Int. Agrophysics, 2006 20, 85-90

INTERNATIONAL
Agrophysics
www.ipan.lublin.pl/int-agrophysics

Precipitation effect on colour characteristics of argillic horizons in well-drained soils developed under Mediterranean climate

P.E. Barouchas and N.K. Moustakas*

Laboratory of Soil Science and Agricultural Chemistry, Agricultural University of Athens, 75 Iera Odos, Botanikos 11855, Athens, Greece

Received June 13, 2005; accepted July 8, 2005

A b s t r a c t. This paper is a study of the effect of the climate, and above all of the precipitations, on the formation of the colour characteristics of *value* and *chroma* in the argillic horizons of soils that have developed in two regions of Greece with 500 mm difference between them in precipitation levels. Calculation of colour was effected through obtaining reflectance spectra in the range of the visible region in a fraction of smoothed soil less than 250 μm in diameter. From analysis of the reflectance spectra, the colour characteristics (*hue-value-chroma*) of the CIE system were calculated and subsequently converted into Munsell colour system readings. To ascertain the differences between the colour characteristics of the two regions, two linear statistical models were used in combination: the piecewise linear regression model and the nested linear model. Implementation of the piecewise linear regression model indicated that this model possesses a significant capability for predicting the *value* and *chroma* of argillic horizons. Implementation of the nested linear model on the predicted quantities emerging from the piecewise linear model revealed that different levels of precipitation do not lead to differentiation in the *value* and *chroma* in the argillic horizons of soils developed under Mediterranean climatic conditions.

K e y w o r d s: argillic horizons, soil colour, nested linear model, piecewise linear regression

INTRODUCTION

Colour is the most easily definable morphological characteristic of soils and in combination with other morphological characteristics can provide useful information on the conditions of their genesis. It is conditioned first and foremost by the soil-genesis factor of climate and according to Soil Taxonomy (Soil Survey Staff, 1996) the predominance of the prevailing colour in soils shifts from yellow to red as we move from colder areas towards the equator, with a simultaneous increase in its *value*. Soil colour is a function of the soil organic matter content (Henderson *et al*., 1992; Richardson and Daniels, 1993), of the secondary iron oxide content (Karmanova, 1982; Torrent *et al*., 1983; Schwertmann, 1993), of parent material (Mokma, 1993), of geomorphological position, and of the soil moisture regime (Richardson and Daniels, 1993). Organic matter has a significant influence on colour and above all on colour *value*, when concentration levels are higher than 2% (Baumgardner *et al.*, 1970; Schulze *et al*., 1993). The effect of temperature on the development of soil systems, as a characteristic of the climate, is undisputed and is even more obvious in surface horizons (A), where its fluctuations over time are significant. Temperature fluctuations and moisture concentration both affect decomposition of the organic matter and the process of rubefaction, *ie* the functions affecting soil colour (Dobos *et al.*, 1990). But in sub-surface horizons (B), where both temperature fluctuations and concentration levels of organic matter are small, the effect of temperature on colour will be minimal. The colour of sub-surface horizons is thus a function chiefly of the soil moisture regime (Richardson and Daniels, 1993). In soils with good drainage (aerobic conditions), the iron oxides that are formed remain at the site of their formation, reflecting the iron content of the original rock. In soils where the drainage is poor, the Fe^{3+} is reduced through respiration of microorganisms to Fe^{2+}. The Fe^{2+} is soluble and may percolate to zones that are more aerobic or less, *ie* zones with a good drainage and aeration regime. This process will have obvious effects on soil colouration, for iron oxide concentration is the most important single determinant of soil *hue* (Schwertmann, 1993).

*Corresponding author's e-mail: barouchas@labnet.gr

According, again, to Soil Taxonomy (Soil Survey Staff, 1996), the importance of specifying colour derives from the fact that soil characteristics, such as organic matter content or secondary iron oxide content and soil moisture levels, correlate with soil colouration and can serve as predictors for it. Colour specification is carried out primarily through utilization of the tables of the Munsell colour system. This technique tends to be used more by soil cartographers, being easily and quickly adaptable to rural conditions. However, it is not able to represent colour accurately as it does not take into account the source of light. Observation, moreover, does not always take place under stable lighting conditions. It is also possible for colour specification to be carried out by means of reflectance spectra on disturbed soil samples in the visible region, utilizing a variety of techniques and chromatic systems (Fernandez and Schulze, 1987). Numerous researchers (Bedidi *et al*., 1992; Kosmas *et al*., 1986; Moustakas, 1990; Moustakas and Barouchas, 2003; Torrent and Barron, 1993; Yassoglou *et al*., 1997) have successfully used this technique for colour calculation. Unlike with the Munsell system, colour calculation by means of reflectance spectra takes into account both the type of light source and the conditions of observation (Hunt, 1998).

