DEVELOPMENT OF AN EFFICIENT SUGAR BEET CULTIVATION SUPPORT SYSTEM USING THE AGRICULTURAL SPATIAL INFORMATION - PREDICTION OF ROOT YIELD USING METEOROLOGICAL DATA AND SATELLITE DATA

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Introduction:

Sugar beet is cultivated only in the Hokkaido prefecture, located in the northern part of Japan. The sugar beet cultivation area is 30,000ha in Tokachi District, which is equal to about 45% of the national total production area[1)]. Because the sugar beet crop is suitable to cool weather conditions, the sugar beet is an important rotation crop in Hokkaido.
The production of the beet sugar in Hokkaido is about 640,000 tons, that is 3/4 of the total production amount[1)]. The Japanese government has enforced the "New policy on sugar beet and other sweet resource crop", and the government is instructing the cost reduction of the production and manufacturing processes through this policy.

It is considered that, the reduction of the fertilizer amount which is 25% of the total production cost can contribute to the reduction of the agricultural production cost. In addition to the fertilizer cost reduction, the sugar concentration in the root increases according to the optimization of the application amount of the nitrogen fertilizer. And also, through making an appropriate schedule of the sugar materials collection work with use of the predicted root yield data before the harvesting, it is expected to reduce the fuel cost of the transportation. This is another effective method to utilize the predicted root yield data.

To realize the above benefits, the root yield data of "each individual field" is necessary, but at present the yield data"by each farmer" is only available. It is hard work to collect and unify such kind of the data for practical use, so it is highly required to develop new methods to recognize the crop status and the yield data of the individual field. Under these circumstances, the study on "Development of an efficient sugar beet cultivation support system using the agricultural spatial information" was started to construct a new method to collect the field observation data using the remote sensing, GIS and meteorological data. The objective of this study is to assess the potential of development of an efficient sugar beet cultivation support system effective to reduce the cost for the beet crop cultivation, sugar production and sugar material distribution, with use of the agricultural spatial information data.

In the previous research work in earlier phase of the agricultural remote sensing research in Japan, the root yield of sugar beet was estimated by the reflectance with red wavelength (650nm) and the reflectance with near infrared wavelength (850nm) of the cultivated sugar beet grown under different fertilizer conditions[2)]. Moreover it was reported that the K-value derived from the reflectance of 650nm and 850mn was suitable index to estimate the root yield in August[3)]. The possibility of nutritional diagnosis for nitrogen and phosphoric deficiency was also reported[3)]. In the 1990's, the study of estimation of sugar concentration in root and root yield using a Landsat TM data[4)], and the study of estimation of the nitrogen absorption amount using a Landsat TM data were carried out[5)]. These research results indicated that the remote sensing data was useful to assess the quantity and quality of individual field and to improve the productivity of the sugar beet by appropriate application of nitrogen fertilizer. Through the analysis of the sugar beet damaged by cold and wet weather using a Landsat TM data and the soil data, the relatively low root yield region was related to the poor drainage soil condition, existence of compact subsoil and lack of gravel layer[6)].

In our previous papers, we reported that the root yield estimation possibility by analyzing the remote sensing data to be acquired in summer season was indicated, because there was positive correlation between the beet top in July and the root yield and sugar yield in the harvesting season[7,8,9)].

Up until now, data for predictors of most of the conventional estimation formula is measured at the harvesting time, and the absolute yield value cannot be derived before the harvesting time even if the remote sensing data of July is analyzed. The root yield observation data is necessary to know the absolute yield data. It means that we have to wait until October to assess the yield. In this study, to predict the root yield of sugar beet "three months before of harvesting season", the analysis of the satellite data and meteorological data was carried out. The new method of the root yield prediction to be constructed by cumulative temperature, cumulative precipitation, cumulative solar radiation and NDVI is reported.

