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Development of Nondestructive Grouping System for Soil Organic Matter Using VIS and NIR Spectral Reflectance

J. H. Sung

Abstract: This study was conducted to develop a nondestructive grouping system for soil organic matter using visible (VIS) and near infrared (NIR) spectroscopic method. The artificial light was irradiated on the cut soil surface at 15 to 20 cm depths to reduce the errors of light at open field. The reflectance energy from the cut soil surface was measured to group the soil organic matter using VIS/NIR light sensor with narrow band pass filter. From reflectance spectra of soil samples, the sensitive wavelengths for measuring the soil organic matter were selected and compared to previous research results. The grouping system for soil organic matter consisted of light sensor with band pass filter measuring the reflectance energy of the cut soil surface, global positing system (GPS), analog-to-digital (AD) converter, computer and operating software. The regression models to predict the soil organic matter were developed and evaluated. From field test, the accuracies of the developed light sensor system were 81.3% for five-stage grouping of the soil organic matters and 91.0% for three-stages grouping of the soil organic matters, respectively. It could be possible to support the decision making for variable rate applications with the developed grouping system for soil organic matter in precision agriculture.

Keywords: VIS/NIR, Precision Agriculture, Soil Organic Matter

Introduction

In agriculture, the support of soil nutrient for optimum levels is very important. In general, the agricultural chemical application process has been performed under description as recommended by some equation using soil properties that was obtained and analyzed after previous-years harvest. For the chemical description, the soil properties should be analyzed frequently. However, in the conventional method, the expert system and/or techniques are needed to analyze the soil organic matter, moisture contents and other soil properties, and laborious and non-real time system.

For real-time precision agriculture, machines with the non-contact sensors are required. The first step to develop the non-contact sensor is analysis of visible (VIS) to near infrared (NIR) spectral reflectance of underground soil. The rays from artificial light are incident to the soil surface and the reflectance of light is measured. The reflected energy was examined with soil organic matter to analyze the relationship between reflectance energy and soil organic matter. The sensors for precision agriculture machine are different from the ordinary sensors, these kinds of sensors are made some groups due to their properties. The agricultural management decision system makes some decision using these grouping data and sends the decision to VRA (Variable Rate Application).

The NIR spectroscopy has been widely and increasingly used as a means for rapid and accurate determination of the properties and qualities of agricultural products, food and soil. Cho et al. (2001) performed to investigate the possibility of real time measurement of the soil organic matter using NIR spectrum analysis. They analyzed NIR spectral absorbance of well dried soil with uniform particle size. From the regression results between NIR spectral absorbance and soil organic matter, the soil organic matter was measurable without any preprocessing of soil. Ryu et al. (1999) developed a soil analyzer using NIR spectral technique. With the soil analyzer, it was possible to analyze the water content, organic matter and total nitrogen in soil. Kano et al. (1985) have developed a portable soil moisture meter, which could accurately measure the moisture of soil having different textures. Sudduth (1989, 1991, 1993) developed a soil organic matter measuring and mapping system, but it did not reach practical use because of unstable response. On the other hand, Shibusawa (1999a and 1999b) developed the soil fertility and organic measurement systems using VIS and NIR spectrophotometer.

The authors is **Jehoon Sung**, Production machinery Engineering Division, National Institute of Agricultural Engineering, RDA, Sudun-dong 249, Suwon-si, Gyonggi-do 441-100, KOREA; e-mail: jhsung@rda.go.kr

This study was performed to develop the grouping system for soil organic matter. The main objective of this research was to show that the soil analyzer based on VIS/NIR spectral reflectance can assess soil organic matter. The artificial light was irradiated on the cut soil surface at 15 cm to 20 cm depths to reduce the errors of light. The spectral reflectance from cut soil surface was measured using VIS/NIR sensor with the narrow band pass filter. Finally, the grouping system for soil organic matter was developed for precision agriculture.

Materials and Methods

1. Grouping System for Soil Organic Matter

(1) Grouping system for soil organic matter

The grouping system for soil organic matter was constructed. The system collected the reflected energy in the chamber beneath soil surface. In order to minimize the drawbar pull of subsoil, the cutting width of 15 cm was made. Collection area for reflected light was focused on the center of section. The schematic diagram of bottom part of soil organic matter grouping system is shown in Figure 1.

