Estimation of soil colour from visible reflectance spectra

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Abstract
A method for measuring soil colour using visible reflectance spectra (400-700 nm) was tested. 25 air-dry soil samples with a wide range of colour were used in this study. The visible reflectance of the soil samples was measured by using a Cary 500 ultraviolet, visible and near-infrared diffuse reflectance spectrophotometer. The Munsell Conversion program (Version 6.41, 2004) was used to convert blue (450-515 nm), green (525-605 nm) and red (630-690 nm) colour components of the visible reflectance spectra into Munsell colour notations i.e. hue, value and chroma. Visual measurements of soil colour were done by five independent observers using Munsell soil colour charts. Variations in visual colour measurements among different observers were of significant magnitude to cause serious errors in the application of soil colour criteria outlined in the Australian Soil Classification System (Isbell, 1996). Soil colour measured by the spectroscopic method was compared with the visually measured soil colour. The three Munsell parameters measured by the two methods (visual and spectroscopic) were significantly correlated (r^2>0.84). The results of this study suggest that a more accurate colour measurement can be achieved from visible reflectance spectra in the laboratory. More research is suggested for the development of a field method of estimating soil colour by using the portable infrared spectrophotometer.

Key Words
Munsell colour chart, spectrophotometer, visible reflectance spectra.

Introduction
Although the visible spectrum (VIS, 400-700 nm) forms a small portion of the electromagnetic spectrum, it has obvious significance for soil classification. Soil visible reflectance, or colour, is a differentiating characteristic for many soil classes in all modern classification systems and it is an essential part of the definitions for both surface and subsurface diagnostic horizons (Baumgardner *et al.* 1985). Obukhov and Orlov (1964) reported that soils with an elevated content of iron could be easily distinguished by the inflection characteristic for pure iron oxides. They found the intensity of the reflection in the region from 500 nm to 640 nm to be inversely proportional to the iron content in soil. Krishnan *et al.* (1980) found that the VIS wavelength region (623.6 nm and 564.4 nm) provided a better prediction for soil organic matter level than the infrared wavelength region. Despite its pedological significance, precise methods to measure soil colour and soil reflectance properties, especially under field conditions, have not been widely adopted (Post *et al.* 1993). Nagano and Nakashima (1989) also shows relationship between colour and concentration of different iron oxides such as hematite and goethite.

The normal method of measuring soil colour requires visual matching of a sample with standard colour chips for example Munsell Colour (1994). This method is at best semi quantitative, because it is limited by a subjective match and by the number of Munsell colour chips (Baumgardner *et al.* 1985). Shields *et al.* (1966) found that 12 experienced observers agreed on the Munsell value of samples within a range of between 0.5 and 0.2 units. Post *et al.* (1993) found that soil scientists agreed only 52% of the time on the same colour chip for all three colour components. Such variability may result in serious error in the application of soil colour criteria in soil classification (Shields *et al.* 1966). Precise soil colour measurement that is independent of the observer's vision may be obtained from spectroscopic reflectance measurements. Fernandez and Schulze (1987) suggested more accurate and precise measurements of soil colour to develop relationships between colour and the kind and amount of organic matter or Fe oxide minerals present in soil. We conducted this study to assess the magnitude of the variability of soil colour measurement among different observers and to develop a spectroscopic reflectance technique to measure soil colour from visible reflectance spectra.

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Materials and methods

Soil sampling

25 soil samples were sampled from southwest of Western Australia representing various agricultural regions of the state (Singh 1991). The sample set included 11 surface (0-30 cm) and 14 subsurface (30-65 cm) soil samples from Dandaragan, Wungong, Pinjarra, Narrogin, Jerramungup, Bridgetown, Pemberton, Coolie and Merredin regions. The samples represented a wide range of soil colour.

Visual measurement of soil colour

The colour of 25 air-dried soil samples was independently measured in the laboratory under controlled lighting conditions (40-watt fluorescent tubes) by five observers using Munsell soil colour charts (Munsell Colour 1994). The observers were pedologists and students, all of whom were familiar with, and had previously used the Munsell method. In the Munsell system, colour space is conceptualized as a cylinder where the perceptual attributes colour lightness (Munsell value, V) and saturation (Munsell chroma, C) are represented as linear coordinates, while the third dimension (Munsell hue, H) is represented as a polar coordinate (Barrett 2002). Figure 1 represents Munsell colour spacing.

