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MODELING SOIL COLOR AND SOIL FERTILITY RELATIONS

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ZEINAB ABDİ DJAMA**

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MODELING SOIL COLOR AND SOIL FERTILITY RELATIONS

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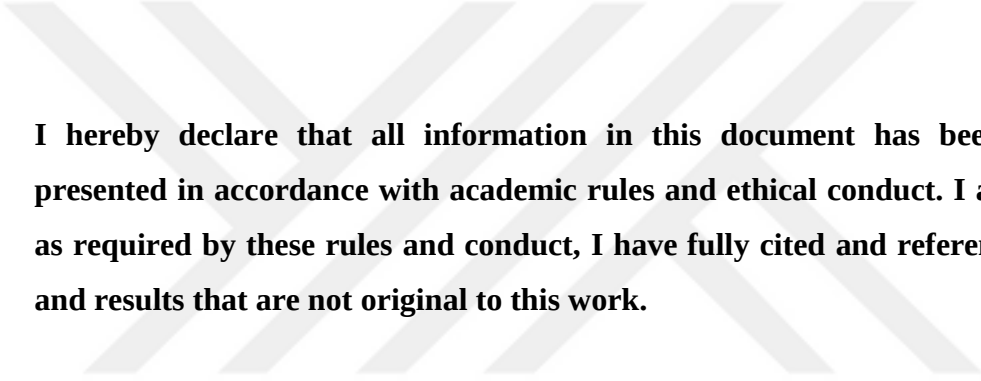
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Zeinab ABDI DJAMA

ABSTRACT

MODELING SOIL COLOR AND SOIL FERTILITY RELATIONS

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Master of Science in Forest Engineering

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Soil color provides significant information on soil properties. Soil color frequently changes on cultivated semi-arid sloping landscapes, indicating differences in soil properties that affect soil fertility. This study aimed to determine the relationships between color variables (L^* : soil brightness, a^* : soil redness and b^* : soil yellowness) and some basic soil properties on 155 soil samples representing soils on a semi-arid sloping landscape under a wheat cultivation. Soil properties were determined in the laboratory. Color properties measured with a spectrophotometer on both air-dry (L^* -dry) and wet (approximately FC) (L^* -wet) soil samples. The values of color variables and soil properties were graphed and relationships between them were modeled using most proper regression model. Among a^* , b^* , and L^* , L^* values were the most strongly correlated with soil properties and the correlations were the strongest when samples were wet. The CaCO_3 content of the soils was the most significant variable associated with L^* -wet ($r=0.84$). The relationship between L^* -wet and CaCO_3 content was described with a first-degree linear regression equation. The EC values were correlated relatively strongly with L^* -wet ($r=0.74$), and the relationship was described with a third-degree polynomial equation. Clay, sand, and K content were correlated with L^* -wet to a lesser extent, and silt, OM content, FC, WP and ASI were not significantly correlated. The extremely high CaCO_3 content of soils would probably mask OM to show its association with L^* . The results suggested that the water content of soil is an important variable in this relationship and that prediction of soil fertility from color variables may not be possible due to the high CaCO_3 content.

2021, 66 pages

Keywords: Modeling, Soil color, Soil fertility, Soil water content, Spectrophotometer

ÖZET

TOPRAK RENGİ VE TOPRAK VERİMLİLİĞİ İLİŞKİSİNİN MODELLENMESİ

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Orman mühendisliği, Yüksek Lisans

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Toprak rengi, toprak özellikleri hakkında önemli bilgiler sağlamaktadır. Toprak rengi işlenen yarı kurak eğimli arazilerde sıklıkla değişmekte olup bu durum arazi üzerinde toprak verimliliğindeki farklılıklara işaret edebilir. Bu çalışma ile buğday tarımı altında yarı-kurak eğimli bir arazideki toprakları temsilen alınan 155 toprak örneğinde renk değişkenleri (L^* : toprak parlaklığı, a^* : toprak kızarıklığı ve b^* : toprak sarılığı) ile bazı temel toprak özellikleri arasındaki ilişkilerin modellenmesi amaçlanmıştır. Temel toprak özellikleri laboratuvarında analiz edildi, renk değişkenleri ise bir spektrofotometre ile hem hava kuru hem de ıslak (yaklaşık tarla kapasitesi) toprak numunelerinde ölçüldü. Renk değişkenlerinin ve toprak özelliklerinin değerleri karşılıklı grafiklendi ve aralarındaki ilişkiler en uygun regresyon model tipi kullanılarak modellendi. a^* ve b^* değerleri ile kıyaslandığında L^* değerleri ile toprak özellikleri arasındaki korelasyon katsayıları daha yüksek bulunmuş olup, söz konusu korelasyonların toprak örnekleri ıslakken çok daha güçlü olduğu görülmüştür. İncelenen topraklarda, toprağın CaCO_3 içeriği ile $-L^*$ -ıslak arasındaki ilişki en yüksek olup ($r=0,84$), bu ilişki birinci derece bir lineer regresyon denklemi ile açıklanmıştır. EC değerleri ile L^* -ıslak arasında nispeten kuvvetli bir ilişki bulundu ($r=0,74$) ve bu ilişki üçüncü derece bir polinom denklemi ile modellendi. Kil, kum ve K içeriği L^* -ıslak ile daha düşük ancak önemli bir korelasyon gösterirken; silt, OM içeriği, FC, WP ve ASI ile L^* -ıslak arasındaki ilişki önemli bulunmamıştır. Toprakların aşırı yüksek CaCO_3 içeriği muhtemelen OM ile L^* arasındaki ilişkiyi gölgelemiştir. Sonuçlar, CaCO_3 içeriğinin aşırı yüksek olması nedeniyle çalışma alanında toprak verimliliğinin renk değişkenleri kullanılarak tahmin edilmesinin mümkün olmayabileceğini ve toprak renk değişkenlerinin laboratuvarında belirlenmesinde toprağın su içeriğinin dikkate alınması gerektiğini göstermiştir.