The reflected energy from the cut soil surface at 15 cm to 20 cm depths was focused on the surface of light sensor, through the focusing lens. As is shown in Figure 2, focusing lens, the narrow band pass filter, filter holder and light sensor were assembled in series.

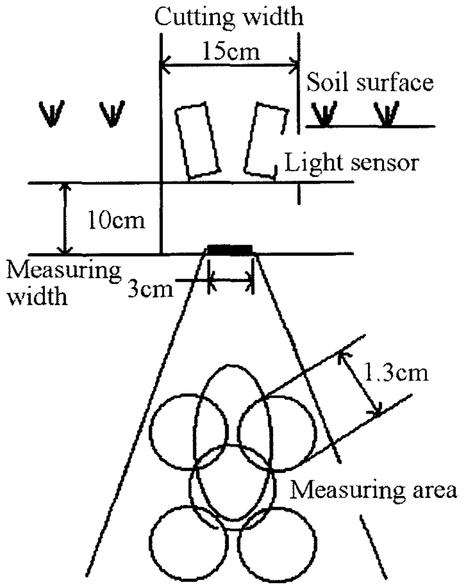

Fig. 1 Schematic diagram of bottom part of soil organic matter grouping system.

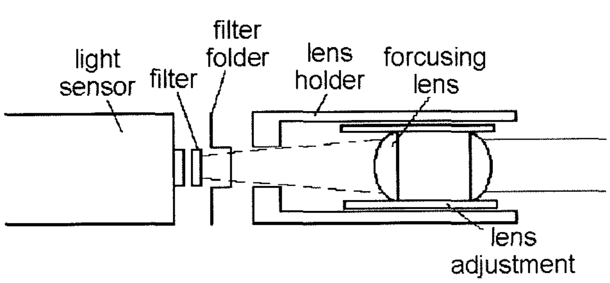

Fig. 2 Schematic diagram of light sensor to measure the reflectance energy from soil surface.

(2) Development of the operating program

The operating program to measure and store the contents of soil organic matter at each position within working space was developed. The operation of the grouping system for soil organic matter is as shown in Figure 3.

2. Analysis of Spectral Reflectance of Soil Organic Matter

(1) Preparation of soil samples

The soil samples from paddy field, upland and house

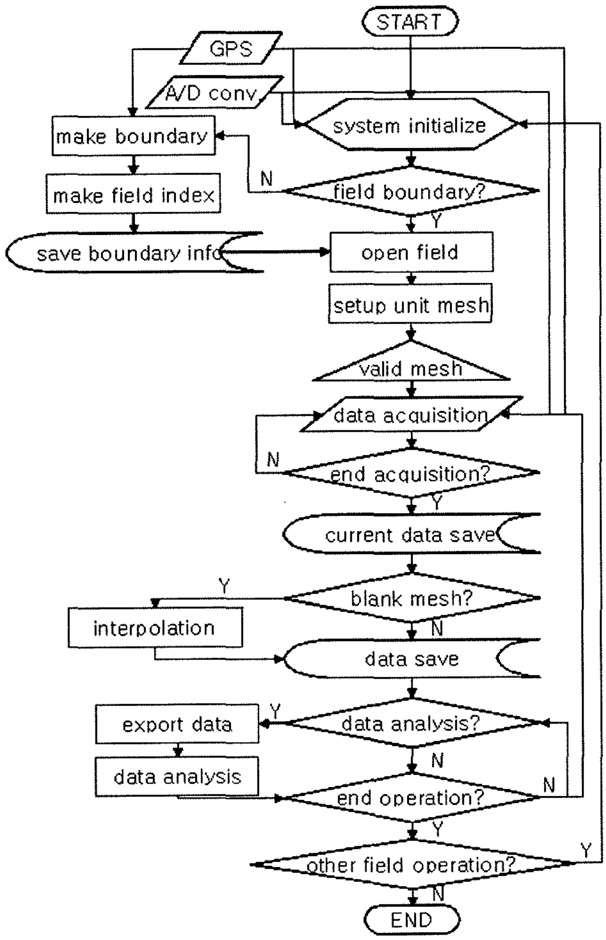

Fig. 3 Flow chart of operating program of grouping system for soil organic matter.

land were prepared to select the sensitive wavelength to soil organic matter using spectral analysis. 92 soil samples were collected from Suwon-si, Kimpo-si, Youngju-si, Naju-si, Haenam-gun, and Eumsung-gun, Korea. These soil samples were ground and allowed to pass though 0.2 mm opening sieves.

