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Development of a Real-time Grouping System of Rice Crop Canopy Chlorophyll Contents

J. H. Sung, I. G. Jung, C. K. Lee

Abstract: This study was carried out to develop a real-time grouping system of chlorophyll contents of rice crop canopy for precision agriculture. The system measured reflected light energy of a rice canopy on a paddy field from visual to near-infrared range and analyzed the collected information of chlorophyll contents of rice crop canopy with given position data. The four filters, 560 nm (±10 nm), 650 nm (±25 nm), 700 nm (±12 nm), and 850 nm (±40 nm), were used for a multiple regression to estimate the chlorophyll contents of rice crop canopy. Every 0.2 m^2 area of the open field was inspected at a distance of 1 m above the rice canopy. According to the results of verification test, the chlorophyll content grouping by a commerical chlorophyll meter (SPAD) and by the developed system showed 58.7% match for five-stage chlorophyll contents of rice crop canopy grouping and 93.5% for the five±1-stage grouping. In addition, the results showed 63.0% match for three-stage grouping and 100.0% for the three±1-stage grouping.

Keywords: Chlorophyll Contents, Grouping System, Precision Agriculture, Rice Canopy, Light Reflectance

Introduction

Fertilizer application is a very complex, intricate, and fastidious procedure where, farmers should judge and decide the vigor of crops based on leaf color observations. Field history, field conditions, weather conditions, species and other factors should be considered in determining crop growth. Knowledge of spatial variance of fertilizer application also leads to adjustment of fertilizer application.

When the size of the field becomes larger, mechanization should be considered. Environmental preservation also becomes important. Thus, precision agriculture becomes essential. In the site-specific application, application rate varies with sensor readings on the applicator. Map and sensor based approaches are the basic methods of implementing site-specific management (SSM) for the variable rate application of crop inputs (Bredemeier and Schmidhalter, 2003). SSM is a strategy that seeks to address within field variability and to optimize inputs such as pesticides and fertilizers on a point-by-point basis within a field (Sudduth et al., 1997).

Information on the growth distribution of plant in a field is necessary in precision agriculture. For the time efficient and labor-saving measurements, sensors are required to determine and to predict the plant mass and yields of crops on line. Determination of spatially variable plant mass is important in optimizing inputs of agro-chemicals, and in improving management and environmental protection (Ehlert et al., 2003).

One technique to observe the chlorophyll contents of rice crop canopy by non-contacting method is detecting the crop reflectance. The reflectance pattern of white light that was irradiated to crop canopy changes under surface texture, internal structure, and contents of biochemical matter of leaf. Therefore, from the analysis of reflectance pattern of white light, the biochemical matter can be determined quickly (Suh, 2000). Measurement of reflectance of canopy and/or plant leaves have shown the potential in predicting nutrient status in the field with a high degree of accuracy (Tumbo et al., 2002a).

For the last 30 years, researches in detecting crop condition have been widely and increasingly performed. The study of measuring chlorophyll fluorescence of a green leaf was performed (Kornet et al., 1992). Heege and Thiessen (2002) dealt with the reflectance and fluorescence for the control of nitrogen top dressing. They studied the effects of reflectance and nitrogen, fluorescence and nitrogen, and nitrogen and LAI (leaf area index) on chlorophyll respects. They reported the reflectance signals were better suited in sensing the nitrogen. The technique to observe the N (nitrogen)-status in wheat and maize for site-specific nitrogen fertilization was developed by Bredemeier and Schmidhalter (2003). They reported that the fluorescence ratio F690/F730 under field conditions was well inversely correlated with

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chlorophyll and N content as well as uptake dry biomass and SPAD (Minolta, Japan) value in both wheat and maize.

In addition, the chlorophyll sensitive spectra were well known (Anatoly and Merzlyak, 1996, Anatoly, 1996, 1998). A multi-spectral imaging sensor (MSIS) associated with a VRA (variable rate application) system was evaluated for the application of supplemental N (nitrogen) to corn crops based on real time N and chlorophyll estimates derived from the MSIS reflectance responses of crop canopies. This study reported that the MSIS based supplemental N treatment improved the crop N status and increased the yield in most plots (Kim et al., 2002). An on-the-go system for sensing chlorophyll status in corn using neural networks and fiber-optic spectrometry, which was used to acquire spectral response patterns (SRPs), was developed and tested. The neural network model showed good correlation between predicted SPAD chlorophyll readings based on statically acquired SRPs and actual chlorophyll readings (r^2=0.85) (Tumbo et al., 2002a, 2002b).