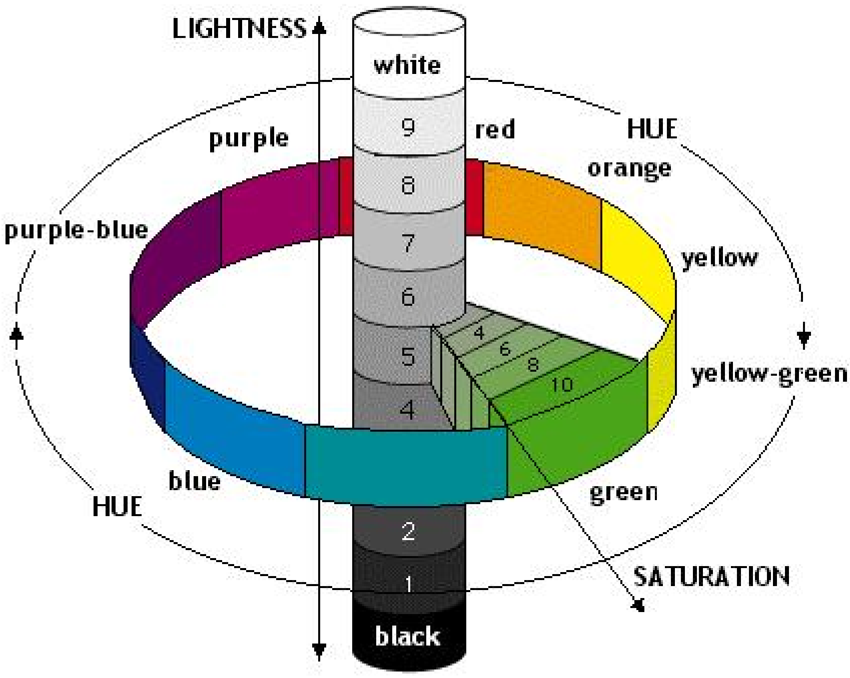

Figure 1. Munsell's cylindrical arrangement of colours. The horizontal line represents chroma (saturation), the vertical line represents value (lightness) and the circle represents hue (home.wanadoo.nl/paulschils/04.03.html).

Spectroscopic reflectance measurement of soil colour

A Cary-500 UV-VIS-NIR spectrophotometer equipped with a diffuse reflectance accessory (Labsphere DRA-CA-50D) was used to measure visible reflectance spectra. For each sample, approximately 20 g of air-dried soil was placed into a sample holder with a quartz window. A standard sample supplied by the instrument manufacturer was used as a reference material for baseline correction. The visible (400-700 nm) reflectance spectra were measured at 1.1 nm intervals and it required approximately 30 seconds to scan one sample. Munsell Conversion program, version 6.41 (Munsell Conversion 2004) was used to convert blue (450-515 nm), green (525-605 nm) and red (630-690 nm) portions of the visible spectra into Munsell notations (hue, value and chroma). Figure 2 represents the visible spectra of 15 soil samples and Figure 3 represents various steps used to convert soil colour measured in the visible reflectance spectra to Munsell colour notations.

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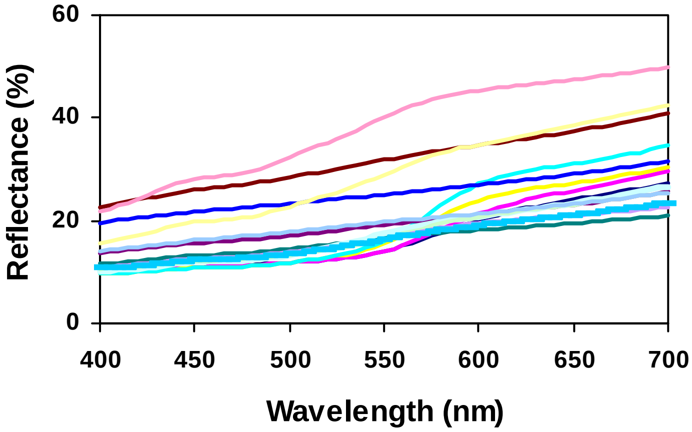

Figure 2. VIS (400-700 nm) spectra for 15 soil samples illustrating variations in their reflectance.