Generally in Korea, the average contents of soil organic matter are 2.2% for paddy land and 1.9% for upland, respectively. Therefore, in this study, the range from 0% to 7% of soil organic matter was prepared. Dry basis gravimetric soil moisture content was calculated as follows;

$$\text{Moisture content (\%)} = 100 \times (\text{mass of moist soil} - \text{mass of dry soil})/(\text{mass of dry soil})$$

For soil moisture content, samples were oven-dried at 110 C for 24 hours.

(2) Spectral analysis

The NIR spectrum analyzer (model 6500, NIRSystem, Perstorp Analytical, Inc., USA) was used to inspect the collected soil spectrum. NIR spectrum analyzer could measure the absorbance from 400 nm to 2,500 nm at each two wave lengths interval. This instrument displays the absorbance from 0 to 6 levels using the derivative procedure for spectral reflectance of sample and standard plate. In this study, the absorbance from 400 nm to 1400nm was used to develop the grouping system for soil organic matter based on narrow band pass filter.

(3) Chemical analysis of soil organic matter

The content of soil organic matter was determined by the Walkley-Black method suggested by RDA (1988). The NIR reflectance spectra of soil were measured using the soil analyzer (model : KA-P, Soiltek Inc., Korea).

3. Correlation Analysis and Development of Prediction Model

The prediction model for soil moisture and soil organic matter were developed, respectively, using multiple linear regression (MLR). The original spectrum from the cut soil surface and its first and second derivative were analyzed. From the first and second derivative, the slope at each spectra was calculated after the initial lines of all data were fitted to zero. Multiplicative scatter correction (MSC) was used for preprocessing of data and then forward selection method was used to develop the regression model. The selected spectrum to group soil organic matter was compared with the result of previous study (Table 1).

Prediction models for soil moisture and soil organic matter were developed using the NEWSIS software (Ver. 4.0, NIRSystems, Silver Spring, USA). Thirty five soil samples were used to develop the calibration model.

4. Validation of the Prediction Model

The test equipment was developed to validate the prediction models for soil moisture and soil organic matter. The artificial light, from VIS to NIR, was irradiated to the illumination chamber isolated from open light. In addition, the reflected light energy that was passed narrow band pass filter was measured by two kinds of light sensors. All collected data was stored every 10 seconds, and three datum after start and before end were renounced, while the remaining four datum were averaged to use for validation.

5. Construction of Sensor Systems and Operating Software

The developed system worked on the cut soil surface at 15 cm to 20 cm depths to reduce the errors of light. The reflectance from the cut soil surface was measured using light sensor with narrow band pass filter. Therefore, the system was designed as light was irradiated and collected the reflected energy in the chamber under soil surface. The data storage system and global positioning system (GPS) were mounted on the grouping system for soil organic matter. The width of cut subsoil was minimized as low as possible load. That width should have covered the space of light irradiation and that of chamber to collect the reflected energy. Therefore the reflected energy of center section within irradiated area was collected.

As the light sensors, PBS-050-I and S-050-I (Electro Optical System Inc., USA), were used to collect the reflectance energy. These sensors converted the reflectance energy

Table 1 Sensitive wavelength for soil organic matter presented by Ryu et al. (1996) and Shibusawa et al. (1999a)

source	original spectrum (nm)	1st derivative (nm)	2nd derivative (nm)
Shibusawa et al. (1999a)	480, 747, 616, 1372, 704, 879, 1008, 1335, 529	523, 928, 526, 700, 1200, 1020, 1214, 1420, 1657, 416, 606	431, 556, 1105, 1542, 606, 1311, 1238, 849, 1639, 499, 660, 903, 1063
Ryu, et al. (1996)	1736, 1868, 2168, 2212		

to output voltage in the range of 0 Volt to 10 Volt. The PBS-050-I light sensor collected the reflectance energy in wavelength range of 700 nm to 1,500 nm. The S-050-I light sensor collected the reflectance energy in wavelength range of 300 nm to 700 nm.

The operating program was developed to measure and store the contents of soil organic matter at each position that was determined using GPS within the working space. The Visual C++ (Ver. 6.0, Microsoft, USA) was used to develop the operation software.