Methodology:

2.1 Study site

This study was conducted in Memuro town located in the middle west of Tokachi plain, Hokkaido, Japan (East longitude 143.1°, North latitude 42.9°) (Fig.1). The area of a test site for this study is 22.6km from east to west, 35.4km from north to south. A large-scale agricultural management is performed here. The Memuro town is mostly covered by farm land and forest, of that ratio is about 42% and about 40% respectively. The cultivation area of Memuro town is 19,720ha, and the averaged cultivation area is 28ha per farmer. The cultivation season of Memuro is from April to October. The major crops are sugar beet, potatoes, wheat, sweet corns and legumes and the planting acreage of each crop is 20.9%, 19.8%, 36.0%, 5.6%, and 14.2% respectively. Rotation of crops is executed by combination of major crops and vegetables at three years or four years interval. In this study, sugar beet was selected in order to analyze the root yields. The acreage of cultivation of sugar beet is 3,505ha in Memuro, and the averaged cultivation area of sugar beet is 6.9ha per farmer[10)].

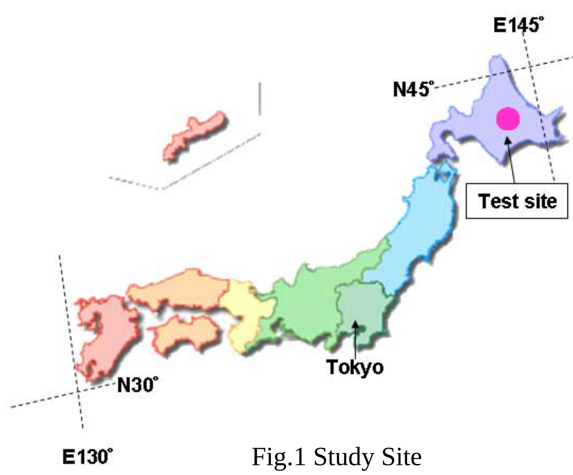


Fig.1 Study Site

It is an inland climate in Memuro, and the most of fine weather days of Japan is recorded here. The averaged temperature of a year is 6℃, and the yearly difference is very large, of which temperature in summer season is over 30℃, while in winter season below -20℃.

The altitude of Memuro ranges from 45m to 300m. The test site can be divided into four main geographical types which are lowlands, low, middle and high terraces[11)]. The main parent materials are constituting each geographical type are follows; the lowland with alluvial deposit, the low terrace with volcanic ash and alluvial deposit, and the middle to high terraces with volcanic ash[11)]. These soil types are classified based on the soil classification of FAO, into Hapic Fluvisols (Alluvial deposit areas), Mollic Fluvisols (Volcanic ash / Alluvial deposit areas) and Andic Gleysols and Mollic Andosols (Volcanic ash area).

2.2 Root yield data and ground observation data

Two kinds of root yield data were prepared to predict the root yield of sugar beet. One is the annual averaged root yield data in Memuro town from 1990 to 2007 which were edited by Hokkaido Government Tokachi Subprefectural Office. The data from 1990 to 2005 were used to construct the prediction formula of root yield, and the data of 2006 and 2007 were used for validating the accuracy of the predicted root yield. The other yield data is the annual averaged root yield of farmer's group. In Memuro town, there are 121 farmer groups of sugar beet. These data were used for validating the accuracy of the predicted root yield after calculating the predicted yield value in proportion to the NDVI value.

Moreover, sugar beet field observation data was prepared to analyze the relationship between beet tops and root yield. To measure the plant height, leaf color (SPAD: Soil & Plant Analyzer Development), root yield and sugar concentration, the investigation points were set in 56 different places, and each place has an area of three rows×2m width area (fig.2). The field survey was performed from June to October, 2006 and 2007.

2.3 Meteorological data

Data on cumulative temperature, cumulative rain fall amount and cumulative solar radiation from the end of April to the middle of July were collected from Obihiro meteorological observatory and Memuro observation site. These data were added to the table on the GIS of the farmer groups.

2.4 Satellite data

Spot5 satellite (HRG-X) data were acquired on July 27, 2006 and July 27, 2007. There are 4 bands in the imagery, of which the observation wavelength includes green band(500-590nm), red band(610-680nm), near infrared(780-890nm) and short wavelength infrared(1580-1750nm), 10m image resolution with visible band and near infrared band, 20m image resolution with short wavelength infrared band.

2.4 GIS data

GIS data of 2006 and 2007 were used to identify sugar beet fields in the satellite data. Moreover, GIS of the farmer groups were prepared to unify various yield data, meteorological data and satellite data.

2.5 Procedure

The procedure of the root yield prediction is described in Figure 3.