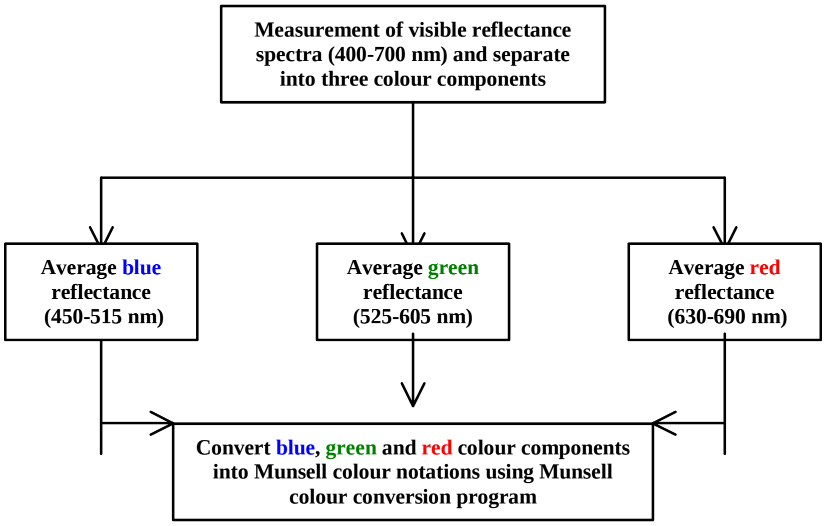

Figure 3. A summary of various steps required for spectroscopic measurement of soil colour from VIS spectra.

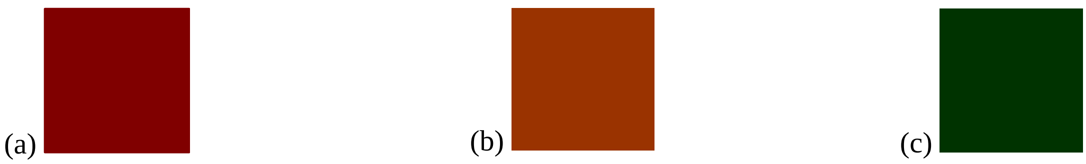

Figure 4. Some examples of Munsell colour chips; (a) 7.5 R 3/6, (b) 10 R 4/6 and (c) 5G 3/2 respectively (Munsell Colour 1994).

Results

Variability of visual colour measurement

The Munsell colour terms conventionally are expressed in the following sequence: hue, value/chroma. A number and one or two capital letters represent Hue (e.g. 10 YR, 5 Y etc). Value and chroma are each represented by a number (e.g. 5/6, 7/8 etc.). Figure 4 represents some Munsell colour chips. For statistical analysis involving Munsell measurements (whether visual or spectroscopic), Munsell hue (H) is converted into a numerical value (hue number) following the method of Hurst (1977). In this system, hue 10 R is numbered 10, 5 YR becomes 15, 10 YR becomes 20, and 10Y becomes 30. Visual estimation of hue by 5 observers showed a variation of from 0 to 10.5 units with an average of 3.6 units. The standard deviations of the hue ranged from 0 to 4.1, the average of which was 1.8 units (Table 1). Visual estimations of Munsell value (V) by five observers for the 25 samples showed a variation between 0 and 3.0 units, the average variation was 1.2 units. The standard deviations of the value ranged from 0 to 1.1, the average of which was 0.5 units. The variation of the chroma (C) as determined by 5 observers was higher than variation found in Munsell values (V), ranging from 0 to 5.0 units with an average of 2.0 units. The standard deviations of chroma recorded ranged from 0 to 1.8 with an average of 1.1 units.

Table 1. Statistical summary of the Munsell colour notations determined by five individual observers for 25 soil samples.