Results and Discussion

1. Sensitive Spectrum for Soil Organic Matter

The spectrum, from 400 nm to 1400 nm, was analyzed to investigate sensitive spectrum for soil organic matter sensitive spectrum. The selected spectra from the original spectra and the first and second derivatives data were compared with the results of previous studies (Ryu et al., 1996 and Shibusawa et al., 1999a). In this study, the first and second derivatives data were not useful for analysis. The data should have been collected for continuous spectrum for derivative, but in this study only a few narrow band pass filter spectrum was used. Thus, in this system, the original reflectance data was used, only.

Result of tests for 480, 530, 558, 620, 700, 880, 906, 908, 964, 1000, 1104, 1200, 1274, 1350, 1470, 1750 and 2200 nm were selected for soil organic matter sensitive spectrum of original data. In addition, the 420, 520, 700, 950, 1000, 1200, 1450 and 1650 nm and 430, 550, 600, 850, 900, 1100, 1300 and 1500 nm were selected for the first and second derivative spectrum data, respectively.

2. Development of Prediction Models

(1) Soil moisture contents

The prediction model for soil moisture content was developed as;

Soil moisture content = $26.467 + 6408.920\times A_{1372} - 459.161\times A_{1102} - 6076.708\times A_{1374} + 964.059\times A_{684} - 1034.398\times A638 + 214.059\times A574$ (1)

Where, $A_{\lambda} = \log(1/R)$, λ means spectrum, R means reflectance energy.

The coefficients of determination of Eq. (1) were 0.530, 0.737 and 0.816 for the original spectrum, and the first and second derivative data, respectively. The coefficients of determination is due to the limitation of spectrum range of

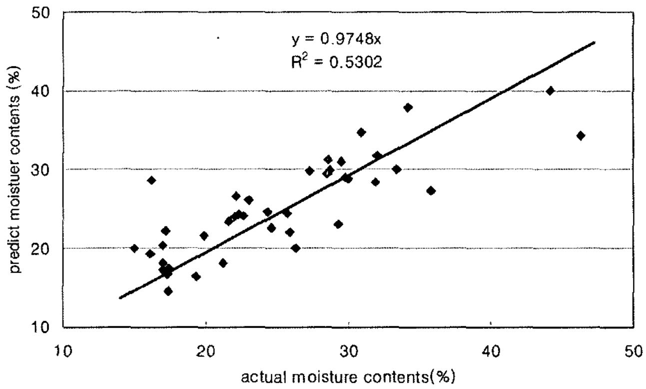

Fig. 4 Relationship between measured and predicted soil moisture contents.

400 nm to 1400 nm. The developed system with low cost narrow band pass filter may be used in the open field for real time grouping of soil organic matter since the limitation of spectrum range is acceptable.

The spectra used in the prediction model for soil moisture content were 574, 638, 684, 1102, and 1374 nm. In practice, these spectra could be changed into 570, 640, 680, 1100 and 1370 nm (±30 nm) to utilize the narrow band pass filter. Prediction results of predicting the moisture content of soil for original spectrum are shown in Figure 4. The linear relationship between measured and predicted values is shown in Figure 4.

(2) Soil organic matter

The prediction model for soil organic matter was developed as;

Soil organic matter = $2.776 - 5.678\times A_{558} - 19893.067\times A_{906} + 232.047\times A_{1274} - 1186.028\times A_{964} + 21122.419\times A_{908} - 266.952\times A_{1104}$ (2)

Where, $A_{\lambda} = \log(1/R)$, λ means spectrum, R means reflectance energy.

The coefficient of determination of Eq. (2) using original spectrum is 0.597. On the other hand, the coefficients of determination for the first and second derivative data were very low. For prediction model for soil organic matter, the range of spectrum was limited within 400 nm to 1400 nm, which is similar to the case of soil moisture contents.

The spectra used in the prediction model for soil organic matter were 558, 906, 908, 964, 1104 and 1274 nm. In practice, these spectra could be changed into 560, 910, 960, 1100 and 1270 nm (±30 nm) to utilize the narrow band pass filter. Prediction results of the organic matter of soil for original spectrum are shown in Figure 5. The linear relationship between measured and predicted values is shown in Figure 5.

