COMBINED APPLICATIONS OF NIR, RS, AND GIS FOR SUSTAINABLE SUGARCANE PRODUCTION

By

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Abstract

Near Infrared Reflectance (NIR) and Remote Sensing (RS) were used to gather detailed information on soil and crop conditions that play an important role in sustainable sugarcane production. The NIR system was also used to measure not only sucrose but also P, K, and Mg simultaneously. Large quantities of data collected using the NIR system were combined in a Geographic Information System (GIS) in order to execute spatial analyses. Mapping of the information on cane quality and minerals in the juice and soils was carried out for all cane fields in Minami-Daito and Kita-Daito Islands. The results of analyses showed the presence of high levels of K in the cane juice and that fields needed adjustments in the application rates of K to insure optimum sugar yields. As a complement to NIR, high-resolution satellite images, such as those developed by the IKONOS system, were used to evaluate the cane growth conditions and to prepare field maps. The combined applications of NIR, RS and GIS are proving effective in improving management practices on individual farms.

Introduction

Sugarcane is a major crop in the Nansei Arcs located in the southwestern area of Japan, especially in Okinawa where it is cultivated by 70% of the farmers on 50% of the farmland (Okinawa Prefectural Government, 2003). Sugarcane is valued as an indispensable crop in Okinawa because of its economic effect on the rural society, especially in small islands, its high production of biomass, and its tolerance to typhoons and drought.

It is also regarded as a key crop to prevent global warming through less release of CO₂, as its biomass (bagasse) can be used for the co-generation of electricity and the production of ethanol. A new production information system is needed to ensure sustainable crop production in the region (Sun et al., 1998).

Effective and low cost data collection is a key point of consideration in producing information systems. Fortunately, the current payment system introduced in 1994–1995 can generate this information, for example, on cane quality and payments. NIR is being used to evaluate cane quality as Pol in cane (POC) and also to measure other components (Meyer, 2000, Ueno et al., 2000).

NIR calibration equations were developed and incorporated into the system (Ueno et al., 2000). The determined values of POC and mineral contents on a farm basis were analysed in a Geographic Information System (GIS) (M. Ueno et al., 2000).

The linkage of NIR and GIS has provided useful information for the management of sugarcane crops on individual farms as the relationship between crop/soil conditions and cane quality is better understood. Other information on crop conditions affected by drought, typhoons and calamities has been obtained by using remote sensing (RS) techniques.

The combination of NIR, GIS and RS completes an information system in which the Global Positioning System (GPS) is also used to assist with mapping. Using the Minami-Daito and Kita-Daito Islands, the objectives of this study were to: (1) use the NIR function for the measurement of minerals in cane juice and soil; (2) develop GPS applications for mapping; (3) develop RS applications by using high-resolution satellite images; and (4) develop an information system by combining NIR, GIS, GPS and RS.

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Methods

Outline of the information system

Sugar content (as POC) and yield data were automatically collected for all cane fields through the current payment system to develop a database containing information on crop and soil conditions. NIR, GIS and RS were combined for fertiliser applications and management of the farms.

NIR measurements

Pol in juice was measured by the NIR optical system and POC was then calculated from it to determine cane payments to the farmers. Contents of K, P and other minerals in juice, bagasse, soil and leaves since 1996 were also measured by NIR. About 100 to 200 samples were supplied each year, during a 5-year period, to establish the NIR calibration equations for mineral measurements (Ueno et al., 2000). NIR absorption spectra in juice were obtained by using the Infraalyzer 500 (Bran+Luebbe Co. Ltd.) in the wavelength range from 1100 to 2500 nm with 2 nm steps. Inductively Coupled Plasma (ICP), (ICPS-2000, Shimazu) was used to analyse mineral contents for making calibrations. Minerals in soil samples were extracted by ammonium acetate and measured by ICP. The sample set was divided into two groups for calibration and validation. After establishing the calibration equations, the NIR was installed in the sugar mill at Minami-Daito Island. Approximately 7000 samples were measured each year during the harvest years of 2000–2001 to 2002–2003.

GIS applications

The POC and mineral contents in the samples were related to cane fields and digital field maps of Minami-Daito and Kita-Daito Islands in the GIS (Esri, ArcView). They included data on topography and from high-resolution satellite images of IKONOS (Space Imaging Co. Ltd.). As a result of new plantations and changes occurring in the cropping pattern, the digital field maps were renewed every year.

GPS applications

An inexpensive single user GPS receiver (GPS508PC, SPA Co. Ltd.) was mounted on a truck to record the position of trips and fields. The receiver was connected to a PDA (GENIO e660, TOSHIBA) to continuously acquire position data. Accuracy of measurement was about 5 m. Departing from the sugar mill, the truck travels to and from the fields being harvested. In the field, it moves alongside the harvester for loading cane. In this way, a series of positioning data at one second intervals was obtained.