Sample	Hue Number				Value				Chroma			
	Range	Max.-Min.	Mean	s.d.	Range	Max.-Min.	Mean	s.d.	Range	Max.-Min.	Mean	s.d.
1	15.0-20.0	5.0	16.0	2.2	3.0-5.0	2.0	3.6	0.9	4.0-6.0	2.0	4.8	1.1
2	12.5-12.5	0.0	12.5	0.0	3.0-4.0	1.0	3.8	0.4	4.0-6.0	2.0	4.8	1.1
3	17.5-20.0	2.5	19.0	1.4	3.0-5.0	2.0	4.0	0.7	1.0-3.0	2.0	1.8	0.8
4	12.5-20.0	7.5	18.0	3.3	6.0-7.0	1.0	6.2	0.4	1.0-1.0	0.0	1.0	0.0
5	20.0-20.0	0.0	20.0	0.0	3.0-4.0	1.0	3.8	0.4	3.0-4.0	1.0	3.6	0.5
6	17.5-20.0	2.5	19.5	1.1	3.0-4.0	1.0	3.8	0.4	3.0-4.0	1.0	3.8	2.2
7	20.0-20.0	0.0	20.0	0.0	6.0-6.0	0.0	6.0	0.0	3.0-6.0	3.0	4.2	3.1
8	17.5-17.5	0.0	17.5	0.0	4.0-5.0	1.0	4.2	0.4	3.0-6.0	3.0	3.0	1.4
9	17.5-20.0	2.5	19.0	1.4	4.0-5.0	1.0	4.6	0.5	2.0-6.0	4.0	5.2	1.8
10	15.0-20.0	5.0	19.0	2.5	5.0-6.0	1.0	5.0	0.7	1.0-3.0	2.0	1.8	0.8
11	12.5-22.5	10.5	19.0	4.1	5.0-7.0	2.0	6.0	0.7	1.0-1.0	0.0	1.0	0.0
12	15.0-20.0	5.0	18.0	2.7	3.0-4.0	1.0	3.6	0.5	2.0-4.0	2.0	3.6	0.9
13	15.0-20.0	5.0	18.5	2.2	3.0-4.0	1.0	3.8	0.4	3.0-4.0	1.0	3.4	0.5
14	17.5-22.5	5.0	20.0	3.8	7.0-8.0	1.0	7.2	0.4	2.0-4.0	2.0	3.0	0.7
15	17.5-22.5	5.0	20.0	3.8	5.0-6.0	1.0	5.8	0.4	2.0-3.0	1.0	2.4	0.5
16	15.0-17.5	2.5	16.0	1.4	5.0-7.0	2.0	4.6	0.8	6.0-6.0	0.0	6.4	0.9
17	12.5-17.5	5.0	15.0	1.8	4.0-5.0	1.0	4.2	0.4	6.0-8.0	2.0	6.8	1.1
18	15.0-17.5	2.5	15.5	2.1	4.0-5.0	1.0	4.2	0.4	4.0-6.0	2.0	5.6	0.9
19	15.0-17.5	2.5	16.0	1.4	4.0-5.0	1.0	4.6	0.5	6.0-8.0	2.0	6.4	0.9
20	15.0-17.5	2.5	17.0	1.1	5.0-6.0	1.0	5.4	0.5	6.0-8.0	2.0	7.6	0.9
21	12.5-20.0	7.5	17.0	2.7	4.0-6.0	2.0	4.4	0.9	3.0-8.0	5.0	5.4	1.9
22	17.5-20.0	2.5	19.5	1.1	6.0-7.0	1.0	6.2	0.4	4.0-8.0	4.0	6.0	1.4
23	15.0-20.0	5.0	18.5	2.2	4.0-5.0	1.0	4.6	0.5	4.0-6.0	2.0	4.4	0.9
24	15.0-17.5	2.5	17.0	1.1	5.0-6.0	1.0	52.	0.8	4.0-8.0	4.0	5.6	1.7
25	17.5-20.0	2.5	19.5	1.1	4.0-7.0	3.0	5.6	1.1	4.0-6.0	2.0	4.4	0.9
Average		3.6		1.8		1.2		0.5		2.0		1.1