(3) Validation of the prediction model

To validate the prediction model 29 soil samples were used. The artificial soil organic matter were prepared as the similar with the method of the predict model. The result of validation showed that the coefficient of determination is 0.909 as shown in Figure 6; the measured values are in good agreement with the predicted values.

(4) Development of the operating program

Before field test, the boundary data of the field was collected. And then all instruments such as GPS, AD converter, and light sensor were initialized. Also the working unit, legend range, and color were selected. In the practical operations, the output data of light sensor with position data from GPS receiver were stored. After the practical operations, the stored data was converted to another range of unit mesh and legend.

The screen picture captured by the operating program is shown in Figure 7. The bottom side part at left part is a position data set and right part is a display of soil organic matter contents with inside the boundary line.

3. Result of Field Test

The field test was performed at 37 points in the paddy field and 342 points in the upland field (total 379 points) to evaluate the performance of grouping system for soil organic matter. Results are shown in Figure 8; the measured values by chemical analysis are in good agreement with the predicted values by grouping system for soil organic matter. The coefficient of determination was 0.9774

In Figure 8, the range of vertical quadrangle is an actual stage of soil organic matter that was analyzed by chemical method. The range of horizontal quadrangle is measured by grouping system for soil organic matter. The large circle overlapping on the vertical and horizontal quadrangle is a correct measuring points. This means that the result of chemical analysis measured by sensor is identical. The

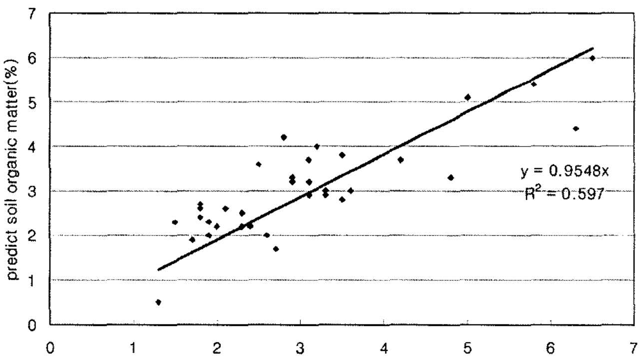

Fig. 5 Relationship between measured and predicted soil organic matter.

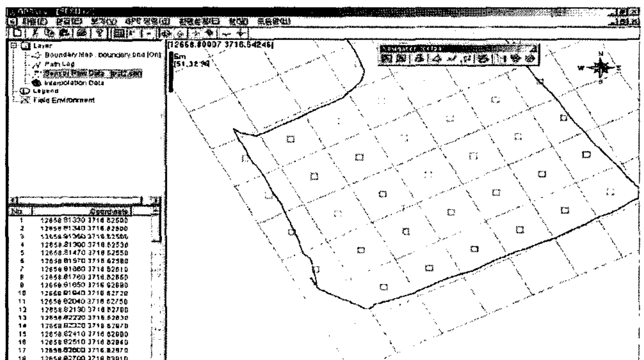

Fig. 7 The screen image captured by operating program of grouping system for soil organic matter.

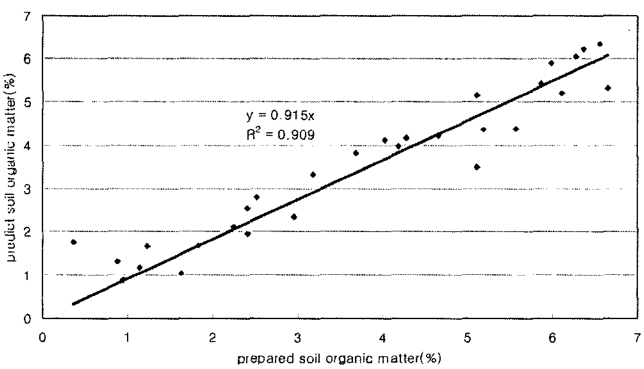

Fig. 6 Result of model verification actual vs. predict soil orgamic matter by soil organic matter predict model.