Techniques of statistical analysis such as analysis of variance (Ulery and Graham, 1993), linear regression analysis (Post *et al*., 1994; Qian *et al*., 1993), multivariate analysis (Mokma, 1993; Shi, 2003) and piecewise linear regression (Barouchas and Moustakas, 2004) have been used to analyse information that can predict soil colour. The last technique can estimate colour characteristics from reflectance spectra of soil samples expressed in a linear form and can be subjected to statistically documented comparison providing differences in readings, primarily for colour *value*, even smaller than a single unit, between soil samples. The Munsell colour system cannot register these differences (Barouchas and Moustakas, 2004).

The aim of this paper is to investigate whether or not there are significant differences in the colour characteristics of *value* and *chroma* of argillic horizons of soils developed in Mediterranean climate conditions under different levels of precipitation.

MATERIALS AND METHODS

Soils

The soil samples were taken from the argillic horizon of soils in the Alfisols order (Soil Survey Staff, 1996) from two regions in Greece. Specifically, there was sampling from the argillic horizon of six representative soil profiles of Alfisols in the Agrinio area (P1) and from the argillic horizon of three representative Alfisols soil profiles in the area of Oinofyta, Viotia (P2). The soil profiles that were chosen were in the same geomorphological position (alluvial terrace of Holocene period, slope 2%), with the same drainage (good drainage) in both areas. The average content of organic matter in the Agrinio area was 0.5% (with a standard deviation of 0.06) and in the Oinfyta area 0.48% (with a standard deviation of 0.04). The soils in both areas derive from alluvial deposits of sedimentary rocks (limestone).

Climatic characteristics

The soil moisture and temperature regimes of the two areas are designated xeric and thermic, respectively (Soil Survey Staff, 1996). In the Agrinio district, average annual precipitation is 1010 mm, while in the Oinofyta area it is 488 mm, over a period of thirty years. The mean annual air temperature in the Agrinio area is 17.9°C and in the Oinofyta area 17.6°C. The bioclimate of the Agrinio area is characterized as intense meso-Mediterranean; that of the Oinofyta area as weak thermo-Mediterranean (Papadakis, 1985).

Reflectance spectra sampling procedure and colour calculation

Once transferred to the laboratory, the soil samples were air-dried, smooth-rubbed and passed through a 250 μm sieve to introduce surface uniformity, as irregularity affects the value of reflectance (Fernandez and Schulze, 1987). Spectra acquisition was performed on this fraction of soil following the procedure described by Fernandez and Schulze (1987) and Torrent and Barron (1993). The colour was then calculated utilizing the CIE system (Hunt, 1998). In this instance, there was recording of the spectra from soil samples in the field of visible light in relation to the white reference material ($BaSO_4$) in a diffuse reflectance, with the use of a Perkin-Elmer Lamda 15 UV/VIS spectrophotometer equipped with an integrated sphere. For calculation of colour, the entire spectrum was measured with readings at 5 nm intervals and the X, Y, Z (tristimulus values) calculated from the following relationships:

$$X = k\Sigma R(\lambda)S(\lambda)x(\lambda)\Delta\lambda,$$

$$Y = k\Sigma R(\lambda)S(\lambda)y(\lambda)\Delta\lambda,$$

$$Z = k\Sigma R(\lambda)S(\lambda)z(\lambda)\Delta\lambda,$$

where: $k = 100/(\Sigma S(\lambda)y(\lambda)\Delta\lambda)$, and:
$R(\lambda)$ = the reflected radiation on a scale from 0 to 1 for perfect reflectance,
$S(\lambda)$ = the related spectral strength for a CIE standard of illumination,
$x(\lambda), y(\lambda), z(\lambda)$ = colour description functions.

The coefficients X, Y, Z are converted into colour coordinates x, y, z, in accordance with the formulae (Wyszecki and Stiles, 1982):

$$x = X/(X+Y+Z),\ y = Y/(X+Y+Z),\ z = Z/(X+Y+Z).$$

Conversion of the colour from the CIE system to the Munsell system was performed using a GretagMacbeth Company software program.

