0038-075X/83/1366-0354$02.00/0
SOIL SCIENCE

December 1983
Vol. 136, No. 6
Printed in U.S.A.

QUANTITATIVE RELATIONSHIPS BETWEEN SOIL COLOR AND HEMATITE CONTENT

J. TORRENT

Departamento de Edafología, Escuela Técnica Superior de Ingenieros Agrónomos, Apdo. 3048, Córdoba, Spain

U. SCHWERTMANN AND H. FECHTER

Lehrstuhl für Bodenkunde, Technische Universität München, D-8050 Freising-Weihenstephan, Federal Republic of Germany

F. ALFEREZ

Departamento de Edafología, Escuela Técnica Superior de Ingenieros Agrónomos, Apdo. 3048, Córdoba, Spain

Received for publication 26 April 1982; revised 20 September 1982

ABSTRACT

We determined that the degree of redness of soils from Europe and Brazil, as given by redness ratings based on visual or spectrophotometric color measurements, was highly correlated with hematite content.

For the European soils (mostly Alfisols) the pigmenting power of hematite was higher than for Brazilian soils (Oxisols and Ultisols). This suggests that, for predictive purposes, different calibration lines should be used for different groups of soils. In spite of this general limitation, color appears to be a useful tool to predict approximately the hematite content of soils.

INTRODUCTION

The secondary Fe oxides are the most important pigmenting agents in soils having a low content of organic matter. Goethite (yellowish brown) and hematite (red) are very common in soils, whereas ferrihydrite (reddish brown), lepidocrocite (orange), and maghemite (reddish brown) are less abundant.

Soils containing only, or almost exclusively, goethite have yellowish brown colors (10YR to 2.5Y Munsell hue; Munsell Color Co. 1975), but when hematite is present colors usually become reddish (7.5YR and redder) (Schwertmann and Lentze 1966; Davey et al. 1975; Bigham et al. 1978; Childs et al. 1979), because the red color of hematite is very effective in masking the yellow color of goethite. Scheffer et al. (1958) stated that only 1.7% hematite could give a soil a red color, and Resende (1976) reported that the Munsell hue of a yellow Oxisol was altered from 10YR to 5YR when 1% fine hematite was added. Childs et al. (1979) found that reddening occurs even when the hematite-Fe:dithionite-Fe ratio is as low as 0.3. We have found that the addition of only 1% hematite to a mixture containing kaolinite, silt-sized quartz, biotite, K-feldspar, and 3% goethite causes a shift in Munsell hue from 2Y to 5YR.

In view of the pigmenting power of hematite, it is not surprising that numerical color indexes based on the Munsell notation, such as Munsell hue (H), Munsell hue × value ($H \times V$), or Munsell hue × value / chroma ($H \times V/C$), are more correlated with the hematite content of soils (Childs et al. 1979; Torrent et al. 1980) than with either the hematite:goethite ratio (Taylor and Graley 1967; Bigham et al. 1978) or the total Fe oxide content (Soileau and McCracken 1967; Hurst 1977).

The objective of this work is to find out whether there is a quantitative relationship between redness and hematite content in soils containing hematite and goethite and having a wide range of morphological and mineralogical characteristics.

MATERIALS AND METHODS

Soil Samples

Soils included in this study were Alfisols, Inceptisols, Ultisols, and Oxisols from Spain, Portugal, France, Germany, and Brazil. Samples were usually taken from their B horizons, although some A horizons low in organic matter were also included. The soils were described elsewhere (Torrent et al. 1980; Kämpf 1981; Schwertmann et al. 1982).

Mineralogical analyses

The hematite and goethite concentrations were obtained either from conventional x-ray diffraction after concentrating the Fe oxides by a boiling NaOH treatment (Norrish and Taylor 1961; Kämpf and Schwertmann 1982*a*) or by using differential x-ray diffraction (DXRD) on the untreated clay fraction (Schulze 1981). Details of the XRD procedure are given by Torrent et al. (1980) and by Kämpf and Schwertmann (1982*b*).

Color measurement

The color of soils was measured on samples that were ground to pass a 50-μm sieve, and the color of the clays on the gently crushed lyophilized samples.

Two different spectrophotometers were available for color measurements. For a Bausch & Lomb Spectronic 20 equipped with a reflectance attachment, the samples (soils from Europe) were placed in cylindrical Perspex holders (12 mm in diameter) with a thin cover glass at their bottom and then gently pressed against this cover glass. The reflectance measurements were converted to tristimulus values (X, Y, Z) by the weighed-ordinate method and also, when needed, to the Munsell renotation hue, value, and chroma using the methods described by Wyszecki and Styles (1967). For an ELREPHO apparatus 3 g of the gently crushed sample (soils from Brazil) was pressed into a tablet 45 mm in diameter and about 1 mm thick before automatic measurement of X, Y, and Z.