RS applications

The Normalised Difference Vegetation Index (NDVI), Ratio Vegetation Index (RVI) and Difference Vegetation Index (DVI) were calculated from Landsat TM5 images taken in July, September, and December of 1997 and January of 1998. The processed NDVI image was overlaid onto the digital field map to enable the forecasting of yield.

Results and discussions

Calibration equations for mineral measurement

Calibration equations for the measurement of K, P and Mg were made using the original and second derivative of the spectrum employing Multiple Linear Regression (MLR). Calibration and validation showed high performance for measuring K, P and Mg as shown in Table 1.

<table>
<thead>
<tr>
<th>Constituent</th>
<th>N</th>
<th>Range</th>
<th>Ave</th>
<th>Std</th>
<th>R</th>
<th>SEC*</th>
</tr>
</thead>
<tbody>
<tr>
<td>K (ppm)</td>
<td>98</td>
<td>1822 - 2155.0</td>
<td>2775.2</td>
<td>42428</td>
<td>0.94</td>
<td>139.4</td>
</tr>
<tr>
<td>P (ppm)</td>
<td>100</td>
<td>57.7 - 442.5</td>
<td>208.6</td>
<td>71.3</td>
<td>0.90</td>
<td>32.1</td>
</tr>
<tr>
<td>Mg (ppm)</td>
<td>100</td>
<td>75.0 - 281.7</td>
<td>153.5</td>
<td>37.3</td>
<td>0.88</td>
<td>18.3</td>
</tr>
</tbody>
</table>

*SEC: Standard error of calibration.

Relationship between sugar content and potassium content

The influence of some minerals on sugar content was investigated using results of juice analyses. There were negative correlations between POC and K content that were accurately measured using ICP. The samples of cane juice were collected from several islands including Minami-Daito Island over years. The
correlation became remarkable in the lower POC sample set relating to the annual differences ($r = 0.637$ for lower POC, $r = 0.333$ for higher POC). Generally, it followed the correlations in the figure that K content of most samples was excessive suggesting that K rates should be reduced.

Figure 1 shows the relationship between the values of POC and K content of all of the cane growing fields in Minami-Daito Island over three years. In this figure, K content was measured using NIR, and about 7000 values were plotted each year. Weak negative correlations were observed in 2000–2001 and 2002–2003 (Figure 1). The correlation of the former was −0.363 and the latter −0.41.

The values of POC in 2001–2002 were extremely high compared with the other two years; thus, there was no correlation. These results confirmed the reliability of NIR measurement for K content and the generality of the negative correlation. Thus, the information on K content using NIR was useful to improve K recommendations.

Mapping application for time series analyses

Applications of GIS to grasp the spatial relations among records in the database were developed. Figure 2 shows a time series of POC in Kita-Daito Island over five years. The values of POC in mapping were normalised with each year and graded by the standard deviation in order to make comparison.
Transitions of the POC distribution could be seen clearly; for example, the low sugar content areas could be identified. The potential production of each field was classified using distribution maps.

Fig. 2—Time series of normalised pol in cane (POC) in Kita-Daito Island in five years as an example of GIS application.

Fig. 3. Distributions of K content in Minami-Daito Island in 2000–2001 (juice).

Spatial distribution of K content

Figure 3 shows the spatial distributions of K in 2000–2001 at Minami-Daito Island. As mentioned above, the K content was negatively correlated with sugar content.

The fields with high K levels were identified easily from the map, and the properties of spatial distribution were also seen without difficulty. The spatial distributions could also be used to analyse the cause of low sugar content and to examine the concrete countermeasures by the control of fertiliser application for each field, which are discussed in the following.
RS application for the unit yield prediction

RS was applied to predict yields for every cane growing field using the satellite image produced by Landsat TM5 in 1997. Table 2 shows the predicted results by some types of vegetation index for Minami-Daito Island. Spatial resolution of the TM5 and the size of fields were 30 m and about 1 ha respectively, so the prediction accuracy was relatively low in this case. However, the correlations reached more than 0.6 especially in December, which increased the predictive capacity of the model used. The total volume predicted in the island was highly correlated with the actual data, and implies that the prediction accuracy can improve remarkably by the use of high-resolution satellite imagery.

**Table 2—Prediction results for unit yield of Minami-Daito Island by vegetation.**

<table>
<thead>
<tr>
<th></th>
<th>1997/7/15</th>
<th>1997/9/1</th>
<th>1997/12/6</th>
<th>1998/1/7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample number</td>
<td>135</td>
<td>160</td>
<td>169</td>
<td></td>
</tr>
<tr>
<td>Unit yield (t/ha)</td>
<td>50.1</td>
<td>47.9</td>
<td>48.6</td>
<td>49.1</td>
</tr>
<tr>
<td>Correlation coefficient</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NDVI</td>
<td>0.334</td>
<td>0.258</td>
<td>0.614</td>
<td>0.578</td>
</tr>
<tr>
<td>RV*</td>
<td>0.385</td>
<td>0.262</td>
<td>0.621</td>
<td>0.576</td>
</tr>
<tr>
<td>DVI**</td>
<td>0.403</td>
<td>0.237</td>
<td>0.628</td>
<td>0.631</td>
</tr>
<tr>
<td>Band2/Band3</td>
<td>0.324</td>
<td>0.330</td>
<td>0.596</td>
<td>0.525</td>
</tr>
<tr>
<td>Band4/Band5</td>
<td>0.553</td>
<td>0.335</td>
<td>0.688</td>
<td>0.638</td>
</tr>
</tbody>
</table>