The method, used for statistical processing of the spectra, involved a combination of linear regression, piecewise linear regression and nested linear regression models, as cited by Neter *et al*. (1996) and Medenhall and Sinich (1994), respectively.

RESULTS AND DISCUSSION

Piecewise linear regression was carried out on the reflectance spectra measured (Neter *et al*., 1996), as expressed in the formula:

$$R_i = b_o + b_1 X_{i1} + b_2 (X_{i1} - 500) X_{i2} + b_3 (X_{i1} - 600) X_{i3},$$

where: R_i = the reflected radiation on a scale from 0 to 1, for perfect reflectance, X_{i1} = the wavelength of the radiation, with b_0, b_1, b_2, b_3 remaining stable, X_{i2} = 1 when X_{i1}>500 or X_{i2} = 0, when X_{i1}< 500 nm, X_{i3} = 1 when X_{i1}>600 or X_{i3} = 0, when X_{i1}< 600 nm.

Specifically, the reflectance spectrum may be divided into three areas depending on the wavelength of the radiation (380-500, 501-600 and 601-770 nm). These areas of the spectrum correspond to the basic colours - blue (380-500 nm), green (501-600 nm) and red (601-770 nm). In each area a linear approach is adopted to the linear regression between the wavelength and *R*.

The results of application of the piecewise linear regression are displayed in Table 1.

From the reflectance spectra that emerged after the application of piecewise linear regression, the predicted Munsell system (Table 2) colour characteristics of *hue*, *value* and *chroma* were calculated. Figure 1a and b show characteristically that there are no differences between predicted and observed values for *value* and *chroma* of Munsell colour. Thus the spectra that emerge following the application of piecewise linear regression, essentially express the *value* and *chroma* of colour of the soil samples.

T a b l e 1. Slopes of reflectance spectra in three bands for all the soil samples, according to piecewise linear regression ($y = b_o + b_1 X_1 + b_2 (X_1 - 500) X_2 + b_3 (X_1 - 600) X_3$)

Area	Sample	380-500 nm		501-600 nm		601-770 nm	
		Slope	R^2	Slope	R^2	Slope	R^2
P1	1	0.001	0.99	0.001	0.99	0.0001	0.99
	2	0.001	0.99	0.001	0.99	0.0001	0.99
	3	0.001	0.99	0.0014	0.99	0.0002	0.99
	4	0.0009	0.99	0.0009	0.99	0.0001	0.99
	5	0.0008	0.99	0.001	0.99	0.0002	0.99
	6	0.001	0.99	0.0011	0.99	0.0001	0.99
P2	1	0.001	0.99	0.0015	0.99	0.0003	0.99
	2	0.0009	0.99	0.0014	0.99	0.00002	0.99
	3	0.0009	0.99	0.0012	0.99	0.00006	0.99

T a b l e 2. Observed and predicted *hue*, *value* and *chroma* notations

Area	Sample	Observed[1]			Predicted[2]		
		Hue	*Value*	*Chroma*	*Hue*	*Value*	*Chroma*
P1	1	3.17YR	4.21	3.59	4.29YR	4.24	3.60
	2	3.74YR	4.25	3.16	4.78YR	4.30	3.21
	3	3.96YR	4.46	3.86	4.97YR	4.51	3.97
	4	3.98YR	4.06	2.91	4.98YR	4.09	2.92
	5	4.66YR	4.22	3.01	5.44YR	4.25	3.08
	6	4.07YR	4.19	3.54	4.84YR	4.22	3.59
P2	1	3.09YR	3.98	3.79	5.29YR	3.99	3.82
	2	2.42YR	4.07	4.10	5.44YR	4.13	4.17
	3	1.72YR	4.30	3.68	4.84YR	4.30	3.56

[1]soil colour characteristics estimated from the original spectral data, [2]soil colour characteristics estimated after the use of piecewise linear regression model.