For the visual color measurement of dry soil or clay, samples from Europe were placed in aluminum frames and then pressed against a filter paper to obtain flat surfaces that were then compared with the chips of the Munsell Color Charts. Color measurements were performed by six individual observers who had used the charts before. Prior to the calculation of the mean of the six observations, extraneous values were rejected using the method of Dixon (1965). All comparisons were done in a chamber with controlled light conditions. Illuminant D50 (daylight) was used, and the geometrical conditions were those indicated by Hunter (1975).

Redness ratings

Munsell color was converted to the redness rating (RR) suggested by Torrent et al. (1980), according to the following expression

$$RR = \frac{(10 - H) \times C}{V} \tag{1}$$

where C and V are the numerical values of the Munsell chroma and value, respectively, and H is the figure preceding YR in the Munsell hue, so that for 10YR H is 10 and for 10R H is 0. This RR is similar to that of Hurst (1977), but provides a better discrimination between yellowish brown and red colors.

A second redness rating (henceforth RI) was used. It is defined as follows

$$RI = \frac{(x - 0.35)^2}{(y - 0.35)Y} \tag{2}$$

where x and y are the chromaticity coordinates, and Y is the luminosity based on the CIE (Commission Internationale de l'Eclairage) 1931 Standard Observer using Illuminant C. The 0.35 values subtracted from x and y are the values x, y of the Munsell color 10YR 7/2.3 (very pale brown), which can be considered as typical of a hematite-free, reference soil. The rationale for using this RI is as follows: (1) this RI is easily computed from the x, y, and Y values given by the spectrophotometers, and (2) it is almost linearly correlated with hematite content for artificial mixtures of hematite with other soil minerals, at least to about 10% hematite (Fig.

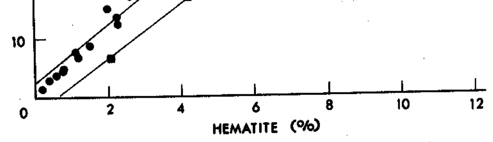

FIG. 1. Relationship between RI and hematite content for two types of artificial mixtures. The first type (■) had bentonite, 5.3% of synthetic goethite, and various amounts of hematite (synthetic). The second (●) had silt-sized quartz (40%), feldspar (25%), biotite (25%), 0.4 to 10% synthetic goethite, and various amounts of hematite (synthetic).

1). In contrast, the *RR* defined above is linearly related to hematite content only to about 4% hematite and then quickly follows a parabolic increase (not shown).

RESULTS AND DISCUSSION

Comparison between visual and spectrophotometric measurements

Table 1 gives the extreme and mean values of the standard deviation for Munsell hue, value, and chroma of the visual (six observers) and spectrophotometric (Spectronic 20) measurements and shows that the precision of the spectrophotometric method is higher than that of the visual. For both spectrophotometric and visual measurements, the coefficient of variation in a sample was found to be usually less than 5% in terms of the *RR* or *RI* defined above.

The agreement between visual measurements (six observers) and spectrophotometric measurements of soil through glass was good. Comparison between the two sets of measurements showed that: (1) visual hues were usually redder than the spectrophotometric ones by an average of 0.5 units; (2) visual values were higher by about 0.3 units; and (3) visual chromas were about 10% higher than the spectrophotometric ones. Some of these differences were similar to those found by Shields et al. (1968) when measuring color through thin cover glasses. We found that these differences were similar to the differences between the theoretical and the measured (through glass) Munsell color of the Munsell chips.

The *RI* values obtained from the measurements with the ELREPHO instrument were systematically higher than those obtained with the Spectronic 20, but they were highly correlated (*RI* for ELREPHO = 1.64 × *RI* for Spectronic 20 = 12; $r = 0.973$, significant at the 0.1% level). For all the relationships reported below the ELREPHO *RI* values were converted to the equivalent Spectronic 20 *RI* values using the regression equation given above (so as to have results that would allow us to compare different soils).