2021, 66 sayfa

Anahtar Kelimeler: Modelleme, Spektrofotometre, Toprak rengi, Toprak verimliliği, Toprak su içeriği

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LIST OF SYMBOLS

%	Percent
>	Greater than
<	Less than



LIST OF ABBREVIATIONS

a*	Soil redness
ASI	Aggregate Stability Index
B*	Soil yellowness
CaCO ₃	Calcium carbonate
CV	Coefficient of variation
dS	Deci Siemens
EC	Electrical Conductivity
FC	Field Capacity
Ha	Hectare
K	Potassium
Km	Kilometer
Kurt	Kurtosis
L*	Soil brightness/Soil luminosity
M	Meter
Max	Maximum
Min	Minimum
N	Nitrogen
Na	Sodium
OM	Organic Matter
pH	Soil reaction
P	Available Phosphorus
S	Skewness
SD	Standard deviation

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1. INTRODUCTION

Agriculture has faced three major challenges in last several decades: feeding the planet, reducing its impact on the environment (Clay 2004), and being profitable for farmers (Lowenberg-DeBoer and Swinton 1997). These environmental, societal and economic pressures forced farmers to change their working methods. The technological solutions developed such as synthesis of fertilizers, genetic engineering, application of soil cultivation maps or precision agriculture) make it possible to provide, plot by plot, key information to make better decisions throughout the agricultural season and thus optimize the entire agricultural system (Whelan *et al.* 1997). However, these technological advances are not at the service of all farmers. These methods are expensive and time consuming depending on the scale and area of the territory to be studied (Walter 2002). The results are often incomprehensible to farmers and are not available or incomplete in some areas.

In this context, important functional relationships can be established between soil color and soil fertility. The mathematical expression of the relationships between soil color and soil fertility can provide significant advantages on the management and sustainable use of soil. Such a mathematical expression would provide information of capital importance at low budgetary cost. The mathematical expression used to describe the relationship between soil color and soil fertility is based on a set of models having different regression equations (linear, exponential, logarithmic, polynomial, etc.).

Having been used for over 4000 years, color is one of the widely used morphological characteristics that is used to describe the soil. Indeed, as the soil color can be determined easily and at very low cost, many researchers have conducted research on its use to determine the physical, chemical, mineralogical, and biological soil properties and to classify soils (Günel *et al.* 2008). It allows to interpret the soil by giving clues on the agronomic properties of the soil such as the quantity of organic matter or the quantity of iron contained in the soil. The soil color is common knowledge that light soils are rich in calcium carbonate are considered less fertile than dark brown to black soils, which are rich in organic matter (Shields *et al.* 1968, Schulze *et al.* 1993) or reddish soils rich in iron

(Bigham *et al.* 1978, Schwertmann 1993). Thus, soil color can be considered as an indicator of soil fertility. Nowadays, soil color can now be determined much more easily and accurately by several methods and instruments (spectrometric reflection methods, remote sensing, etc.) (Schulze *et al.* 1993). Therefore, integrating a function between the soil color and soil fertility would allow farmers and agricultural engineers to optimize the management of their fields and their agricultural operations. Soil color can be greatly influenced by soil-forming factors (parent material, climate, type of vegetation, topography, and time), soil moisture, CaCO₃ content, salt content, and soil texture. On the other hand, color retains its interest as an indicator of the presence of a particular constituent in the soil, but it cannot always be interpreted in terms of current functioning.

Although maps are essential tools for agricultural development, when making maps of soil crop suitability, opening soil profiles to describe and interpret soil morphology is difficult and expensive at large scales (Walter 2002). This method therefore represents a major constraint for some countries. This is why it is necessary to improve the methods of morpho-pedology by making them simpler and more comprehensive for farmers. For this purpose, soil color can be used as an indicator by establishing important functional relationships between soil color and soil fertility, or rather between soil color and those soil properties of soil fertility.

However, the color of soils usually does not necessarily have an agronomic significance, since the same color can occur due to different constituents and correspond to soils of different and uneven appearance and properties. Indeed, two soils having the same color as in the surface horizons can have different agronomic properties because of very variable depths. However, in a region with a limited number of soil types, the color can be specific to a well-defined soil type and therefore involve specific agronomic properties.

Soil color changes frequently depend on topographic conditions in semi-arid sloping areas. The soils are generally poor in water and nutrient content, especially in the light-colored eroded localities, while the soil color is darker on the depressions where soil is more fertile, resulted from accumulation of sediments and water transported from erosion sites. This

condition may be considered in management of those soils, especially in application of fertilizers. This study conducted to determine the relationships between quantitative values of soil color determinants and soil fertility indicators (organic matter content, available P and K contents, soil pH, etc.) and to evaluate potential use of the results in perceiving soil fertility status across a sloping agricultural landscape under typical semi-arid climatic conditions.