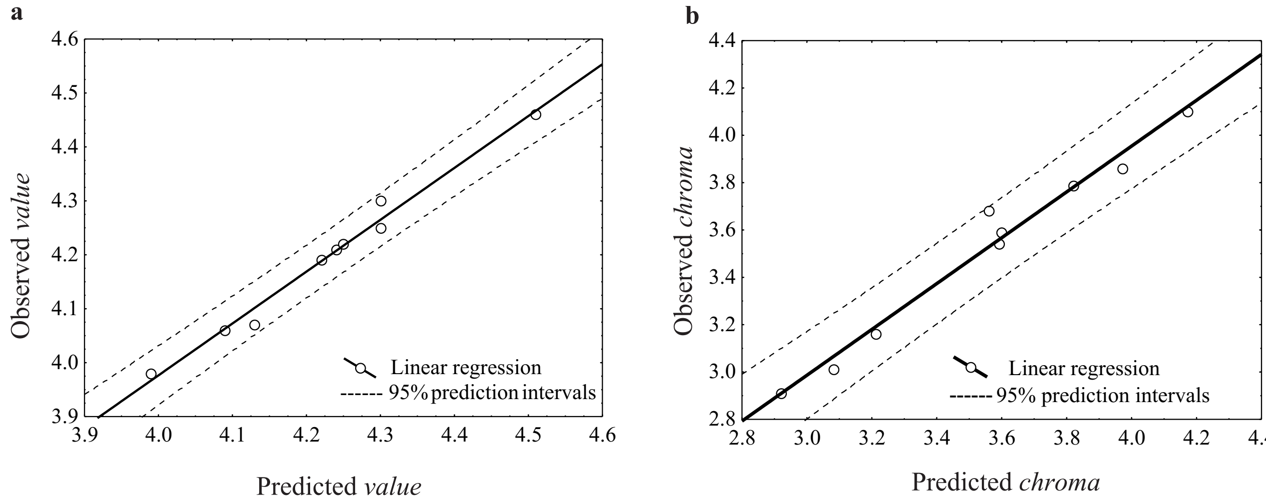

Fig. 1. Linear regression between observed and predicted: a) *value* and b) *chroma* for all soil samples. Dot lines indicate 95% prediction intervals for linear regression.

The average spectrum readings for soil samples from the two areas (Fig. 2) were used for comparison of the reflectance spectra of the two areas. This choice was made because the average reading for all spectra in each area may be considered representative of each sampling area, while at the same time there is reduced likelihood of error.

Comparison of the spectra was carried out through application of the 'nested' linear model which may be described as follows: the linear relationship between R and the wavelength of the reflected radiation is the same for all the soil samples:

$$R = b_0+b_1X_1+b_2X_2+b_3X_3 \quad \text{(Model 1)},$$

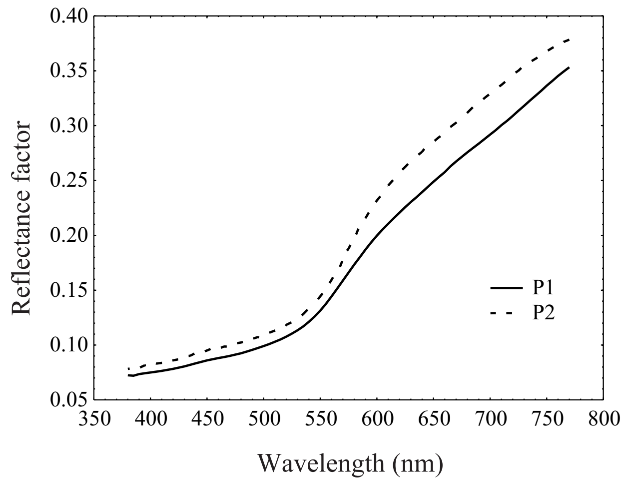

Fig. 2. Mean reflectance spectra of soil samples for the regions P1 and P2.

where: $380<X_1<500$ nm, $501<X_2<600$ nm and $601<X_3<770$ nm, corresponding to the average reading for the soil samples under examination.

The linear relationship between R and the wavelength is different for each soil sample, but the rate of increase of R for each nm of alteration in the wavelength is the same for all the soil samples examined:

$$R=b_0+b_1X_1+b_2X_2+b_3X_3+\ldots+b_{3n-2}X_{3n-2}+b_{3n-1}X_{3n-1}+b_{3n}X_{3n} \quad \text{(Model 2)}$$

where: X_1, X_2, X_3 represent the wavelength and $X_{3n-2}, X_{3n-1}, X_{3n}$ 'dummy' variables, yielding the figures:
$X_4 = X_5 = X_6 = 1$, when sample 2 is examined and $X_4 = X_5 = X_6 = 0$, when it is not examined,
$X_7 = X_8 = X_9 = 1$, when sample 3 is examined and $X_7 = X_8 = X_9 = 0$, when it is not examined,
$X_{3n-2} = X_{3n-1} = X_{3n} = 1$, when sample n is examined and $X_{3n-2} = X_{3n-1} = X_{3n} = 0$, when it is not examined.