Most previous studies focused on corn or maize. The studies about paddy were performed by Sung et al. (1999, 2001, 2003), Okado and Nakamura (1993), and Okado et al. (1995, 1996). The variation of chlorophyll contents of rice crop canopy within paddy field for site-specific fertilized rice crop on Korean paddy fields was described by Sung et al. (1999, 2001, 2003). In this study, the variations of chlorophyll contents of rice crop canopy within leaf, stalk, and unit mesh were overlooked statistically. In addition, chlorophyll contents of rice crop canopy has a linear relationship with SPAD value in paddy. Okado and Nakamura (1993), and Okado et al. (1995, 1996) reported the possibility of real time detection of crop condition for paddy using crop reflectance.

This study was performed to develop the hardware and software of a grouping system of chlorophyll contents of rice crop canopy. The developed system measured and analyzed the light reflectance patterns of rice crop canopy on an open paddy field and predicted the chlorophyll content levels. The ultimate goal of this study is the grouping of rice crop canopy according to the chlorophyll contents which leads to the precision agriculture VRA.

Materials and Methods

1. Chlorophyll Sensitive Spectrum Selection

Although, the chlorophyll sensitive spectrum was generally known to be 680 nm, another spectrum (750 nm, 845 nm, 880 nm, or 940 nm etc.) was added to separate the influence of water and light in the open field. The chlorophyll sensitive spectrum was selected through the range from 400 nm to 1400 nm. Spectrum range was limited for the developed system to be used in the open field for real time grouping of chlorophyll contents of rice crop canopy. Thirteen kinds of spectra were selected from the results of reviewing previous studies; 450 nm (±10 nm), 550 nm (±10 nm), 560 nm (±10 nm), 650 nm (±25 nm), 650 nm (±40 nm), 660 nm (±11 nm), 680 nm (±11 nm), 700 nm (±12 nm), 850 nm (±25 nm), 850 nm (±40 nm), 950 nm (±11 nm), 1,280 nm (±12 nm) and 1,400 nm (±13.6 nm). The reflectance energy through narrow band-pass filters was investigated and compared to the value of SPAD 502 chlorophyll meter (Minolta Corporation, Japan) to select the chlorophyll sensitive spectrum. SPAD values were measured in the range of 650 nm and 940 nm wavelength using the following equation.

$$SPAD = K \log_{10}[(IRt/IRo)/(Rt/Ro)] \qquad (1)$$

Where, SPAD : chlorophyll level (SPAD) value,

K : constant (spectrum Technologies, Inc.),

IRt and IRo : light intensity transmitted with and without the leaf at 940 nm,

Rt and Ro : light intensity reflected by and without the leaf at 650 nm (Tumbo et al., 2002a).

2. Structure of Light Sensor

In this study, the system was designed to collect the reflected sun light energy from paddy canopy by compensating diffusion of light using a reference plate. In addition, the reflectance energy of paddy canopy was collected at above 1 m of the paddy. In this study, focusing lens, a narrow band pass filter, a filter holder, and two light sensors were assembled together in order. Schematic diagram of the light sensor is shown in Figure 1.

The light sensors, PBS-050-I and S-050-I (Electro Optical System Inc., USA), were used to collect and converted the reflectance energy to electric voltage in range of 0 to 10 volt. The PBS-050-I light sensor collected the reflectance

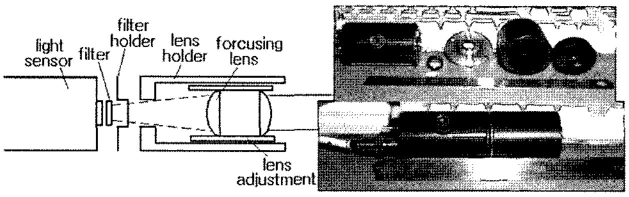

Fig. 1 Assemble of light sensor for measuring the reflectance of paddy canopy.

energy in spectrum range of 700 nm to 1,500 nm and the S-050-I light sensor collected the reflectance energy in spectrum range of 300 nm to 700 nm.