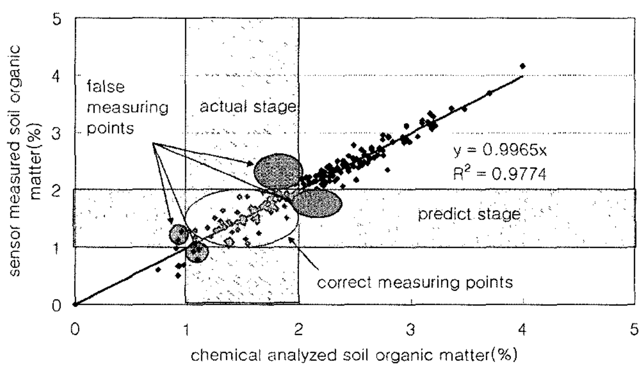

Fig. 8 Relationship between soil organic matter by chemical analysis and sensor system.

Table 2 Coincidence summary matrix of the five-stages grouping of soil organic matter contents. Gray cells are correct measuring points and the result of the chemical analysis and sensor measured are identical

Sensor measured / Chem. Analyzed	1st group	2nd group	3rd group	4th group	5th group
1st group	5	1	0	0	0
2nd group	3	15	4	1	0
3rd group	0	5	93	9	1
4th group	0	0	19	151	21
5th group	0	0	0	7	44

Table 3 Coincidence summary matrix of the three-stages grouping of soil organic matter contents. Gray cells are correct measuring points and the result of the chemical analysis and sensor measured are identical

Sensor measured / Chem. Analyzed	1st group	2nd group	3rd group
1st group	196	11	0
2nd group	15	141	6
3rd group	0	2	8

small four circles which didn't overlapped with the vertical and horizontal quadrangle were a false measuring regions. This means that the result of chemical analysis and measured by sensor is different each other.

Table 2 and 3 show the results of grouping of soil organic matter. The first group is classified under a lower soil organic matter contents part (0% to 1%). As shown in tables, the accuracies of grouping results are 81.3% (308 points over 379 points) and 91.0% (345 points over 379 points) for the five and three groups, respectively. Specifically, the errors over stage two are just 0.5% (2 points over 379 points) in five-stage grouping. The error were an acceptable level for the real time grouping of soil organic matter, in precision agriculture VRA. Figures 9 and 10 show the sample maps of contents of soil organic matter by chemical analysis and sensor system, respectively.

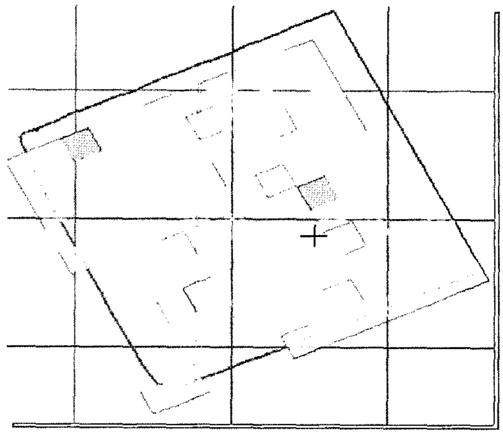

Fig. 9 Sample map of contents of soil organic matter obtained by chemical analysis.

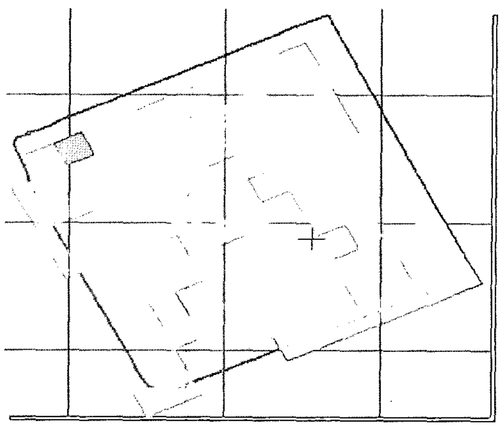

Fig. 10 Sample map of contents of soil organic matter obtained by grouping system for soil organic matter.

Conclusions

This study was conducted to develop a nondestructive grouping system for soil organic matter using visible and near infrared spectroscopic method. The reflectance energy from the cut soil surface was measured to group the soil organic matter using VIS/NIR light sensor with narrow band pass filter. The grouping system for soil organic matter consisted of light sensor with band pass filter measuring the reflectance energy of the cut soil surface, global positing system (GPS), analog-to-digital (AD) converter, computer and operating software. From field test, the accuracies of the developed light sensor system were 81.3% for five-stage grouping of the soil organic matters and 91.0% for three-stages grouping of the soil organic matters, respectively. The developed grouping system for soil organic matter could be possible to support the decision making for variable rate applications in precision agriculture.

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