This model is a combination of two separate models: a 1st-degree linear model ($R = b_0+b_1X_1+b_2X_2+b_3X_3$) with three quantitative variables (X_1, X_2, X_3) and a 1st-degree linear model ($R=b_0+b_1X_1b_2X_2+b_3X_3+\ldots+b_{3n-2}X_{3n-2}+b_{3n-1}X_{3n-1}+ b_{3n}X_{3n}$) with three or more qualitative variables (X_{3n-2}, X_{3n-1}, X_{3n}).

The second model presupposes that there is no interaction between the quantitative and qualitative variables.

To describe how far the linear equations correlating R and the wavelength differ for two or more soil samples, *ie* how far the figures for the intercepts with the Y axis and the slopes differ for the two linear equations, the following model is used:

$$R = b_0+b_1X_1+b_2X_2+b_3X_3+b_{3n-2}X_{3n-2}+b_{3n-1}X_{3n-1}+b_{3n}X_{3n}+b_{3n+1}X_1X_4+b_{3n+2}X_2X_5+b_{3n+3}X_3X_6+b_{3n+4}X_1X_7+b_{3n+5}X_2X_8+b_{3n+6}X_3X_9+\ldots+b_kX_3X_{3n},\ n = 2,3\ldots \quad \text{(Model 3)}$$

The terms signifying the quantitative variables X_1, X_2, X_3 and the qualitative variables X_{3n-2}, X_{3n-1}, X_{3n}, respectively are called 'main effect terms', while the terms X_1X_{3n-2}, X_2X_{3n-1}, X_3X_{3n} are called 'interaction terms'.

Each of the three models described was constructed through adding terms to model 1. Model 2 was constructed by adding to model 1 the main effect terms, while model 3 was constructed by adding the interaction terms to model 2. These models are 'nested' (model 1 is 'nested' in models 2 and 3; model 2 is 'nested' in model 3) and may be compared using the F-test for 'nested' models (Medenhall and Sinich, 1994). The quantity F in this case is calculated through the formula:

$$F = ((SSE_R - SSE_C)/(k-1))/(SSEc/(n-(k+1))) =$$

$$((SSE_R - SSE_C)/(k-1))/MSEc,$$

where: SSE_R = the sum of squared errors for model 1, SSE_C = the sum of squared errors for model 3, $MSEc$ = the mean square error for model 3, k-1 = the sum of the b parameters cited in the zero hypothesis, k+1 = the number of b parameters in model 3 including b_0 and n= the size of the sample.

The rejection region for quantities $F>F_a$, where quantity F is based on $v_1 = k-1$ degrees of freedom of the numerator and $v_2 = n-(k+1)$ degrees of freedom of the denominator, at significance level α. In comparison of the spectra, quantity F was found to be 0.1, a figure much smaller than the critical quantity of $F_{0.05} = 2.1$, indicating that average figures, both for *value* and for *chroma* of colour characteristics, are no different in the two regions.

The concentration of organic matter in the soils studied is, moreover, very low (<0.5%); the drainage conditions are good; the parent material derives from calcareous alluvial deposits – meaning that the soil genesis factors normally accounting for differentiation in the *value* and *chroma* of soil colour are no different as between the two areas. Differences are detectable only in the level of precipitation.

CONCLUSIONS

1. The 'piecewise' linear regression model is able to function as a satisfactory predictor of the reflectance spectra of soil samples derived from argillic horizons, making it possible for the levels of *value* and *chroma* colour characteristics to be calculated successfully.

2. Through the application of the 'nested' linear model, it was possible to provide statistical proof for the lack of difference in the colour characteristics of *value* and *chroma* between the argillic horizons of areas with different levels of precipitation that develop under Mediterranean climatic conditions. Munsell colour notations cannot document such a different for *value* or *chroma* between two soil samples.

3. Given the similarity in terms of parent material, drainage and organic matter content in the two regions, the conclusion may be drawn that, in these concrete conditions, differences in levels of precipitation do not contribute to differences in the *value* and *chroma* of colour characteristics in argillic horizons.

REFERENCES

Barouchas P.E. and Moustakas N.K., 2004. Soil colour and spectral analysis employing linear regression models I. Effect of organic matter. Int. Agrophysics, 18, 1-10.

Baumgardner M.F., Kristof S.J., Johannsen C.J., and Zachary A.L., 1970. Effects of organic matter on the multispectral properties of soils. Proc. Indian Academy of Sciences, 79, 413-422.