Relationships between redness and hematite concentration

Redness ratings, *RR* and *RI*, were found to be correlated in all cases with the percentage of hematite in soil. For the 66 European soils, both the linear correlation between *RI* and hematite content (Fig. 2) and between *RR* and hematite content (Fig. 3) gave similar correlation coeffi-

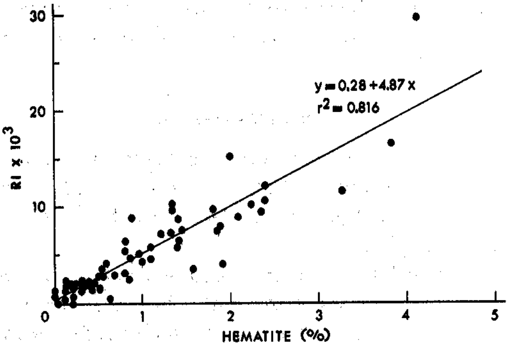

FIG. 2. Correlation between *RI* and hematite content in soils from Europe. A linear least-square fit is shown.

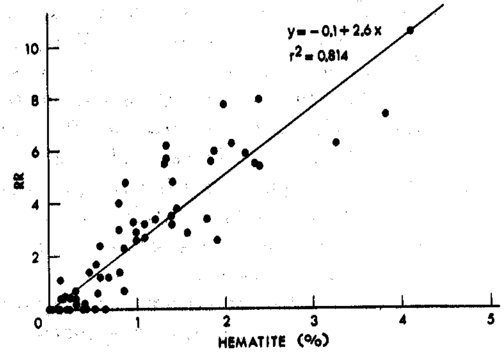

FIG. 3. Correlation between *RR* and hematite content in soils from Europe. A linear fit is shown. The *RR* were determined visually (six observers).

TABLE 1

Standard deviations for the Munsell hue, value, and chroma in visual measurements (100 samples, 6 observers) and spectrophotometric measurements (15 samples, 5 observations) using a Spectronic 20

Standard deviation	Munsell notation (visual)			Munsell notation (spectrophotometric)		
	Hue	Value	Chroma	Hue	Value	Chroma
Extreme values	0–1.3	0–0.5	0.1–1	0–0.4	0–0.4	0–0.2
Mean values	0.5	0.2	0.4	0.2	0.1	0.1

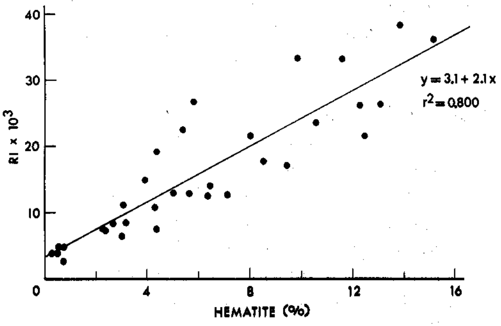

FIG. 4. Correlation between *RI* and hematite content for the Brazil soils. A linear fit is shown.

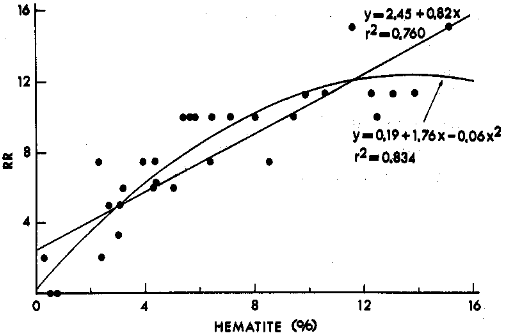

FIG. 5. Correlation between *RR* and hematite content for the Brazil soils. Linear and parabolic fits are shown. The *RR* were determined visually.

cients (r = 0.903 and r = 0.902, respectively), and a parabolic fitting did not improve the r^2 values substantially.

For the 33 soils of Brazil a satisfactory liner correlation existed between *RI* and hematite content (Fig. 4), whereas the relationship between *RR* and hematite content was slightly better described by a parabolic curve (Fig. 5). This means a redness "saturation" as the hematite content increases above about 5%. This lack of linearity is also observed in artificial mixtures, as previously mentioned. In consequence, *RI* seems to be a more useful tool than *RR* to predict hematite content.

Most of the soils contain less than 10% hematite. For those soils with more than 10%, it may be useful to dilute the sample, for *RI* also appears to begin to "saturate" above this value (Fig. 1). Dilution can be accomplished using a standard dilutant, such as quartz, kaolinite, or bentonite. Experiments using silt-sized (2 to 50 μm) quartz as dilutant show that a linear correlation is obtained between *RI* and hematite content for the diluted samples. Quartz can then be used as a standard dilutant.