3. Multiple Regression Model

The reflected light energy of paddy canopy through thirteen kinds of spectra was compared to the chlorophyll contents of rice crop canopy measured with the SPAD. Principal component analysis was applied by SAS (ver. 8.01, SAS Institute Inc., NC) to select the sensitive spectrum for chlorophyll. Then, a multiple regression model was developed using selected spectra. The SYSTAT (ver. 8.0, Systat Software Inc., USA) was used to make the multiple regression model for 135 samples.

4. Construction of Chlorophyll Contents Grouping System

In order to select the sensitive spectrum for chlorophyll, experiments have been carried out with the thirteen kinds of spectra that were selected from results of previous surveys (Anatoly and Merzlyak, 1996, Heege and Thiessen, 2002, Okado et al., 1995, Sung et al., 1999 and Tumbo et al., 2002a). Light reflectance of about 0.2 m^2 area at a distance 1 m above paddy canopy was collected. Simultaneously, the light reflectance of reference plate (model : SRS-50-020, Labsphere Inc., USA) was collected to minimize light diffusion at the open field. Schematic diagram of the paddy chlorophyll contents of rice crop canopy grouping system was shown in Figure 2.

In addition, leaves of paddy were pushed aside for regular reflectance as shown in Figure 3. Data storing system and GPS data receiving system were mounted on the system. Signal flow diagram of the chlorophyll contents of rice crop canopy grouping system was shown in Figure 4.

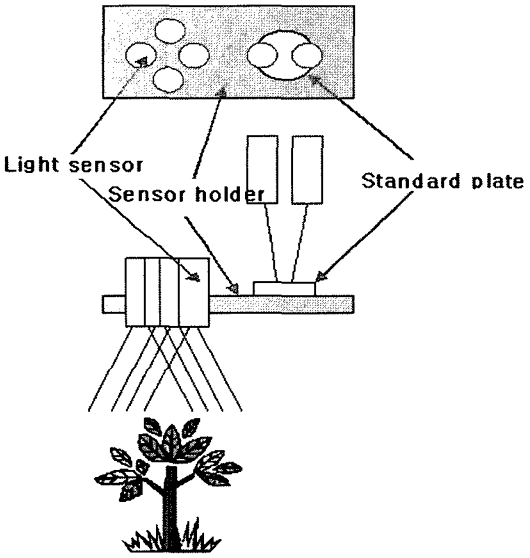

Fig. 2 Schematic diagram of the paddy chlorophyll contents of rice crop canopy grouping system.

Fig. 3 The leaves of paddy were pushed aside for regular reflectance.

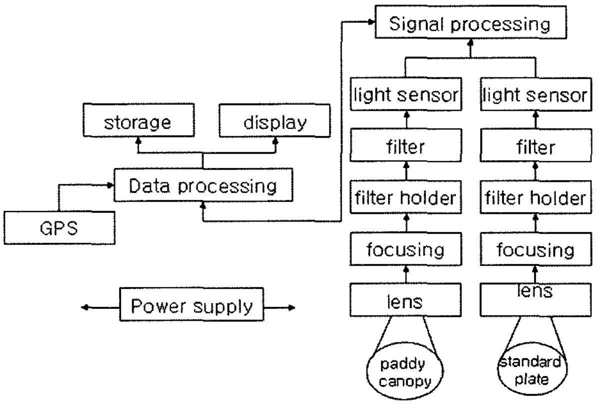

Fig. 4 Signal flow diagram of the chlorophyll contents of rice crop canopy grouping system.

5. Development of the Operation Software

The operation software was developed to measure and store the chlorophyll contents of rice crop canopy at each position that was determined using a GPS receiver within the field. The Visual C++ (Ver. 6.0, Microsoft, USA) was used to develop the operation software.

6. Verification Test

In order to verify the chlorophyll contents of rice crop canopy grouping system, 46 data were tested. The data collected from about 0.2 m^2 area at a distance of 1 m above the paddy canopy was compared to the value of SPAD that was averaged in 17 points value as shown in Figure 5.