2. LITERATURE REVIEW

2.1 Soil Color

More than 4000 years ago, the Chinese Yu already classified soils according to their color and their structure. Farmers named soils based on their color, most often by the color of their surface horizons. Soils with a dark color were considered to be more fertile compared to soils with a lighter color without knowing the exact reason for this difference in fertility according to the color. Naturally, the first pedologists, too, used color criterion to judge the suitability of soils (Baize 2018).

According to the early pedologists, the soil color was an important property to characterize the soil. Serres (1605) noted that the black color of the soil was the most popular of all and the red color of the soil was the least popular. Between these two colors, there were the other colors of the soil, which indicated soils neither too fertile nor too infertile (Serres 1605). Thus, since the beginning of pedology, soil color has played a very important role in classifying the soil's suitability for fertility. However, it was admitted that the soil color could be misleading in some cases (Serres 1605).

With the birth of pedology in Russia between 1879-1890 and its first developments in Europe and the USA (1930-1960), the first classifications and names of soils for scientific purposes made extensive use of colors and types of vegetation supposed to be associated with it (Baize 2018). Until today, many soils have names derived from their colors in different soil classification systems. This is the case, for example, with Chernozem soils which are black soils (Escadafal 1988). Table 2.1 presents some examples of scientific designations of soils according to their color (Baize 2018) (Table 2.1).

Table 2.1 Some soils in soil classification according to their color (Baize 2018)

Color	Russia	The USA
Black	Chernozems	Black cotton soils
Brown	Burozems	Brown earths, brown soils
Grey		Grey forest soils
White	Bielozems	
Red	Krasnozems	Red podzolic soils
Yellow	Jeltozems	Yellow podzolic soils

To date, color is an important characteristic of the soil; it is a morphological characteristic widely used by pedologists as it can be easily determined, especially in the field (Günel ve Erşahin 2006). Soils with dark and thick surface horizons are distinguished from other soils in most soil classification systems and are classified in the highest categories due to their high productivity (Schulze *et al.* 1993).

Color is the visual perception of the appearance of a surface, based on the spectral distribution of light, which stimulates specialized nerve cells located on the retina. This perception varies due to the fact that the light that strikes objects is partially absorbed and partially reflected. We perceive a white color if all wavelengths reach our eyes at the same time (the wavelengths in the visible spectrum (380 nm and 780 nm)). And we perceive a black color if no light reaches it (Taillet *et al.* 2013). Thus, depending on whether a soil reflects more or less certain parts of the spectrum, the soil will have one color or another.

In pedology, the soil color is an immediate criterion of differentiation, easily recognizable by all. It is appreciated both during an auger survey and on the wall of a soil pit. It has been used and still is used for the differentiation of soils (Escadafal 1988). Indeed, soil color makes it possible to interpret the soil. By observing the color, one can have very important

clues about the organic matter content (Shields *et al.* 1968; Schulze *et al.* 1993), mineralogy, aeration, and many similar properties of the soil. Soil color, which is one of the most important of its morphological characteristics, can provide information on the mineral composition of the soil (Shen *et al.* 2006), the organic matter content (Fang *et al.* 1999), the field capacity, the wilting point, the soil aggregate stability, and nutrient content of plants (Budak *et al.* 2018). Soil color can also provide information on chemical processes as a function of the soil moisture regime (Ji *et al.* 2007). This is due to the fact that the different components of the soil have their own reflective characteristics (Torrent and Barrón 1993). Thus, soil color considered as an indicator of the physical, chemical and biological properties of the soil (Gözükara *et al.* 2021) and of the soil formation processes (Schwertmann 1993). In addition, color allows the identification and classification of different soils (Günel ve Erşahin 2006). Soil scientists use color differences to determine the limits of soil horizons (Gözükara *et al.* 2021). So, each change in color of one or more soil horizons represents a change in activity by natural events or by human activity. Tracking soil changes allows us to interpret changes over time periods, compare information from different localities on a site, and track soil characteristics (Richter and Markewitz 2001).

Quantitative expression of soil color started in 1905 when Munsell defined soil color with hue, value and chroma components (Budak *et al.* 2018). Today, the most common method used by soil scientists to determine soil color is the comparison with Munsell color charts (Thompson *et al.* 2013). In this method, color is characterized by three different parameters: hue (hue), value (brightness of color) and chroma (color intensity) (Viscarra Rossel *et al.* 2006). Although it is a very easily applicable method, the fact that it is limited to a certain number of colors, environmental conditions, color perception changes significantly from person to person due to knowledge and experience threatens the reliability of the results (Günel ve Erşahin 2006). Therefore, determining the color with the Munsell color cards is subjective and may not match between different users (Stigliz *et al.* 2016). In a study, it was reported that the rate of expression of the same soil sample as a different color by different researchers was quite high (Post *et al.* 1993). Although this

method is very easy to apply, it has some disadvantages because it is limited to a certain number of colors in the color scale and color perception changes according to the individual (Moritsuka *et al.* 2014). Post *et al.* (1993) found that the rate of perception of the same sample as the same color by different researchers was very low. Melville and Atkinson (1985) grouped the factors affecting the perception of colors by people under three headings which are: i.) the characteristics of the light source illuminating the object whose color is being looked at, ii.) the surface characteristics of the object, and iii.) the differences in perception of the human eye (Melville and Atkinson 1985). These characteristics result in people to perceive color differently (Post *et al.* 1993). Thus, in this thesis, we worked on the results obtained from a colorimeter.