s.d., standard deviation; Max., maximum; Min., minimum

Comparison of visual and spectroscopic soil colour measurements

To compare visual hue, mean hue numbers of five observations were converted to hue notation (Hurst 1977). The comparison of the results of visual and spectroscopic reflectance methods of soil colour measurements indicated that the mean difference between the hue, value and chroma is 0.6, 2.2 and 1.4 unit, respectively (Table 2). The relationship between visual measurement (mean of five individual observations) and spectroscopic reflectance measurement is presented in Figure 5. The Munsell hue, value and chroma for visual and spectroscopic measurement were significantly correlated ($r^2 > 0.84$) (Figure 5). The small divergence between visual and spectrophotometer measurements of Munsell hue could be attributed to methodological difference in precision level. When visual estimates were made to the nearest chip, colour in the hue intermediate between hue pages were rounded to 2.5 hue units, but with the spectrophotometer hues were determined to a precision of 0.1 Munsell hue unit. Visual estimates of Munsell value and chroma were over estimated compared with the corresponding spectrophotometer measurements. For example, visual estimates of high Munsell value (V=5 or 6) most often corresponded to spectrophotometer Munsell value between 2.9 and 3.6 (Table 2). The reason may be explained from the preference on the part of the human observer for the extreme numbers (Barrett 2002) as well as lighting conditions in the lab etc.

Table 2. Comparison of Munsell colour notations (hue, hue number, value and chroma) of 25 soil samples as measured by visual (mean of five independent observers) and the spectroscopic method.

Sample	Visual soil colour				Spectroscopic soil colour				Maximum-minimum		
	H	H number	V	C	H	H number	V	C	H number	V	C
1	6.0 YR	16.0	3.6	4.8	5.8 YR	15.8	1.7	2.9	0.2	1.9	1.9
2	2.5 YR	12.5	3.8	4.8	5.1 YR	15.1	1.8	3.4	2.6	2.0	1.4
3	9.0 YR	19.0	4.0	1.8	8.8 YR	18.8	2.0	1.5	0.2	2.0	0.3
4	8.0 YR	18.0	6.2	1.0	7.8 YR	17.8	2.7	1.2	0.2	3.5	0.2
5	10.0 YR	20.0	3.8	3.6	9.6 YR	19.6	1.8	2.0	0.4	2.0	1.6
6	9.5 YR	19.5	3.8	3.8	9.3 YR	19.3	1.8	2.2	0.2	2.0	1.6
7	10.0 YR	20.0	6.0	4.2	9.7 YR	19.7	3.4	3.1	0.3	2.6	1.1
8	7.5 YR	17.5	4.2	3.0	7.4 YR	17.4	2.3	3.3	0.2	1.9	0.3
9	9.5 YR	19.0	4.6	5.2	9.3 YR	19.3	2.5	3.8	0.3	2.1	1.4
10	9.5 YR	19.0	5.0	1.8	9.1 YR	19.1	2.9	1.7	0.1	2.1	0.1
11	9.5 YR	19.0	6.0	1.0	9.7 YR	19.7	3.2	1.5	0.7	2.8	0.5
12	8.0 YR	18.0	3.6	3.6	8.6 YR	18.6	1.6	1.9	0.6	2.0	1.7
13	8.5 YR	18.5	3.8	3.4	8.6 YR	17.5	2.3	2.8	1.0	1.5	0.6
14	10.0 YR	20.0	7.2	3.0	9.4 YR	19.4	4.4	3.0	0.6	2.8	0.0
15	10.0 YR	20.0	5.8	2.4	9.8 YR	19.4	3.2	1.7	0.6	2.6	0.7
16	6.0 YR	16.0	4.6	6.4	5.5 YR	15.5	3.1	4.9	0.5	1.5	1.5
17	5.0 YR	15.0	4.2	6.8	6.8 YR	16.8	2.1	3.5	1.8	2.1	3.3
18	5.0 YR	15.5	4.2	5.6	6.5 YR	16.5	2.1	3.7	1.5	2.1	1.9
19	6.0 YR	16.0	4.6	6.4	7.0 YR	17.0	2.3	3.7	1.0	2.3	2.7
20	7.0 YR	17.0	5.4	7.6	7.6 YR	17.6	3.1	4.8	0.6	2.3	2.8
21	7.0 YR	17.0	4.4	5.4	7.4 YR	17.4	2.2	3.2	0.4	2.2	2.2
22	9.5 YR	19.5	6.2	6.0	9.0 YR	19.0	3.6	3.7	0.5	2.6	2.3
23	8.5 YR	18.5	4.6	4.4	7.5 YR	17.5	2.6	3.3	1.0	2.0	1.1
24	7.0 YR	17.0	5.2	5.6	6.9 YR	16.9	3.3	4.0	0.1	1.9	1.6
25	9.5 YR	19.5	5.6	4.4	9.8 YR	19.8	3.5	3.1	0.3	2.1	1.3
Average									0.6	2.2	1.4