In general, in VRA of precision agriculture, the appli-

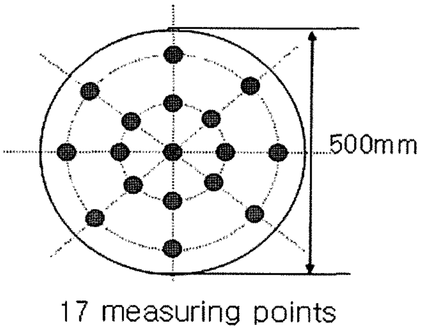

Fig. 5 Seventeen measuring points for the SPAD.

cation levels are divided into five or three stages (Okado et al., 1996). Five levels stand for, very high, high, normal, low, and very low amount of fertilizers. And three levels stand for, high, normal, and low amount of fertilizers. Thus, in this study, the value of predicted SPAD was grouped into five and three levels.

Results and Discussion

1. Principal Component Analysis an Multi-regression Equation

In the result of principal component analysis, eight filters were selected, 550 nm (±10 nm), 560 nm (±10 nm), 650 nm (±25 nm), 650 nm (±40 nm), 660 nm (±11 nm), 680 nm (±11 nm), 700 nm (±12 nm) and 850 nm (±40 nm). All narrow band pass filters, that were mounted on the chlorophyll grouping system, have their own bandwidth. Therefore, the selected eight filters could be summarized into four spectra, 560 nm (±10 nm), 650 nm (±25 nm), 700 nm (±12 nm), 850 nm (±40 nm) (Figure 6).

The multiple regression model for chlorophyll grouping, that was developed from comparison of reflected energy and SPAD value, is shown in eq. (2). The narrow band pass filters of 700 nm (±12 nm) and 650 nm (±25 nm) had main influence to the SPAD value. That was similar to well known chlorophyll sensitive spectrum, 680 nm. The narrow band pass filters of 850 nm (±40 nm) had minimum influence to the SPAD value. In addition, the standard plate was used to reduce diffusion of the open field light influenced to the SPAD value.

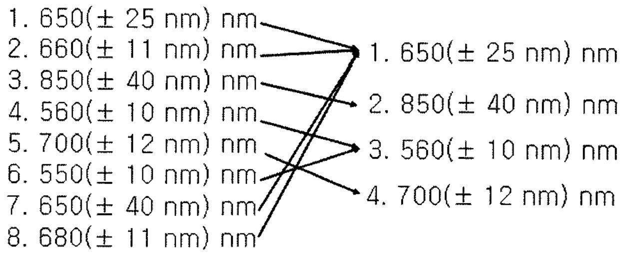

Fig. 6 Summarized four spectra used in chlorophyll grouping system.

$$\mathrm{SPAD} = 0.629\times R_{560}+0.906\times R_{650} + 2.878\times R_{700}-0.568\times R_{850} +0.238\times \mathrm{Ref.}+20.953 \qquad (2)$$

Where, SPAD : chlorophyll level (SPAD) value.

R_{560}, R_{650}, R_{700} and R_{850} = light reflected by 560 nm (±10 nm), 650 nm (±25 nm), 700 nm (±12 nm) and 850 nm (±40 nm), respectively.

Ref.= light reflected by a reference plate.

2. Construction of Chlorophyll Contents Grouping System and Performance Ttest

(1) Design Concept of System

As described in the materials and method, this system was designed to collect the paddy canopy reflected energy

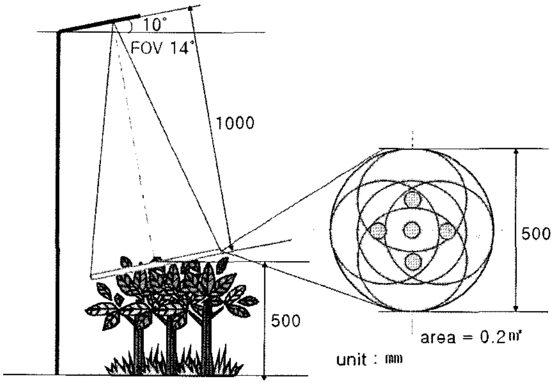

Fig. 7 Schematic diagram of the chlorophyll contents of rice crop canopy grouping system.