The color of the soil surface has a great influence on the rate of warming in the spring and cooling of the soil in the fall, as well as the rate at which soils warm or cool. Indeed, soils with a brighter and / or darker hue, whatever their moisture content, heat up more quickly than soils with a lighter shade because it absorbs more heat than light-colored soils, which are more reflective (Oke 1987).

Likewise, it should be noted that the soil color is a variable criterion with the state of soil humidity. Indeed, the soil moisture content influences the spectral reflectance of the entire solar reflective range (400-2500 nm) (Bablet 2018). Water temporarily darkens the soil color (Post *et al.* 1993, Shields *et al.* 1968, John *et al.* 1969), particularly affecting the brightness of the soil (Shields *et al.* 1968, Post *et al.* 1993), since the water film on the surface of the colloids of organic matter and clay causes multiple reflection and the absorption of light increases (Winters 1930).

To appear dark, a soil only needs about 5% organic matter when wet. This dark color acquired by the soil from moisture causes an increase in the absorption of light by the soil. Therefore, soils with higher moisture content, being darker, absorb more solar radiation, but heat up more slowly than drier soils (Figure 2.1) (Bowers and Hanks 1965).

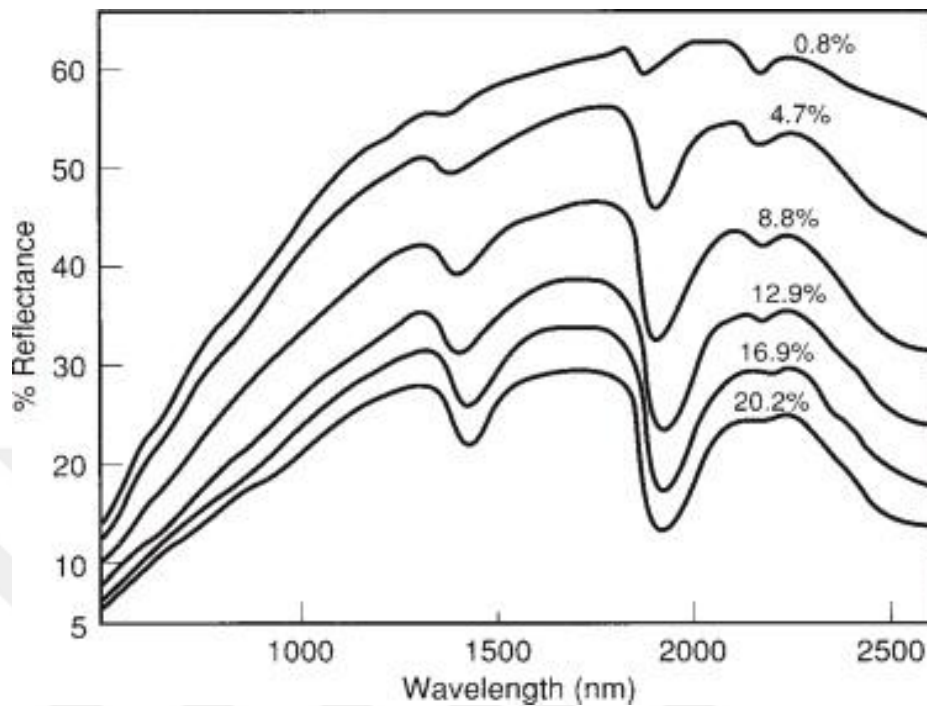


Figure 2.1 Reflection of a silt as a function of wavelength and water content (Bowers and Hanks 1965)

This is due to the ability of water to absorb large amounts of energy when the soil warms, because of high heat capacity of water. The surfaces of sandy and coarse soils heat and cool more quickly than clay soils of the same color because of greater water-holding capacity and porosity (Bowers and Hanks 1965) of clay soils. Soil color also reflects the age of the soil and the temperature and humidity characteristics of the climate. Thus, information derived from soil color is extremely useful for soil management and for determining potential uses of soils (Torrent *et al.* 1983, Prost and King 1983).

2.1.1 Origin of soil color

The reflectance of soils results directly from the color of its constituents. Indeed, it is mainly due to organic matter, ferruginous minerals (goethite, hematite, etc.) and CaCO_3 (Torrent 1983). It varies according to the various combinations between these main constituents. The color of ferruginous minerals (goethite, hematite, etc.) results mainly from iron (Fe). Thus, the soil color is mainly affected by three main coloring agents, namely iron, organic matter and CaCO_3 (Baize 2018).

Studies carried out by Ségalen (1969) on soil samples, showed that the ferralitic soils and the iron-rich soils of Côte d'Ivoire owe their colors mainly to the presence of goethite in the absence of amorphous ferruginous products. However, if these soils contain amorphous ferruginous products, they would owe their colors to the amorphous ferruginous products as the amorphous ferruginous products cover all the other constituents of the soil by hiding their own color, which only appears when the amorphous products have all been abducted (Ségalen 1969).