To derive the root yield prediction equation, the multiple linear regressions analysis was executed using the data on cumulative temperature, cumulative rain fall amount and cumulative solar radiation from the end of April to the middle of July which were observed from 1990 to 2005. The averaged root yield of Memuro town in 2006 and 2007 were predicted using the yield prediction equation.

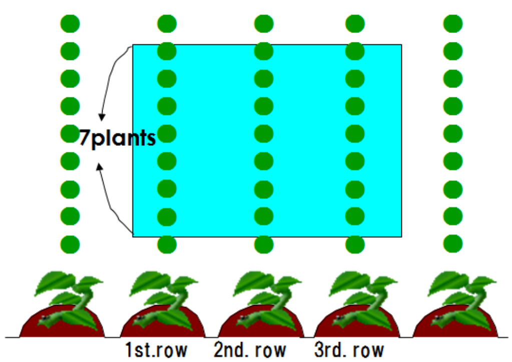
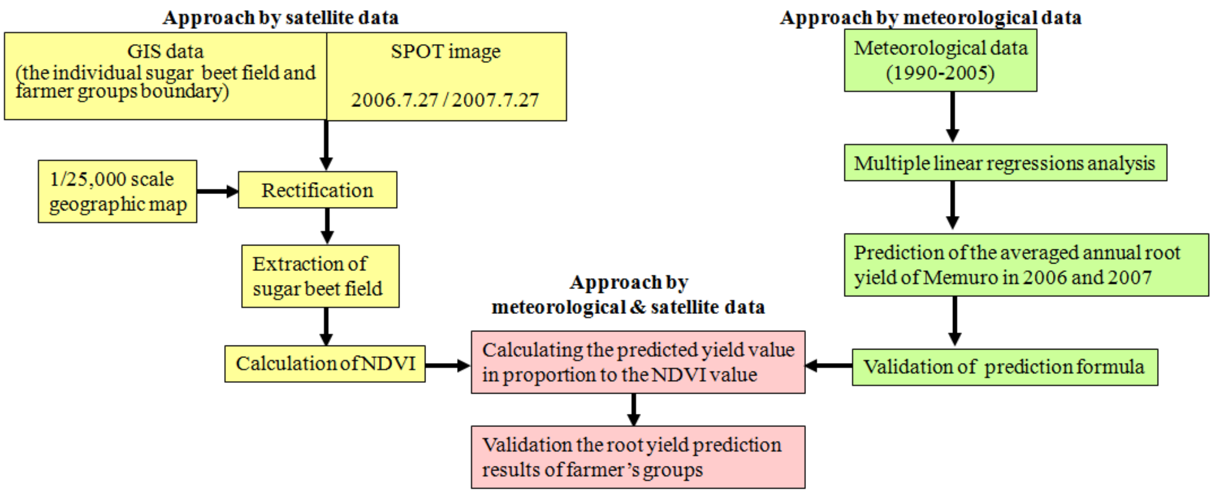


Fig.2 Outline of the ground observation point

Secondly, the satellite data and GIS data were rectified using a geographic map drawn on a scale of 1 to 25,000 by the nearest neighbor resampling algorithm using the selected ground control points. The shape file of sugar beet field was created from GIS data and overlaid on satellite data to extract the sugar beet fields. The digital values of sugar beet fields derived from satellite data were converted to the surface radiance value, and the majority value of NDVI (Normalized Difference Vegetation Index) was calculated from the radiance value of whole sugar beet fields in Memuro town. The definition of NDVI is as follows:

$$NDVI=(NIR-R)/(NIR+R)$$

where NIR=radiance on near infrared wavelength, R= radiance on red wavelength.



The predicted yield value by the meteorological data and the majority value of NDVI are presumed to be equal, the NDVI value of the whole sugar beet fields were transformed into the absolute root yield value after calculating the predicted yield value in proportion to the NDVI value.

Finally, to validate the root yield prediction results of 2006 and 2007, the predicted root yield values of the farmer's groups were compared with the observed root yield values.