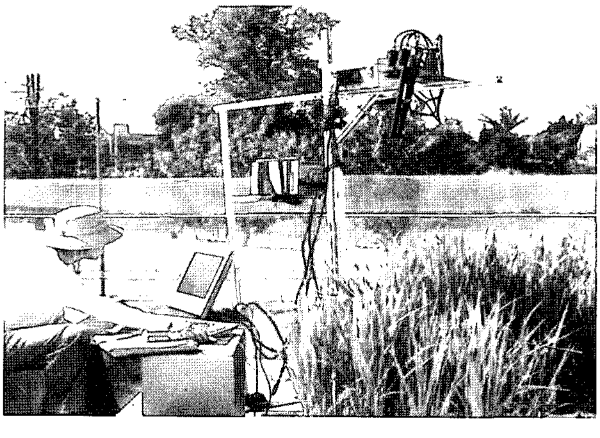

Fig. 8 Field test for verification of the chlorophyll contents of rice crop canopy grouping system.

by compensating diffusion of light using a reference plate. And approximate 0.2 m^2 of the open field was inspected at a distance of 1 meter above the rice canopy. The field of view was inclined about 14 degrees making 0.5 m diameter of reflected paddy crop area at a distance of 1 meter above. The reflectance collected at an angle of under 10 degrees was allowed by pushing aside of paddy crop as showed in Figure 7. In this concept, the chlorophyll contents of rice crop canopy grouping system was developed as shown in Figure 7 and Figure 8.

(2) Development of Operation Software

The operation software was developed to group and store the information of chlorophyll contents of rice crop canopy at each position that was determined using the GPS receiver within the field. The captured view of operating software is shown in Figure 9. It had some options for compensation classified by species, heading status, and growth stage in the future.

3. Results of Field Test

The field test was performed at 46 points of paddy crop to validate the performance of chlorophyll contents of rice crop canopy grouping system. The resulting data were shown graphically in Figure 10. Figure 10 illustrated the linear regression equations and the coefficient of determination for both values of SPAD and chlorophyll contents of rice crop canopy measured by the sensor.

In Figure 10, the range of vertical quadrangle included chlorophyll contents of rice crop canopy measured manually using SPAD, and the range of horizontal quadrangle included chlorophyll contents of rice crop canopy using the chlorophyll contents of rice crop canopy grouping system. In addition, the large circle that overlapped with the vertical and horizontal quadrangle contained correct measuring points. This implied the result of measurements made manually using SPAD and the sensor measurements were the same. The two small circles that didn't overlapped in the vertical and horizontal quadrangle contained false measuring points. This implied the result of measurements made using SPAD and sensor measurements were different. SPAD used just two spectra (650 nm and 940 nm).

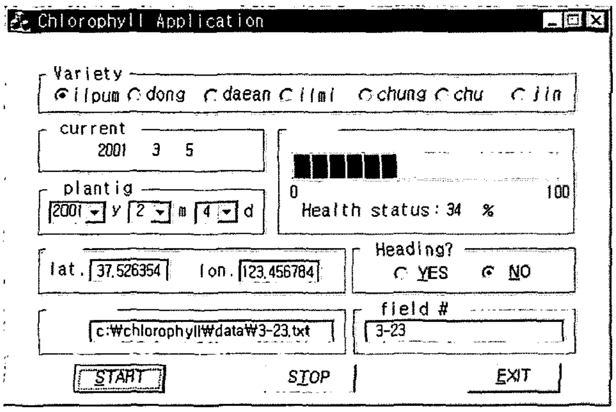

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Fig. 9 The operation software of the chlorophyll contents of rice crop canopy grouping system.

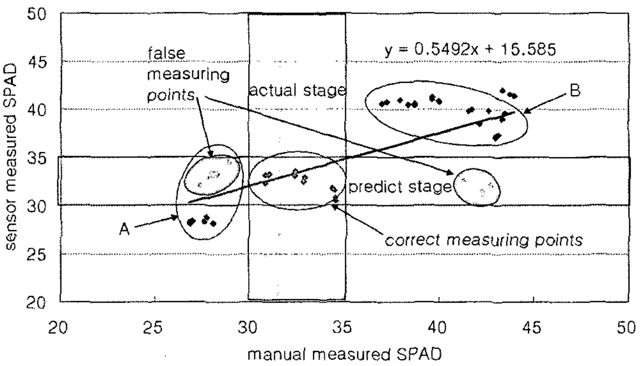

Fig. 10 Result of field test of the chlorophyll contents of rice crop canopy grouping system.