Comparing Fig. 2 with Fig. 4 shows that the reddening effect of hematite is about two times higher in the moderately weathered European soils (mostly Alfisols) than in the more weathered soils from Brazil (Oxisols and Ultisols) (Kämpf 1981). This shows that, in practice, the prediction of hematite content from color is better when based on data from soils having similar characteristics to those of the soil being studied. In spite of this limitation, our results show that color can be used as a useful tool to predict hematite content in soils.

ACKNOWLEDGMENTS

Two of us, Torrent and Alferez, gratefully acknowledge the Comisión Asesora de Investigación Científica y Técnica of Spain for its financial support. The Institut für Bodenkunde, Technische Universität München wants to thank Bayer A.G., Leverküsen, for supplying the ELREPHO instrument.

REFERENCES

Bigham, J. M., D. C. Golden, S. W. Buol, S. B. Weed, and L. H. Bowen. 1978. Iron oxide mineralogy of well-drained Ultisols and Oxisols: 2. Influence on color, surface area, and phosphate retention. Soil Sci. Soc. Am. J. 42:825–830.

Childs, C. W., B. A. Goodman, and G. J. Churchman. 1979. Application of Mössbauer spectroscopy to the study of iron oxides in some red and yellow/brown soil samples for New Zealand. *In* International clay conference 1978. M. M. Mortland, and V. C. Farmer (eds.). Elsevier, Amsterdam, pp. 555–565.

Davey, B. G., J. D. Russell, and M. J. Wilson. 1975. Iron oxide and clay minerals and their relation to colors of red and yellow podzolic soils near Sidney, Australia. Geoderma 14:125–138.

Dixon, W. J. 1965. Extraneous values. *In* Methods of soil analysis, pt. 1. C. A. Black (ed.). American Society of Agronomy, Madison, Wis., pp. 43–53.

Hunter, R. S. 1975. The measurement of appearance. Wiley, New York.

Hurst, V. J. 1977. Visual estimation of iron in saprolite. Geol. Soc. Am. Bull. 88:174–176.

Kämpf, N. 1981. Die Eisenoxidmineralogie einer Klimasequentz von Böden aus Eruptiva in Rio Grande do Sul, Brasilien. Disertation, Techn. Universität München, Lehrstuhl für Bodenkunde.

Kämpf, N., and U. Schwertmann. 1982*a*. The 5-M-NaOH concentration treatment for iron oxides in soils. Clays Clay Miner. 30: 401–408.

Kämpf, N., and U. Schwertmann. 1982*b*. Quantitative determination of geothite and hematite in kaolinitic soils by X-ray diffraction. Clay Miner. 17: 359–363.

Munsell Color Company. 1975. Munsell soil color charts. Munsell Color, Baltimore, Md.

Norrish, K., and R. M. Taylor. 1961. The isomorphous replacement of iron by aluminium in soil goethites. J. Soil Sci. 12:294–306.

Resende, M. 1976. Mineralogy, chemistry, morphology and geomorphology of some soils of the central plateau of Brazil. Ph.D. thesis. Purdue University, West Lafayette, Indiana.

Scheffer, F., E. Welte, and F. Ludwieg. 1958. Zur Frage der Eisenoxidhydrate im Boden. Chem. Erde 19:51–64.

Schulze, D. G. 1981. Identification of soil iron oxide minerals by differential X-ray diffraction. Soil Sci. Soc. Am. J. 45:437–440.

Schwertmann, U., and W. Lentze. 1966. Bodenfarbe und Eisenoxidform. Z. Pflanzenernaehr. Bodenkd. 115:209–214.

Schwertmann, U., E. Murad, and D. G. Schulze. 1982. Is there holocene reddening (hematite formation) in soils of axeric temperate areas? Geoderma 27:209–223.

Shields, J. A., E. A. Paul, R. J. St Arnaud, and W. K. Head. 1968. Spectrophotometric measurement of soil color and its relationship to moisture and organic matter. Can. J. Soil Sci. 48:271–280.

Soileau, J. M., and R. J. McCracken. 1967. Free iron and coloration in certain well-drained Coastal Plain soils in relation to their other properties and classification. Soil Sci. Soc. Am. Proc. 31:248–255.

Taylor, R. M., and A. M. Graley. 1967. The influence of ionic environment on the nature of iron oxides in soils. J. Soil. Sci. 18:341–348.

Torrent, J., U. Schwertmann, and D. G. Schulze. 1980. Iron oxide mineralogy of some soils of two river terrace sequences in Spain. Geoderma 23:191–208.

Wyszecki, G., and W. S. Styles. 1967. Color science—Concepts and methods, quantitative data and formulas. Wiley, New York.