In addition to goethite and amorphous ferruginous products, hematite, which is very common in soils, gives soils the red color. In fact, the redness indices were found to correlate with the percentage of hematite in the soil (Torrent *et al.* 1983). It is a strong coloring agent of the soil. Indeed, 1.7% hematite can give a soil a red color (Scheffer *et al.* 1958). In fact, this percentage is smaller for a yellow Oxisol (10YR) which just need 1% fine hematite for them to take on the hue of 5YR of Munsell (Resende 1976). The pigmenting power of hematite is stronger than the pigmenting power of goethite. In fact, adding only 1% hematite to a mixture containing kaolinite, silt-sized quartz, biotite, K-feldspar and 3% goethite, causes a change in the Munsell hue from 2Y to 5YR (Torrent *et al.* 1983).

The red color of hematite is very effective in masking the yellowish red color of goethite. Soils containing only or almost exclusive goethite have yellowish-red colors (Munsell hue of 10YR to 2.5Y), but when hematite is present the colors generally turn reddish (7.5YR and redder) (Childs *et al.* 1979, Bigham *et al.* 1978, Davey *et al.* 1975).

The other ferruginous minerals are less abundant in the soil than hematite and goethite, but they contribute to the coloring of soils when they are present in sufficient quantity. For example, lepidocrocite gives soils an orange color, ferrihydrite gives soils a reddish-brown color, and magnetite gives soils a reddish-brown color (Torrent *et al.* 1983). Thus, iron can exist in the soil in different forms (amorphous ferruginous products or the iron contained in secondary ferruginous minerals) and depending on the form in which it is found in the soil, the color of the soil is different. It is the most important pigmenting agent in soils with low organic matter content (Torrent *et al.* 1983).

So, iron can exist in the soil in different forms and depending on the form, this element takes on contrasting and different colors. Iron oxides (hematite, magnetite) or iron oxyhydroxides (goethite, limonite, lepidocrocite) are formed by the alteration of the ferromagnesian minerals constituting the bedrock depending on the climate, the acidity of the environment, its redox potential, and the absence or presence of complexing organic material. Iron and its oxides give the soils red, purplish, rusty or brown colors in oxidizing environments and bluish or greenish colors in reducing environments. Soil color depends on the form of the iron in the soil, and the form of the iron in the soil depends on the presence of oxygen in the soil. In the presence of oxygen in the soil, iron is in oxidized form, which forms spots with a fairly wide color palette (from yellow-orange to red-brown) (Ségalen 1964). However, in the absence of oxygen, iron is in reduced form, the soil then has gray-green tints and sometimes takes an almost blue color (Ségalen 1964).

Waterlogging is mainly responsible for the deficiency of oxygen in soils. In fact, when the water level rises and water stagnates in a soil, oxygen becomes increasingly scarce, iron goes from its oxidized state to its reduced state. There is therefore a change in color of the iron in the soil. In addition, in reduced form, iron becomes mobile and is redistributed in the soil (Ségalen 1964).

Also, in contexts of waterlogging, elements like manganese can bind to iron and form ferro-mangan nodules which are generally small rounded volumes or coatings, black in color. Indeed, if the aeration in the soil is insufficient and there is a lack of oxygen, manganese (Mn^{2+}) passes in its reduced form, manganese (Mn^+), and binds to iron. So, the observation of oxidation and / or reduction spots in a soil gives us indications of the presence of alternating oxidizing-reducing conditions in the soil because the yellow and red colors in the soil are considered as an indication that the soil is well aerated and contains oxidized iron and oxidized manganese (Schoeneberger *et al.* 2012), while the predominance of shades of gray and green in the soil indicates that the presence of iron ferrous and manganese in reduced form, that the soil is not well aerated and there is a drainage problem. Colors formed under oxygen limited conditions are often referred to as gleyed earth colors (Schaetzl and Anderson 2005).

In poorly drained soils, gleyed areas are sometimes encountered due to the periodic increase and decrease in groundwater level during the year. Usually, groundwater rises throughout the winter. This rise causes reducing conditions at a certain depth of the soil. In these regions, iron and manganese are reduced. In summer, the groundwater level decreases and iron and manganese are oxidized again in these areas. Thus, these soils are subjected alternately to the processes of oxidation and reduction. This gives rise to soil horizons characterized by their color variation, which associates gray streaks and yellow brown spots (Grosclaude 1999).

When the groundwater level drops, some of the re-oxidized iron and manganese are deposited and cause light-colored areas called wetness mottles or redoximorphic features to form. The distance between these formed mottles and the soil surface gives important clues about the seasonal height of groundwater (Schaetzl and Anderson 2005). Therefore, location of those features is used to determine the depth of the water table during site assessment in agriculture or urban development. Thus, the oxidation state of iron and manganese is one of the soil colors determining constituents and soil color is an indicator of permeability and drainage (Delaunois 2013).

In addition, a vertical color change can be observed. Indeed, the horizons of the same soil can be of different colors. This is the case, for example, with Luvisols. These soils come from loess silt, a loose detrital sedimentary rock formed by the accumulation of silt from wind erosion, in desert and periglacial regions. The upper horizons of these soils are depleted of clay and iron. These horizons have beige or beige-gray colors. While the deeper horizons of these soils, which are horizons of illuvial accumulation, have quite bright ochre colors (Baize 2018).

