Soil P$_2$O$_5$ Calibration and Mapping using Real-Time Soil Sensor (RTSS)

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Abstract

There have been few researches using on-the-go measurement of P$_2$O$_5$. The objectives of this study were to measure soil P$_2$O$_5$ by using an on-the-go Real-Time Soil Sensor (RTSS) and to create soil P$_2$O$_5$ maps. The experiment was conducted on a 4-ha commercial farm in Hokkaido, Japan, in 2008 and 2009. The RTSS collected Vis-NIR soil reflectance spectra (350 to 1700 nm, 5-nm intervals). For calibration, a total of 144 soil samples were collected. A multivariate linear regression technique using a partial least squares (PLS) model for the soil P$_2$O$_5$ was calculated with full cross validation by Unscrambler 9.8. The multiple coefficient of determination ($R^2$) and the root mean square error (RMSE) were calculated for evaluation. The recorded soil parameters were provided as an Inverse Distance Weighted (IDW) map with Arc GIS 9, US. In this study, the $R^2$ and RMSE values of the PLS model for the soil P were 0.66 and 10.12 (mg/100g).

Keywords: P$_2$O$_5$, RTSS, PLS, soil map, precision farming

Introduction

Many researches related to P$_2$O$_5$ measurement using Vis-NIR spectroscopy have been performed in the laboratory, but few have performed on-the-go measurement. One such research using on-the-go measurement of P$_2$O$_5$ was carried out by Mouazen et al. (2006). The objectives of this study were to measure the soil P$_2$O$_5$ by using an on-the-go Real-Time Soil Sensor (RTSS) and to create soil P$_2$O$_5$ maps for site-specific management.

Materials and methods

Experimental fields
The experimental fields were two contiguous parts of a commercial experimental farm in Memuro, Hokkaido, Japan, after crop harvesting in August and October 2008 and in November 2009. The fields were named No.1 (4.43 ha, 303×146 m) and No.2 (4.51 ha, 303×148.8m). The soil was alluvial.

Spectral data and soil samples
The RTSS equipment simultaneously captured several types of data, including soil reflectance spectra range including visible (Vis) and near infrared (NIR) spectra wavelengths (350 to 1700 nm, 5-nm intervals), underground soil surface color images, soil resistance, electric conductivity (EC), and DGPS data.

The RTSS moved longitudinally along six segments of 24 m spacing and collected Vis-NIR soil reflectance spectra every 2.24 m at a depth of 0.2 m. Soil samples were collected every 24.64 m at the same depth.
In 2008, 144 soil samples and soil reflectance spectral data on fields No.1 and No.2 were collected and used for calibrating the PLS model. In 2009, 72 soil samples and soil reflectance spectral data on field No.1 were collected.

Soil samples were dried in an oven, crushed and passed through a sieve before performing chemical analysis. The soil P$_2$O$_5$ was measured with the autoanalyzer QuAAtro by the Truog method, to measure the amount of plant-available phosphorus by the widely-used method in Japan.

Spectral data analysis and soil mapping
To reduce noise and enhance weak signals, Vis-NIR soil reflectance spectra were subjected to Savitzky-Golay second derivative treatment. The sensitivity analysis for calibration was performed using the PLS technique in the Unscrambler v9.8 program (CAMO ASA, Norway). The 144 soil samples were used as the calibration dataset for full cross validation.

The recorded soil parameters were plotted on inverse distance weighted (IDW) maps using ArcMap v9.2 (ESRI, USA).

Results and Discussion

Soil sample parameters
Table 1 shows the maximum, minimum, average and standard deviation values of the soil P$_2$O$_5$ content in each year in each field. Figure 1 shows a histogram of the soil P$_2$O$_5$ content. Soil P$_2$O$_5$ was greater in field No.1 than No.2, and increased slightly from 2008 to 2009.

<table>
<thead>
<tr>
<th>Year</th>
<th>Field</th>
<th>Max</th>
<th>Min</th>
<th>Average</th>
<th>SD</th>
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</thead>
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<tr>
<td>2008</td>
<td>No.1</td>
<td>72</td>
<td>33.40</td>
<td>61.66</td>
<td>17.38</td>
</tr>
<tr>
<td></td>
<td>No.2</td>
<td>72</td>
<td>25.20</td>
<td>46.80</td>
<td>13.73</td>
</tr>
<tr>
<td>2009</td>
<td>No.1</td>
<td>72</td>
<td>40.69</td>
<td>64.36</td>
<td>15.79</td>
</tr>
</tbody>
</table>

$*$SD = standard deviation

![Figure 1. Histogram of soil P$_2$O$_5$ content](image)
The PLS model
Spectral data after smoothing and second derivative treatment are depicted in Figure 2. Some peaks are found around 550 nm, 1350 nm and 1450 nm. Measured soil P\textsubscript{2}O\textsubscript{5} is plotted against validated soil P\textsubscript{2}O\textsubscript{5} for the 144 calibration samples. In this study, the R\textsuperscript{2} and RMSE values of validation were 0.66 and 10.12 (mg/100g) (Table 2), which are compared with those of other studies in Table 3. It can be seen from the R\textsuperscript{2} value that the PLS model for soil P\textsubscript{2}O\textsubscript{5} in this study was at least as accurate as that in other studies.

![Figure 2. Spectral data after preprocessing](image)

![Figure 3. Comparison of measured and predicted soil P\textsubscript{2}O\textsubscript{5} values](image)

| Table 2. R\textsuperscript{2} and RMSE values of the PLS model |
|------------------|------------------|------------------|
| calibration     | validation       |                  |
| R\textsuperscript{2} | 0.70             | 0.66             |
| RMSE (mg/100g)  | 9.48             | 10.12            |
Table 3. Comparison of values

<table>
<thead>
<tr>
<th>Year</th>
<th>Method</th>
<th>Units</th>
<th>Spectral range (nm)</th>
<th>Multivariate method</th>
<th>No.</th>
<th>P</th>
<th>RMSE</th>
<th>R²</th>
<th>Authors</th>
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<tr>
<td>1992</td>
<td>Truog</td>
<td>mg/100g</td>
<td>350-1700</td>
<td>PLSR (4)</td>
<td>144</td>
<td>114</td>
<td>25</td>
<td>9.47</td>
<td>10.12</td>
</tr>
<tr>
<td>2001</td>
<td>Mehlich III</td>
<td>mg/kg</td>
<td>400-2498</td>
<td>PCR</td>
<td>779</td>
<td>507.6</td>
<td>0.7</td>
<td>32.28</td>
<td>0.40</td>
</tr>
<tr>
<td>2006</td>
<td>Olsen</td>
<td>mg/100g</td>
<td>305-1710</td>
<td>PLSR</td>
<td>126</td>
<td>11.63</td>
<td>2.95</td>
<td>0.943</td>
<td>1.202</td>
</tr>
</tbody>
</table>

Soil P₂O₅ maps

Figure 4 shows soil P₂O₅ maps. Each M-map was derived from data of measured soil P₂O₅. Each P-map was derived from predicted soil P₂O₅ calculated with the PLS model from soil reflectance spectra data. In each year and each field, the M-map and P-map showed similar variation patterns.

![Soil P₂O₅ maps](image)

**Figure 4. P₂O₅ soil maps**

**Conclusions**

The main conclusions of this study are as follows:

- The R² and RMSEV values of the PLS model for soil P₂O₅ were 0.66 and 10.12 (mg/100g).
- The R² value showed that the PLS model for soil P₂O₅ in this study was at least as accurate as that in other studies.
- The P-map and M-map showed similar variation patterns.

**References**