Fig.3 The procedure of image analysis

Results and Discussion:

3.1 The relationship of the growth data of sugar beet and satellite data

The relationship between [SPAD×plant height]value and the root yield value was investigated. There is positive correlation between [SPAD×plant height] of July 12 and the root yield of October 4, 2007 (Fig.4). The coefficient of determination is 0.64. The [SPAD×plant height] value is applied to a diagnosis index indicating the status of crop nutrition and crop growth, the high value means the rich amount of nitrogen nutrition and biomass of sugar beet crop. The result shows that the sugar beet with larger amount of leaf and stem in July has relatively higher root yield in the harvesting season, and it is also suggested that the root yield in the harvesting season is determined by the growth status of beet tops in July. Moreover, there is positive correlation between [SPAD×plant height] and NDVI of July 27, 2007 (r^2=0.6) (Fig.5). Through these results, it could be possible to estimate the root yield of sugar beet about three months before the harvesting season.

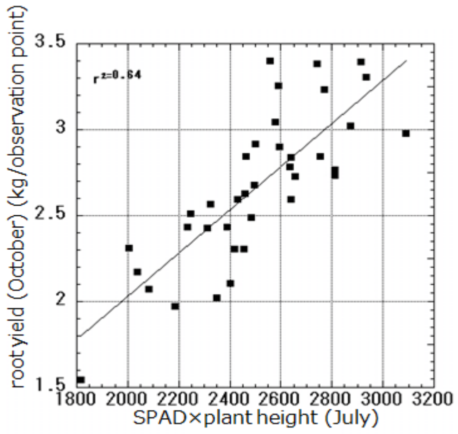


Fig.4 The relationship between SPAD×plant height (July) and the root yield (October)

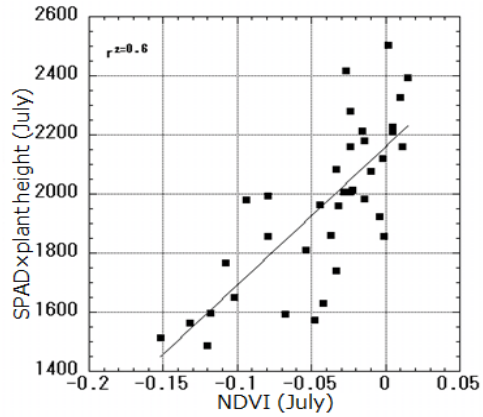


Fig.5 The relationship between SPAD×plant height (July) and the NDVI (July)

3.2 The prediction of root yield of sugar beet of Memuro town using meteorological data

On the previous research, it is reported that the root yield and the beet sugar yield are able to estimate using solar radiation, temperature and precipitation data from the transplantation season to the middle growth stage[8]. It is considered, the above can be interpretation that the photosynthetic rate (sugar production) is strongly affected by solar radiation, and an expansion rate of leaf area is affected by temperature. In addition, the sugar beet yield in Memuro town depended particularly on the soil water content.

Therefore, in this study, a multiple regressions analysis was executed to predict the root yield of harvesting season using the cumulative temperature, cumulative rain fall amount and cumulative solar radiation from the end of April to the middle of July from 1990 to 2005. The root prediction formula derived from these predictors is as follows:

$$RY=0.043675R+0.02783T-1.09513P-39.634(r2=0.87^{**})$$

where RY is root yield, R is cumulative solar radiation, T is cumulative temperature and P is cumulative precipitation.

The coefficient of determination of the prediction formula is 0.87 with 1% significance level. RMSE (root mean square error) is 3.2t/ha, which is calculated from the predicted root yield and observed root yield. The predictive value and observed value are scattered on a line of 1:1. The root yield of 2006 and 2007 were predicted based on the prediction formula. The prediction yield of 2006 was 58.64t/ha, which is 0.4% excess against the 58.04t/ha of Ministry of Agriculture, Forestry and Fisheries (MAFF) statistical data. Further, the prediction yield of 2007 was 72.04t/ha, which is forecasted in 2.1% excess against the 70.54t/ha of MAFF statistical data.

3.3 The prediction of root yield of individual sugar beet field using meteorological and satellite data

The predicted root yield of 2006 and 2007 derived through the prediction formula described in 3.2 was corresponded with the ground observation value of Ministry of Agriculture, Forestry and Fisheries. Then as the next step, the root yield prediction through the new method of individual fields and farmer groups before the harvesting season was investigated using spot satellite data acquired in July 27 2006 and July 27, 2007 and the predicted root yield value from meteorological data.