This difference in color according to the horizons is the consequence of three simultaneous phenomena, which give the genesis of these soils. The first phenomenon is the leaching of clays from the E horizon, under the action of water and gravity and the accumulation of clay in B horizon. This phenomenon is important even if it is not as impactful as the other two phenomena. The second phenomenon is the fact that the clay rich C horizon is transformed and becomes a horizon B. The third phenomenon is the destabilization of the clays in the upper horizons, which leads to the lateral leaching of the clays giving the impoverishment of the horizon B at its summit until it transforms into an E horizon (Legros 2007).

In the field, one can distinguish localities different in redness on a same Luvisol. This is due to partial erosion. In fact, knowing that the deep horizons of Luvisol are redder than the surface horizons, when an area is eroded, it is the deep horizons that emerge on the surface unlike the non-eroded areas. Therefore, the soil appears on the surface much less "red" than where the surface horizons have not been completely eroded (Figure 2.2) (Baize 2018).

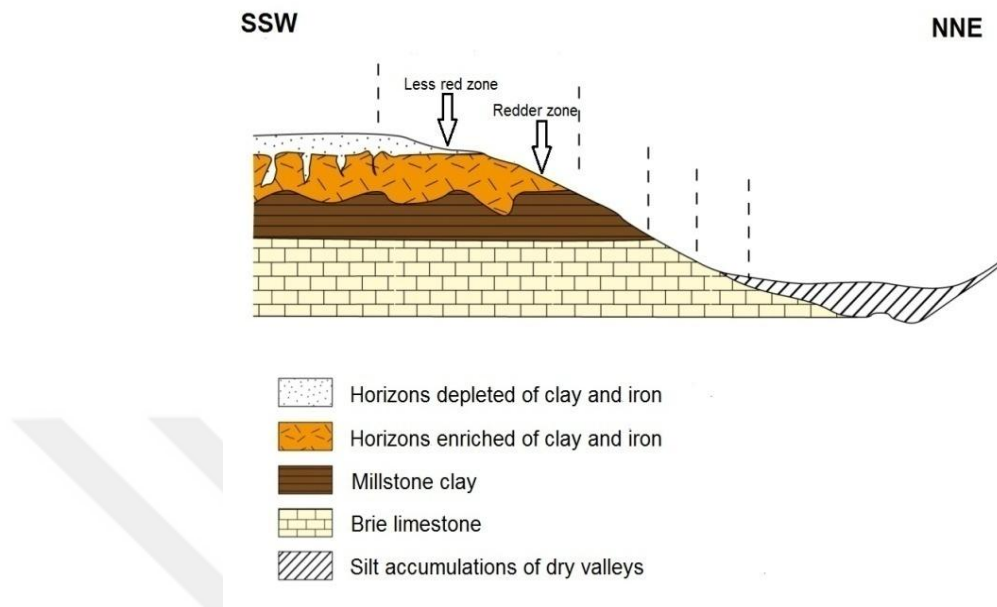


Figure 2.2 Different localities in redness on the same Luvisol due to partial erosion (Baize 2018)

It should also be noted that, in general, the red products appear preferentially when there is a dominance of calcium and magnesium ions and that the ordered iron-silica-kaolinite complexes tend to remain yellow, while the introduction of silica favors the production of red disordered products (Taylor *et al.* 1967).

Organic matter is also one of the constituents determining the soils color. Indeed, organic matter in significant quantity (more than 2%) in soils gives black or brown colors (Baize 2018). In general, the main source of dark color in soils is considered to be the amount of organic matter in the soil. It is believed that the soil color will become darker as the amount of organic matter in the soil increases. The accumulation of organic matter in depths near the soil surface (e.g., A horizon) gives the soil a dark-brown color and is a sign of good drainage. We often observe a decreasing gradient of the organic matter contents along the soil profiles in connection with the inputs which take place from the soil surface (manure, slurry, dead leaves, etc.). In deeper horizons, like the B horizon, a brown color usually means the soil has good natural drainage. Under very specific conditions (regions of high rainfall), a black or dark gray color in deep horizons is generally due to an accumulation of

organic matter and is a sign of poor drainage. This is the case with peaty soils in which the permanent water saturation of the soil leads to an accumulation of organic matter (Torrent 1983, Prost and King 1983).

However, not all dark soils have a high organic matter content. In the study by Budak (2018), it was shown that the reason for the dark color of soils with low organic matter content is the increase in the amount of exchangeable sodium in the soil solution, due to the dispersion of organic matter and its accumulation on the soil surface by capillary rise.

For some soils, the soil color is due to constituents that have individualized, accumulated or concentrated during pedogenesis (alteration complexes and organic matter), while for other soils, the color of the soil is directly inherited from the rock from which they originated; they are called "lithochromes" (e.g., soils derived from pink sandstone or green soils or resulted from the alteration of grains of glaucoma). Indeed, the alteration of glauconia grains gives the soils a green color. However, this green color of the glauconia is only present in the semi-deep sandy clay horizons while the upper horizons are depleted (less clayey) and are gray-beige in color. This is caused by geological stratification and / or a pedogenetic process of destruction and elimination of clay, which results in a variation of the color depending on the horizons. The upper horizons have a coarse texture and the deeper horizons have a finer texture and are less permeable. These soils are called Planosols (Baize 2018).

Soils derived from limestone are also Lithochromes. Indeed, limestone is another color determining constituent in soils. Limestone gives the soil a white color (Baize 2018). Indeed, the carbonate contained in the limestone and in the alumino silicate have a light color, linked to a high reflectance in the visible range, which varies considerably with the size of the particles (Leu 1977).