Region "A" in Figure 10 addressed that, the result of manual SPAD measurement could not separate the chlorophyll contents of rice crop canopy as opposed to the SPAD values via sensor that could be separated. It might occured because the resolution of SPAD or the variation within and/or between leaves were large. Region "B" in Figure 10 showed to the result of SPAD values via sensor could not be separated in the chlorophyll contents of rice crop canopy as manually measured SPAD separately. It might be due to narrow bandwidth of the band pass filters.

Table 1 and 2 showed the results of chlorophyll contents of rice crop canopy grouping. As shown in the tables the accuracies of grouping were 58.7% (27 points over 46 points) at five-stage grouping and 63.0% (29 points over 46 points) at three-stage grouping, respectively. In the five-stage grouping, the 3rd group showed 17% (3 points over 18 points) of SPAD values via sensor predicted one-stage below, 11% (2 points over 18 points) of SPAD values via sensor predicted one-stage over, and 17% (3 points over 18 points) of SPAD values via sensor predicted two-stage over. In the 4th group, 100% (5 points over 5 points) of SPAD values via sensor predicted one-stage over. In the 5th group, 55% (6 points over 11 points) of SPAD values via sensor predicted one-stage below. If ±1-stage (over 1-stage or below 1-stage) was allowed for VRA of precision agri-

Table 1 Coincidence summary matrix of the five-stages grouping of chlorophyll contents of rice crop canopy

Sensor measured / Manual reading	1st group (< 24)	2nd group (25 to 29)	3rd group (30 to 34)	4th group (35 to 39)	5th group (> 40)
1st group (< 24)	0	0	0	0	0
2nd group (25 to 29)	0	6	0	0	0
3rd group (30 to 34)	0	3	10	2	3
4th group (35 to 39)	0	0	0	0	5
5th group (> 40)	0	0	0	6	11

Gray cells are correct measuring points, where the result of manual reading and sensor measured are the same. The number of range indicates the value of SPAD.

Table 2 Coincidence summary matrix of the three-stages grouping of chlorophyll contents of rice crop canopy

Sensor measured / Manual reading	1st group (< 30)	2nd group (31 to 40)	3rd group (> 41)
1st group (< 30)	6	0	0
2nd group (31 to 40)	3	12	8
3rd group (> 41)	0	6	11

Gray cells are correct measuring points, the result of manual reading and sensor measured are the same. The number of range indicates the value of SPAD.

culture, the accuracy of five-stage grouping was reached at 95.3% (43 points over 46 points). Therefore, the results were feasible as acceptable level for real time chlorophyll contents of rice crop canopy grouping for precision VRA.

In the three-stage grouping, in the 1st group, 100% (6 points over 6 points) of SPAD values via sensor predicted as manual readings. In the 2nd group, 13% (3 points over 23 points) of SPAD values via sensor predicted one-stage below, and 35% (8 points over 23 points) of SPAD values via sensor predicted one-stage over. In the 3rd group, 35% (6 points over 17 points) of SPAD values via sensor predicted one-stage below. If ±1-stage (over 1-stage or below 1-stage) was allowed for VRA of precision agriculture, the accuracy of three-stage grouping was 100% (46 points over 46 points).

Conclusions

A grouping system of chlorophyll contents of rice crop canopy was developed to use in VRA precision agriculture. The developed system measured the reflected light energy of a rice canopy on the paddy field from visual to near-infrared range. Approximate 0.2 m^2 open field was inspected at a distance of 1 m above the rice canopy. The four filters, 560 nm (±10 nm), 650 nm (±25 nm), 700 nm (±12 nm) and 850 nm (±40 nm) were used in the multiple regression equation in grouping the chlorophyll contents of rice crop canopy. According to the results of validation test, the relationship between the results of ready-made chlorophyll meter (SPAD) and developed sensor showed 58.7% accuracy for five-stage chlorophyll contents of rice crop canopy grouping and 93.5% for the five ±1-stage grouping. In addition, the result showed 63.0% accuracy for the three-stage grouping and 100.0% for the three ±1-stage grouping. This system could be useful to support the decision making for the variable rate application in precision agriculture machinery.

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