In our previous research, we reported that there was positive correlation between the root yield of the harvesting season and the amount of beet top in July, and it was possible to estimate root the yield analyzing the SPOT satellite data acquired in July[7,8,9].

However, the absolute root yield value cannot be obtained before the harvesting season even if the satellite data in July is applied to this prediction approach because it is necessary to know the ground observation root yield data of October as the input data for prediction formula to derive the absolute root yield value. Then we focused on the relationships between the beet top and NDVI of July and the root yield of October, and the absolute root yield value was derived using the following prediction procedure.

The root yield predicted using the prediction formula described in 3.2 is replaced by the maximum frequency value of the NDVI value of the beet fields cultivated in the study site. The predicted averaged root yield value is converted to the root yield value of individual sugar beet field in proportion to the NDVI value. Finally, the averaged root yield of the each farmer group was calculated from these individual sugar beet fields.

The prediction accuracy of 2006 is shown in Fig.6, of which RMSE is 6.1t/ha and correlation coefficient of prediction value and observation value is 0.54. The scatter graph shows that the data are separated into two groups in fig.6. The group A indicates the overestimation of the farmer groups which actually have extremely small cultivation acreage. The result suggests that the prediction accuracy can be improved by analyzing the weighted average in the future. The scatter graph shows that the relationship between the prediction root yield value and the observation root yield value in 2007(Fig.7). The ground observation root yield data of 2007 is not the farmer group data of MAFF. The data was collected from the observation points of farmer's fields, which were three rows by 7 crops per observation point. The RMS error of the predictive value to the observation root yield t value was 4.8t/ha, and it was corresponded to the error of about 6.8% for 70.54t/ha of the observation value. But the RMS error of the predictive value was 3.8t/ha after eliminating the fields of the brown lowland soils.

The productivity of the root yield has tendency to decrease after 1990 in Memuro town[12]. The characteristic of the brown lowland soils is described by their shallow effective soil layer[11]. The reason of decreasing the root yield productivity might be attributed to the

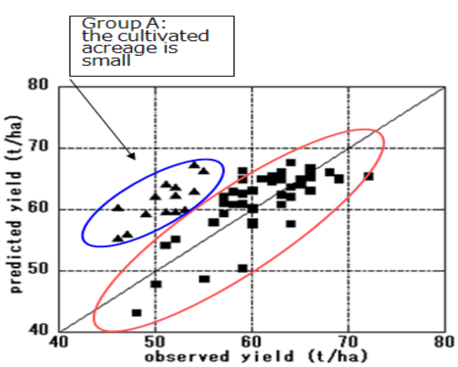


Fig.6 The relationship between predicted yield and observed yield of each farmer group (2006)

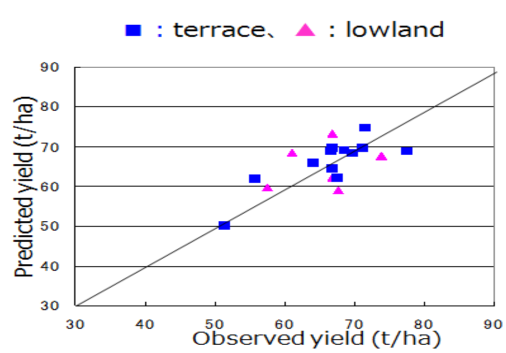


Fig.7 The relationship between predicted yield and observed yield of the field observation point (2007)

beet top growth amount reduction caused by low soil water content under low cumulative precipitation. Niwa et. al.[12] have reported the reduction of root yield at the brown lowland soils in Tokachi District, their research results shows that the formation of tillage pan caused by heavy agricultural machinery is affects the beet top and root yield productivity. In addition, the low productivity phenomenon remarkably appears under heavy precipitation condition. Considering these results, development of the root yield prediction formula for each soil type can contribute to the improvement of the prediction accuracy.

Fig.8 illustrates the root yield prediction map of the individual field created by averaged root yield and NDVI value. The individual root yield value is averaged by each farmer group, and divided into 5 levels according to the yield value; the result map is shown in Fig.9.