Bedidi A., Carvelle B., Madeira J., and Pouget M., 1992. Moisture effects on visible spectral characteristics of lateritic soils. Soil Sci., 153, 129-141.

Dobos R.R., Ciolkosz E.J., and Waltman W.J., 1990. The effect of organic carbon, temperature, time, and redox conditions on soil color. Soil Sci., 150, 506-512.

Fernandez R.N. and Schulze D.G., 1987. Calculation of soil color from reflectance spectra. Soil Sci. Soc. Am. J., 51, 1277-1282.

Henderson T.L., Baumgardner M.F., Franzmeier D.P., Stott D.E., and Coster D.C., 1992. High dimensional reflectance analysis of soil organic matter. Soil Sci. Soc. Am. J., 56, 865-872.

Hunt R.W.G., 1998. Measuring Colour. Fountain Press, Kingston u. Thames, England.

Karmanova L.A., 1982. Effect of various iron compounds on the spectral reflectance and color of soils. Sov. Soil Sci., 13, 53-60.

Kosmas C.S., Franzmeier D.P., and Schulze D.G., 1986. Relationship among derivative spectroscopy, color, crystallite dimensions, and Al substitution of synthetic goethites and hematites. Clays Clay Miner., 34, 625-634.

Medenhall W. and Sinich T., 1994. Statistics for Engineering and the Sciences. Prentice-Hall, New Jersey.

Mokma D.L., 1993. Color and amorphous materials in Spodosols from Michigan. Soil Sci. Soc. Am. J., 57, 125-138.

Moustakas N., 1990. Relations between morphological and physicochemical properties of Vertisols in Greece (in Greek). Ph.D. Dissertation, Agricultural University of Athens, Greece.

Moustakas N.K. and Barouchas P.E., 2003. Free oxide distribution in poorly and well drained soils developed on calcareous alluvial deposits. Pedosphere, 13(4), 345-351.

Neter J., Kutner M.H., Nachtsheim C.J., and Wasserman W., 1996. Applied Linear Statistical Models. McGraw-Hill, New York.

Papadakis J., 1985. The Agricultural Climate of Greece. Academy of Athens Press, 60/85, Athens.

Post D.F., Horvath E.H., Lucas W.M, White S.A., Ehasz M.J., and Batchily A.K., 1994. Relations between soil color and landsat reflectance on semiarid rangelands. Soil Sci. Soc. Am. J., 58, 1809-1816.

Qian H., Klinka K., and Lavkulich M., 1993. Relationship between color value and nitrogen in forest mineral soils. Can. J. Soil Sci., 73, 61-72.

Richardson J.L. and Daniels L.B., 1993. Stratigrafic and hydraulic influences on soil color development. In: Soil Color (Eds J.M. Bigham and E.J. Ciolkosz), Soil Sci. Soc. Am., Madison, WI, 109-125.

Schulze D.G., Nagel J.L., Van Scoyoc G.E., Henderson T.L., and Baumgardner M.F., 1993. Significance of organic matter in determining soil colors. In: Soil Color (Eds J.M. Bigham and E.J. Ciolkosz), Soil Sci. Soc. Am., Madison, WI, 71-90.

Schwertmann U., 1993. Relations between iron oxides, soil color, and soil formation. In: Soil Color (Eds J.M. Bigham and E.J. Ciolkosz), Soil Sci. Soc. Am., Madison, WI, 51-69.

Shi Z., Huang M., and Li Y., 2003. Physico-chemical properties and laboratory hyperspectral reflectance of Coastal Saline Soil in Shangyu City of Zhejiang Province, China. Pedosphere, 13(3), 193-198.

Soil Survey Staff., **1996.** Keys to Soil Taxonomy. Soil Conservation Service, USDA, Washington, DC.

Torrent J. and Barron V., 1993. Laboratory measurements of soil color: Theory and practice. Soil Sci. Soc. Am., Special Publication No. 11, Madison, WI, 21-33.

Torrent J., Schwertmann U., and Schulze D.G., 1983. Quantitative relationships between soil color and hematite content. Soil Sci., 136, 354-358.

Ulery A.L. and Graham R.C., 1993. Forest fire effects on soil color and texture. Soil Sci. Soc. Am. J., 57, 135-140.

Wyszecki G. and Stiles W.S., 1982. Color Science: Concepts and Methods, Quantative Data and Formulae. Wiley, New York.

Yassoglou N., Kosmas C., and Moustakas N., 1997. The red soils, their origin, properties, use and management in Greece. Catena, 28, 261-278.