RV* = Infrared/Red
DVI** = Infrared – Red

GPS application for mapping

The trace of the transport truck was overlaid on the IKONOS image or field layout map. The GPS measured position agreed well with the field map. The location of the field being harvested could be specified and the target digital field could be picked up from the map. The search was carried out quite easily. In-field operation of the truck was also traced very effectively. Thus, time analysis of the transport truck could be carried out using a series of positioning data.

Consulting applications

Values of POC and minerals were used to make diagnostic charts for all cane growing fields. These charts can be distributed to all farmers on the day of harvest when the communication system is completed. The K contents were estimated according to the relationships between its contents in soil and in juice. The demand of K for each field was calculated by the estimated content – the recommended content. Figure 4 shows a recommendation for the application of K. Total amount of K required for the entire island can be calculated by summing up all of the fields.

**Fig. 4—Amount of necessary K calculated by (predicted content–recommended content) in soil.**
Conclusion

Combination of NIR, GIS and RS was used to develop an information system to improve the farming practices and to insure optimum production.

NIR was quite effective in measuring not only sugar content but also mineral contents in cane juice and soil, thus it was useful as a data collecting system. GIS could analyse the spatial distribution of the information and pick up the fields to be improved.

GPS assisted the mapping to distinguish the position of the targeted field. As expected, RS predicted the unit yield fairly accurately.

Adoption of this combined technology by farmers should allow them to increase production efficiency.

REFERENCES


APPLICATIONS COMBINÉES DE NIR, DE RS, ET DE GIS POUR UNE PRODUCTION DURABLE DE LA CANNE À SUCRE
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MOTS-CLÉS: Information de Qualité, Collecte des Données, Composants du Jus, Réflexivité Proche Infrarouge, Système Global D'information, Télédétection.

Résumen
LES TECHNIQUES proches de la réflexivité infrarouge (NIR) ainsi que la télédétection (RS) ont été utilisées pour recueillir des informations détaillées sur les facteurs tels que le sol et les conditions de pousse, jouant un rôle important dans la production durable de la canne à sucre. Le NIR a été également employé pour mesurer le saccharose ainsi que le P, le K, et le magnésium simultanément. De grandes quantités de données rassemblées pour le NIR ont été traitées par un système d'information géographique (GIS) afin d'exécuter des analyses spatiales. Des tracés cartographiques sur la qualité de la canne et des minéraux dans le jus et sur les sols ont été effectués pour tous les champs de canne des îles Minami-Daito et Kita-Daito. Les résultats des analyses ont démontré des taux élevés de K dans le jus de canne les taux d'application de K et de certains champs ont du être réajuster pour assurer un rendement optimal en sucre. Comme supplément au NIR, des images satellites à haute résolution, comme celles produites par le système IKONOS, ont été utilisées pour évaluer les conditions de croissance de la canne et pour produire des cartes de champs. L'utilisation combinée de NIR, de RS et de GIS s’est avérée efficace dans l’amélioration de la gestion des fermes individuelles.

APLICACIONES COMBINADAS DE RCI, DR, Y SIG PARA LA PRODUCCIÓN SUSTENTABLE DE CAÑA DE AZÚCAR
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PALABRAS CLAVES: Información de Calidad, Sistema de Colección de Datos, Componentes de Jugo, Cerca de Infrarrojo, Sistema de Información Global, Detección Remota.

Resumen
REFLECTANCIA Cerca de Infrarrojo (RCI) y detección remota (DR) fueron usados para recoger informaciones detalladas sobre el suelo y condiciones de cosecha, que tienen un papel importante en la producción de caña de azúcar sustentable. El sistema de RCI también se usó para medir no sólo la sacarosa, mas también P, K, y Mg simultáneamente. Se combinaron grandes cantidades de datos colectados usándose el sistema de RCI en un Sistema de Información Geográfico (SIG) para ejecutar los análisis espaciales. Se ejecutó el mapeo de la información sobre la calidad de la caña y los minerales en el jugo y suelos, para todos los campos de caña en Minami-Daito e Islas Kita-Daito. Los resultados de los análisis mostraron la presencia de altos niveles de K en el jugo de caña y que los campos necesitaban ajustes en las proporciones de aplicación de K, para asegurar óptimos rendimientos de azúcar. Como un complemento al RCI, se usaron imágenes de satélite de alta resolución, como las desarrolladas por el sistema IKONOS, para evaluar las condiciones del crecimiento de caña y para preparar los mapes de campo. Las aplicaciones combinadas de RCI, DR, y SIG están demostrándose eficaces para mejorar las prácticas de gestión en haciendas individuales.