season.

The following equations were derived to estimate the root yield successfully:

\[ Y_{91} = 4.720 \times \text{KVI} - 0.043 \quad (n=10, \ r=0.77^*) \]
\[ Y_{93} = 3.508 \times \text{KVI} + 2.490 \quad (n=10, \ r=0.88^{**}) \]

where

\( Y_{91} \) and \( Y_{93} \) are estimated root yields for 1991 and 1993 derived from Landsat/TM data taken August 29, 1991 and July 8, 1993.

4-3 Comparison with the yields in 1991 and 1993

The root yield maps created from these equations are shown in Fig. 3 and Fig. 4. Averages values of estimated root yield for 1991 and 1993 were 5.3t/10a and 4.4t/10a respectively, calculated from the estimated yield.

The decrease in root yield in 1993 as compared with the yield in 1991 was calculated on the basis of 250m grid average of root yield for each year. Fields in Memuro town were not damaged, while those in Sarabetsu village were severely damaged (Fig. 5). The fields in Memuro town were detected frequently on the soil with rich in organic matter, and the KVI value was medium in July, high in August and low in September. However, fields in Sarabetsu village were found in the area with lower soil organic matter, and the KVI value was medium in July, high in August and low in September (Fig. 6, 7). Volcanic ash soils are most widely distributed in Tokachi plain. Therefore, the soil with rich in organic matter and poor drainage of a field caused wet damage (SHIOZAKI et. al.,1985). But, the results do not conform to this rule. The relationships between the extent of the damage, the changes of KVI, and soil organic matter content suggested that the production drop was due partly to leaching of fertilizer by high precipitation in addition to damage from the cool and wet summer.

In the future, it will be necessary to consider weather conditions, nutrient uptake availability and topography during the analysis process.
Fig. 3  Sectional map of root yield in 1991

Fig. 4  Sectional map of root yield in 1993

Fig. 5  Sectional map of yield reduction ratio

Fig. 6  Yield reduction map for soil environment

Fig. 7  Growing pattern map in 1993

Acknowledgments
The authors would like to thank the following Hokkaido National Agricultural Experiment Station researchers: Dr. M. TOYODA, Mr. K. MASUDA, Mr. S. HAKOYAMA and Mr. R. OKUNO who helped to collect the ground truth data. We are also grateful to Mr. K. OKAMOTO for valuable advice on this study and Ms. S. BACCHUS for review of this paper.

Reference
SHIOZAKI, H., 1985: Differences of response to Cool Summer Damage and Wet Damage among Upland Crops. JARQ, 18(4), 268-274