The developed root yield map of farmer group from the meteorological and satellite data correspond to the map of root yield productivity which is now utilized. The results suggest that it is possible to predict the root yield three months before the harvesting season. By providing such result to sugar companies in much earlier before the harvesting, the sugar beet collection and sugar production efficiency will be increased.

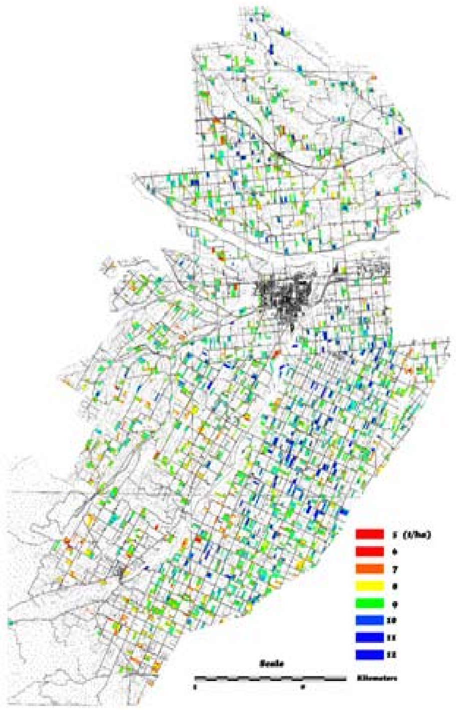


Fig.6 The beet sugar yield of individual field

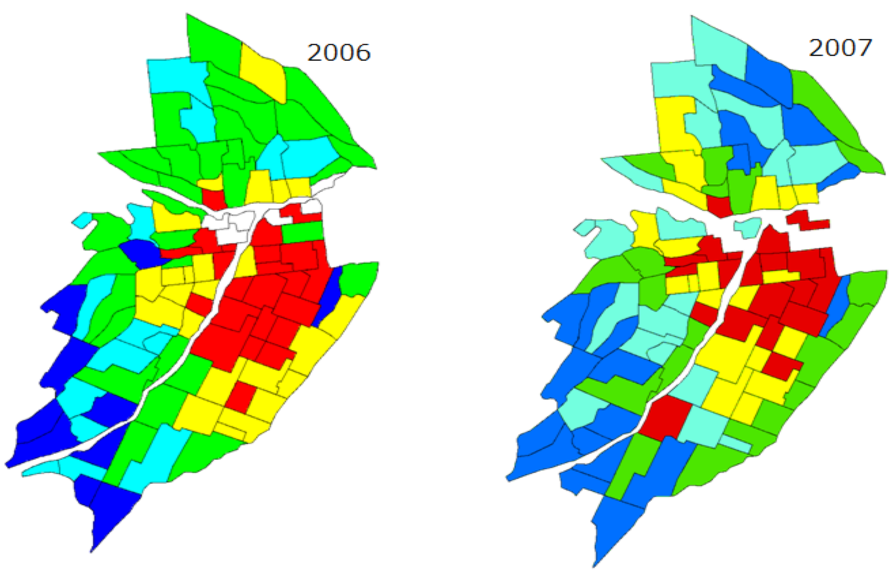


Fig.7 The root yield level maps of farmers group

Conclusion:

In order to assess the feasibility of development of an efficient sugar beet cultivation support system effective to reduce the cost for the beet cultivation and also for the beet collection and sugar production using the agricultural spatial information data, and also to predict the root yield of sugar beet three months before of the harvesting season, the analysis of the satellite data and meteorological data was carried out in this study.

The results show that it is possible to predict the root yield using the meteorological data with high accuracy. Also, the root yield of individual field and farmer group can be predicted using the meteorological data and NDVI value of satellite data. Most of the yield estimation methods that are reported in the previous research have the estimation equations using satellite digital data and ground observation data. In this study, we have constructed the new yield prediction methods using the averaged root yield value predicted from the meteorological data replaced by the maximum frequency value of the NDVI value of the beet fields.

By providing such result to sugar companies in much earlier before the harvesting, the sugar beet collection and sugar production efficiency will be expected to increase substantially. The results will lead to generate the economic and environmental benefits in agricultural field. Our results show a bright outlook on the application of spatial information data for estimating the sugar beet yield. We believe that the practical use of such methods will be realized in the near future by tackling the remaining problems.

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The part of research results has applied for the patent.

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