In the absence of CaCO_3 , the very light colors (white, bleached beige or pale gray) present near the soil surface or above a horizon of clay accumulation are indicative of low in humus and very low in iron (especially clear discoloration in the dry state). Indeed, these colors translate phenomena of soil impoverishment of certain coloring elements such as iron, clay

or organic matter (Baize 2018). This is mainly due to the lasting effect of the climate on the region, on the soil, which resulted in extreme washing conditions. In fact, in a reducing environment, in its reduced form, the iron becomes mobile and can then migrate in the profile and accumulate in another place (vertical transport or lateral transport). Iron-associated clay migration phenomena can also occur, from "eluvial" horizons (horizon A and E), which are depleted, towards "illuvial" horizons (horizon B) where there is an accumulation. This process is called leaching. When the A and / or E horizons are leached, then the color of the residual minerals becomes evident. Indeed, the soil mainly takes the color of quartz, therefore a white color. In addition, the pale color of some soils is due to the fact that it come from rocks poor in iron (e.g., white clays) (Prost and King 1983).

Likewise, if a soil has a whitish gray layer, which is only located on the surface, then this white color is indicative of the presence of lime (CaCO_3), gypsum (CaSO_4) or various salts. Indeed, this color is characteristic of an accumulation of salts in the soil and is useful for detecting carbonate or salty soils. In regions with low precipitation where evapotranspiration exceeds precipitation, instead of filling and leaving a basin area, the water collects and then evaporates, leaving behind trace amounts of minerals collected in the landscape around the basin. Saline soils can also form in low elevation locations (coastlines) where salty groundwater reaches the soil surface. This occurs in areas of saline seepage and saltwater intrusion. Soil salinization can also occur when the land has been irrigated with water rich in salts (Harter and Motis 2016).

Another colored constituent can be mentioned is jarosite. Indeed, jarosite (basic iron and potassium sulfate) is formed by oxidation of pyrite. It occurs in soils as pale-yellow spots and is responsible for the acidity of these soils ($\text{pH} < 4$). Jarosite is particularly present in soils found in estuaries, deltas and polders subjected to the action of the brackish tide, and which are generally covered with a specific plant formation (Baize 2000).

To conclude, iron and its oxides, organic matter, limestone (the main coloring agents) as well as jarosite, alteration of glauconia grains, alteration of pink sandstones, manganese, gypsum (CaSO_4) or the different types of salts are the coloring agents of soils. They give

the soil its dominant color. Therefore, the soil color varies according to the various combinations of these coloring agents of the soil and according to the humidity. Thus, by observing the color, we can have very important information on each of these constituents of the soil since the soil color is influenced by its mineral composition, by its organic matter content as well as by its water content (Torrent 1983, Prost and King 1983).

However, the mineral composition of a soil, its organic matter content and its water content are greatly influenced by the factors of soil formation. Indeed, depending on these factors, two soils formed from the same parent material can be very different if they have evolved under different climatic conditions. There are 5 factors that act on soil formation. These are the parent material from which the soil is derived, the climate, topography, time and vegetation type. These factors act on soils from their formation, but not to the same intensity. This is responsible for the creation of different types of soil having varied colors (Margulis 1954).

So, due to the temperature and humidity of the climate, the soil color in humid and hot regions and colder or arid regions are not the same. Truly, in humid and warm regions, soils tend to be more yellowish brown to red. This is caused by the hydration of ferric oxide, the significant alteration of the parental minerals and the rapid mineralization of organic matter which means the accumulation of an insufficient amount of humus. While in cooler regions, soils tend to have a grayish to black topsoil, due to the accumulation of humus. Arid soils tend to be lighter in color (due to low organic content) and mainly show the color of their parent mineral content. In addition, the texture has an influence on the color of the soil; coarse textured soils have lighter color (Gerbermann and Neher 1979).

2.2 Soil Fertility

Despite the importance of soil fertility in agriculture and agronomy, we note that there is no consensual definition of soil fertility. Existing definitions are either too precise or too vague (Patzeln *et al.* 2000). For example, the Soil Science Society of America (SSSA) defines soil fertility as the quality of the soil to help provide nutrients in adequate and balanced amounts to ensure the growth of given plants or crops. However, this definition creates confusion with the quality of the soil (Fardeau 2015).

According to Morel (1989), “the fertility of a soil responds to the ease with which the root can, in sufficient quantities, benefit in this soil from the various factors of plant growth: heat, water, all the chemical elements necessary for the plant, organic growth substances”. This definition implies on the one hand the existence or production in the soil of nutrients, on the other hand, the transfer to the plant of these elements (Morel 1989).

In addition, soil fertility is defined as the ability of the soil to meet the physical, chemical and biological needs necessary for plant growth in a manner appropriate to the plant type, soil type, soil use and to climatic conditions. A soil is said to be fertile for a type of plant according to its ability to meet the needs of the plant necessary for its productivity, its reproduction and the quality of these products for human and animal nutrition (Abbott and Murphy 2003).