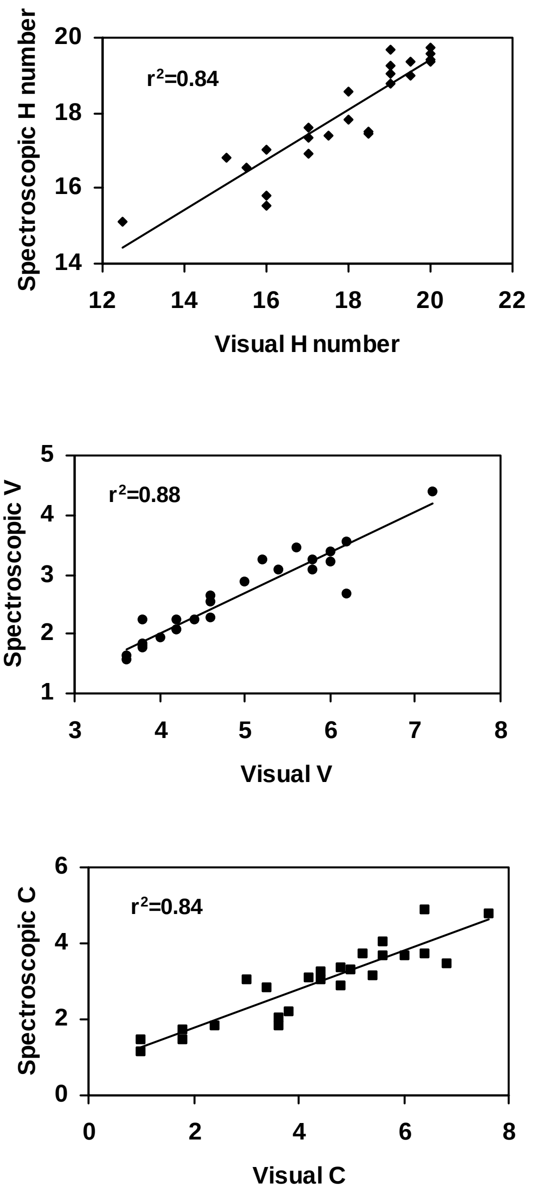

Figure 5. Relationships between visual and spectroscopic measurements of Munsell hue (H) number, value (V) and chroma (C) for 25 soil samples.

Discussion and conclusions

The suborders of Chromosol, Dermosol, Ferrosol, Kandosol, Kurosol and Sodosol in the Australian Soil Classification System (Isbell 1996) are identified based on soil colour of the B2 horizons. Most Vertosol suborders are based on the colour of the upper 50 cm of the solum. The recorded variations in the visual estimation of soil colour by different individuals indicate that serious errors may result in the application of soil colour criteria currently used in the Australian Classification System and several other soil classification systems around the world. The errors are of sufficient magnitude to change the soil classification of a particular soil. The present study has shown that if soil colour is to continue to play a definitive role in soil classification, it is important that a more precise method of colour measurement to be used. Recent investigations into the measurement of soil colour have shown that the instrumental nature of the spectroscopic method is not subject to errors caused by sensory and psychological peculiarities among different observers (Barrett 2002). Moreover the spectroscopic reflectance technique facilitates the measurement of soil colour with a precision of 0.1 unit for Munsell notations hue, value and chroma.

The results of this study indicate that Munsell notations of hue, value and chroma measured from spectroscopy measurements are significantly correlated (r^2>0.84) to the average (five individual observations) of the visually measured Munsell notations, which substantiates the adaptability of the instrumental method for the measurement of soil colour. The accuracy and precision of the spectroscopic reflectance technique may make it possible to use these data in a number of ways for the characterization of the colour attributes to identification of soil horizons. From this study it may be concluded that visible reflectance spectra of a UV-VIS-NIR diffuse reflectance spectrophotometer can be used to make reliable measurements of soil colour in the laboratory. More research is suggested for the development of a field method of estimating soil colour by using a portable infrared spectrophotometer.

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