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Research Paper

# Statistical relationships between soil colour and soil attributes in semiarid areas

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Soil colour has become one of the most innovative indicators used to adjust amendment and fertilizer rates in precision agriculture. This paper uses a combination of colour variables together with geographical, management and pedologic variables in order to find relationships between the three colour components (lightness, hue, and chroma) and several soil characteristics, in a semiarid environment. In these areas soils are weakly developed, and organic matter, nitrogen, phosphorous and iron soil contents are usually low and undergo high spatial variability.

Multivariate analysis was used to find statistical relationships that: determine soil colour in those environmental areas; reveal the most appropriate chromatic variables for each case; and determine the interactions between variables that can mask the effects of individual variables. Colour measurements were collected with a trichromatic colorimeter.

Eighteen soil variables were used, of which eight resulted in statistically significant correlations with colour components. Those variables were sand (%), clay (%), parent material (marls), soil organic carbon (SOC), carbonate content, total nitrogen (TN), iron, and 1:5 soil:water extract electrical conductivity ($EC_{1:5}$). Only sand was significant for all three colour components. The content of organic carbon was not significant in multiple regression analysis with respect to soil lightness in this study of semiarid soils. However it was significant in bivariate regression, in the same way as found in other studies.



## 1. Introduction

Nowadays, it is becoming more important for soil studies to access detailed datasets of soil properties. Site-specific crop management (Bogrekci & Lee, 2005; Eshani, Upadhyaya, Slaugther, Shafii, & Pelletier, 1999), soil erosion and soil degradation control or digital soil mapping (Viscarra, McKenzie, & Grundy, 2010) require the collection of high resolution soil spatial data. However, soils analyses are expensive and time consuming, both at the regional or the global scale.

Soil is an anisotropic natural body and colour is one of the characteristics most used in its classification. Colour provides valuable information on the formation process as well as on constituent elements and other properties.

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Soil colour is the variable of interest in this study, in which we seek significant statistical relationships between soil colour and other pedologic and agricultural variables which are related to both soil formation factors and soil quality. It is commonly accepted that soil colour reflects the proportions of three principal constituents: humus (black), hydroxides of iron (red) and silicic acid, kaolinite and calcium carbonate (white), but there are other soil components, such as oxides of manganese, nitrogen or phosphorus for example, which are important nutrients that can be identified by colour variables such as lightness (Christensen, Bennedsen, Jørgensen, & Nielsen, 2004; Schwertmann, 1993; Simonson, 1993; Torrent & Barrón, 2003). Other soil characteristics, such as texture, different organic matter, soil moisture, soil erosion, and so on, are also major variables that influence soil colour (Brady & Weil, 2006; Konen, Burras, & Sandor, 2003; Schulze, Nagel, Van Scoyoc, Henderson, & Baumgardner, 1993).

When compared to other soil variables, colour is straightforward to measure and does not require complicated sample preparation, so different attempts to find relationships between colour and other soil constituents and properties are abundant in the literature (Doi,Wachrinrat, Teejuntuk, Sakurai, Sahunalu, 2010; He, Vepraskas, Lindbo, & Skaggs, 2003; Mouazen, Karoui, Deckers, De Baerdemaeker, & Ramón, 2007; Sánchez-Marañón, Martín-García, & Delgado, 2011; Viscarra, Fouad, & Walter, 2008).

These studies have drawbacks in relation to the precise designation of the influence of each variable that affects soil formation, and indirectly soil colour. In order to find confident correlations it is necessary to take samples from similar pedologic environments. However, it is not easy to find areas with such uniform environmental conditions.

Even though the most suitable approach is to sample slopes or transects with similar pedologic environments, it is very difficult to find areas where soil colour differences are exclusively due to the attribute under study, without influence from other forming factors. Some authors have done experiments in wider areas which vary in their soil genesis processes (Ibarra-F et al., 1995; Schulze et al., 1993). Furthermore, most of those studies have been conducted in temperate climate areas with decarbonated soils and high contents of organic matter (Konen et al., 2003; Wills, Burras, Sandor, 2007), nitrogen (Eshani et al., 1999) or phosphorus (Bogrekci & Lee, 2005).

In this study, efforts are focused on finding areas homogeneous only with respect to those fundamental variables, such as stoniness, crustability and high carbonate content, leaving out other variables. The few studies in semiarid areas (Sánchez-Marañón, Delgado, Melgosa, Hita, & Delgado, 1997; Sánchez-Marañón et al., 2011; Sánchez-Marañón, Ortega, Miralles, & Soriano, 2007; Sánchez-Marañón, Soriano, Megolsa, Delgado, & Delgado, 2004) support this approach.

It is known from previous research conducted in humid areas, that soil colour is strongly conditioned by the presence of chromogen substances, which in turn are indicators of fertility as well as soil condition. However, two main questions remain unanswered.

The first question refers to the approach used to study colour-soil relationships. The common procedure consists of studying the influence of each individual chromogen component on soil colour, and developing colour-component regression equations where other variables are assumed to be constant (Viscarra et al., 2008). Furthermore, it should be remembered that the influence of each variable is not independent of the others, and that the soil does not remain unaltered over time, which limits this approach.

The second question refers to specific characteristics of arid and semiarid areas. Unlike humid areas, soils in arid and semiarid areas: lack chromogen substances common in humid areas, are rich in substances not present in humid soils, i.e. carbonates and salts, and have very limited range of variability of some components such as soil organic carbon (SOC), N, or P.

With regard to colour determination techniques, it is worth noting that the classical approach to communicating soil colour is based on the use of specific Munsell charts under natural illumination conditions (Munsell Color Co., 1994). Colour spaces developed in the early 1930s by the Commission Internationale de l'Éclairage (CIE) are suitable alternatives to visual techniques, i.e. observation of the Munsell charts, to avoid subjectivity-related issues. The use of those spaces in soil science is well documented in the literature (Torrent & Barrón, 1993; Viscarra, Minasny, Roudier, & McBratney, 2006).

Thus, the goal of this paper is to improve the knowledge about the topographic, management and pedologic variables that contribute to soil colour in a semiarid environment, where the presence of chemical chromogen agents is very limited due to weak soil development.

## 2. Materials and methods

### 2.1. *Site description, sampling and processing of data*

Soil samples were collected near the river Vinalopó in the province of Alicante (southeast Spain). The major soil orders in the area are Aridisols and Entisols (Soil Survey Staff, 2010). A total of 110 topsoil samples (0–15 cm) were collected over an area of 60 $km^2$ with similar climate characteristics, but great diversity in parent material, aspect, elevation, proximity to the river, vegetation, and land management (Fig. 1).

The climate is continental Mediterranean with cold winters and hot and dry summers, an annual rainfall of 350.5 mm and an annual average of temperature of 15.2 °C. This demonstrates the semiarid character of area, more pronounced during the summer months.

The principal types of land use are: crops (60%) with vineyards and fruit trees (olive and almond trees), abandoned fields (19%) and forest (14%) with pines and scrub.

Geomorphology is defined by the valley of river Vinalopó and the terraces and slopes of two mountain ranges with northeast–southwest orientation. The mean terrain height is 540 m above sea level, and slopes are less than 15%. The predominant geologic material is quaternary located in the bottom of the valley, whereas limestone, marls, clays and gypsum are present in the slopes (Fig. 2).

Samples were first air-dried in the laboratory, crushed and sieved using a brass sieve with 2 mm openings (Soil Survey Staff, 2004). This preprocessing was carried out in order to