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

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Abstract. 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.

Keywords: 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 Fe³⁺ is reduced through respiration of microorganisms to Fe²⁺. The Fe²⁺ 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).

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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 (BaSO₄) in a diffuse reflectance, with the use of a Perkin-Elmer Lambda 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:

\[ X = k \Sigma R(\lambda) S(\lambda) \gamma(\lambda) \Delta\lambda, \]
\[ Y = k \Sigma R(\lambda) S(\lambda) \gamma(\lambda) \Delta\lambda, \]
\[ Z = k \Sigma R(\lambda) S(\lambda) \gamma(\lambda) \Delta\lambda, \]

where: \( k = 100 / (\Sigma S(\lambda) \gamma(\lambda) \Delta\lambda), \)

\( R(\lambda) = \) 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 formulæ (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:

\[ R_i = b_0 + b_1 X_{i1} + b_2 (X_{i1} - 500) X_{i2} + b_3 (X_{i1} - 600) X_{i3}, \]

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.

### Table 1. Slopes of reflectance spectra in three bands for all the soil samples, according to piecewise linear regression (\( y = b_0 + b_1 X_{i1} + b_2 (X_{i1} - 500) X_{i2} + b_3 (X_{i1} - 600) X_{i3} \))

<table>
<thead>
<tr>
<th>Area</th>
<th>Sample</th>
<th>380-500 nm</th>
<th>501-600 nm</th>
<th>601-770 nm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Slope</td>
<td>R^2</td>
<td>Slope</td>
</tr>
<tr>
<td>P1</td>
<td>1</td>
<td>0.001</td>
<td>0.99</td>
<td>0.001</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0.001</td>
<td>0.99</td>
<td>0.0014</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>0.001</td>
<td>0.99</td>
<td>0.0009</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>0.0009</td>
<td>0.99</td>
<td>0.001</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>0.0008</td>
<td>0.99</td>
<td>0.0011</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>0.001</td>
<td>0.99</td>
<td>0.0015</td>
</tr>
<tr>
<td>P2</td>
<td>1</td>
<td>0.001</td>
<td>0.99</td>
<td>0.0014</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0.0009</td>
<td>0.99</td>
<td>0.0012</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>0.0009</td>
<td>0.99</td>
<td>0.0012</td>
</tr>
</tbody>
</table>

### Table 2. Observed and predicted hue, value and chroma notations

<table>
<thead>
<tr>
<th>Area</th>
<th>Sample</th>
<th>Observed¹</th>
<th>Predicted²</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Hue</td>
<td>Value</td>
</tr>
<tr>
<td>P1</td>
<td>1</td>
<td>3.17YR</td>
<td>4.21</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>3.74YR</td>
<td>4.25</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>3.96YR</td>
<td>4.46</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>3.98YR</td>
<td>4.06</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>4.66YR</td>
<td>4.22</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>4.07YR</td>
<td>4.19</td>
</tr>
<tr>
<td>P2</td>
<td>1</td>
<td>3.09YR</td>
<td>3.98</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>2.42YR</td>
<td>4.07</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>1.72YR</td>
<td>4.30</td>
</tr>
</tbody>
</table>

¹ soil colour characteristics estimated from the original spectral data, ² soil colour characteristics estimated after the use of piecewise linear regression model.
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 the spectrum of the two areas. This choice was made because the average reading for all spectra in each area may reflect the wavelength of the reflected radiation is the same for all the soil samples:

\[ R = b_0 + b_1X_1 + b_2X_2 + b_3X_3 \]  \hspace{50pt} (Model 1),

where: 380\(<\lambda_1<500 \text{ nm}, 501<\lambda_2<600 \text{ nm} \) and 601<\lambda_3<770 \text{ 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:

\[ R = b_0 + b_1X_1 + b_2X_2 + b_3X_3 + \ldots + b_{3n-2}X_{3n-2} + b_{3n-1}X_{3n-1} + b_{3n}X_{3n} \]

(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:

- \( X_0 = X_5 = X_6 = 1 \), when sample 2 is examined and \( X_4 = X_5 = X_6 = 0 \), when it is not examined,
- \( X_9 = X_6 = X_9 = 0 \), 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 \( (R = 0 + b_1X_1 + b_2X_2 + b_3X_3 + \ldots + b_{3n-2}X_{3n-2} + b_{3n-1}X_{3n-1} + b_{3n}X_{3n}) \) with three or more qualitative variables \( (X_{3n-2}, X_{3n-1}, X_{3n}) \).

The 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:

\[ R = b_0 + b_1X_1 + b_2X_2 + b_3X_3 + b_{3n-2}X_{3n-2} + b_{3n-1}X_{3n-1} + b_{3n}X_{3n} + b_{3n+1}X_{3n+1} + b_{3n+2}X_{3n+2} + b_{3n+3}X_{3n+3} + b_{3n+4}X_{3n+4} + b_{3n+5}X_{3n+5} + b_{3n+6}X_{3n+6} + \ldots + b_{3n+n}X_{3n+n}, n = 2, 3, \ldots \]  \hspace{50pt} (Model 3)

**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.

**Fig. 2.** Mean reflectance spectra of soil samples for the regions P1 and P2.
The terms signifying the quantitative variables $X_1, X_2, X_3$ and the qualitative variables $X_{2n-2}, X_{3n-1}, X_{3n}$ 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:

$$F = \frac{(SSE_R - SSE_C)/(k-1))/(SSE_C/(n-(k+1)))}{(SSE_R - SSE_C)/(k-1)}/MSEC,$$

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

The rejection region for quantities $F>F_{a}$, where quantity $F$ is based on $\nu_1 = k-1$ degrees of freedom of the numerator and $\nu_2 = n-(k+1)$ degrees of freedom of the denominator, at significance level $\alpha$. 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**