Soil fertility can be improved. However, these strategies for an improvement and a better preservation of soil fertility cannot be generalized to all types of regions. Any recommendation should refer to a precisely defined situation after a study of the current state of soil fertility in a region (Pieri 1992). In the context of agricultural development, soil fertility is not the only factor that has an impact on plant growth. There are many other equally important factors. Indeed, the climate is also another factor that must be taken into consideration because average and extreme temperature limit plant growth. If the daytime temperature for several months exceeds 30°C, the life in the soil is very limited. As the average temperature of the earth increases, the climate factor must be the top priority of the world food system for the protection and maintenance of soils and their fertility (Pieri

1992). There is also the technology and manpower available to the farmer, which are factors to be taken into account because the realization of soil fertility cannot exist without the involvement of humans (Fardeau 1992). However, it should also be noted that degradation of soil fertility cannot occur without the human involvement (Steiner 1996).

First, the physical fertility of a soil is defined by the physical properties of that soil. The physical properties of a soil are the properties like depth, texture, bulk density and the structure of the soil. These soil properties are of paramount importance because they control the penetrating capacity of the roots and the movements of water and air within the soil (the soil porosity and its permeability), which affect growth of plants (Fardeau 2015).

The physical fertility of soils can undergo degradation processes, leading to a decrease in crop production. Degradation can be due to heavy rains and excessive tillage in cultivated soils, which degrade soil structure and increase soil compaction and erosion. In fact, compaction, crusting or the plow base are phenomena that can limit the physical fertility of a soil (Labreuche *et al.* 2014).

In addition, the lack of the clay-humic complexes due to the dispersion of clays and the loss of material by selective erosion and by mineralization of organic colloids, is an important sign of deterioration of the physical fertility of the soil. As the clay-humus complex harbors the stock of nutrients and controls their readiness for plants, then its availability is extremely important for plants (Soltner 2014).

Second, soil chemical fertility refers to the soil's ability to store and release the nutrients, including nitrogen, phosphorus, potassium, magnesium, calcium, and sulfur (macro elements), as well as trace elements (copper, iron, manganese, zinc, boron, etc.) that plants need. These elements are of paramount importance for the development of plants because macro-elements are involved in the formation of cell walls and the synthesis of amino acids, participate in energy exchanges and in the constitution of chlorophyll. Whereas the trace elements, present in less quantity in plants, they have metabolic roles as catalysts or inhibitors of various chemical reactions (Amiguet 2012).

It should be noted that the chemical fertility of soils also refers to the soil's ability to balance the various elements it provides to plants (no antagonism between two or more elements) and the soil's capacity to provide to plants neither a large amount, nor a small amount of the harming elements. This balance is important so as not to have either an excess of one or more elements that causes toxicity (phytotoxicity), or a deficiency of one or more elements. Chemical fertility corresponds to the abundance in sufficient proportions of essential nutrients (Amiguet 2012). However, the chemical fertility of a soil should not be confused with the potential chemical fertility of the soil (Mathieu and Lozet 2011). The potential chemical fertility of soil is the store of nutrients that are soluble or part of the solid soil matrix that are in dynamic equilibrium with the cations and anions in the soil solution. The potential chemical fertility of the soil is important especially in tropical regions where the rate of alteration of these minerals can be quite rapid. The size of the reserves that can be mobilized and the way in which they are converted into assimilable forms determine the capacity of a soil to remain chemically fertile or, on the contrary, to undergo rapid depletion (Pieri 1989).

In the latter case, the chemical fertility of the soil undergoes degradation processes (acidity and toxicity) leading to a decrease in plant production. Indeed, the useful "exchangeable bases" are replaced by elements useless for the nutrition of plants: hydrogen ions (H) or toxic ions (Al or Mn). This is responsible for a deficiency in the necessary elements to plants, an acidity of the soil due to the hydrogen ions released (the pH of the soil is then modified). We can also cite the salinization of the soil by irrigation water or by acid rain which leads to soil degradation. Thus, chemical fertility also concerns the pH, the abundance and composition of organic matter, and the size of the cation exchange capacity (Flisch *et al.* 2017).

Organic matter plays an essential role in soil fertility. Organic matter acts as a soil fertilizer (reservoir of nutrients) and as a guarantor of soil bioavailability. Indeed, the cation exchange capacity of organic matter ($150\text{--}250\text{ cmol}_c/\text{kg}$) is 10 times greater than the exchange capacity of goethite (Fe) and kaolinite ($2\text{--}5\text{ cmol}_c/\text{kg}$) (Huber and Schaub. 2011). That is, organic matter has a great capacity to retain cations (possibly charged nutrients)

on its surface by introstatic interaction and releases them when the plant needs them. It also guarantees that there are active biological transformations in the soil since the living organisms of the soil on which it nourishes, will recycle the nutrients (recycling of nutrients), interact with each other (promote biological interactions) and will reduce pathogenic populations. by eliminating them (Huber and Schaub 2011). In addition, soil-living organisms will come into the soil with a good amount of organic matter for food. Thus, organic matter guarantees biodiversity. It also improves the physical properties of soils because organic matter insulates the soil from thermal variations, lowers the bulk density of the soil, allows water to infiltrate into the soil while reducing the speed of runoff in the soil and allows living soil organisms (Huber and Schaub 2011).

Third, biological fertility corresponds to the capacity of organisms living in the soil (plants, bacteria, fungi, animals, protists) to contribute to plant nutrition (Abbott and Murphy 2003). Indeed, "the biological fertility of the soil is the capacity of the soil to meet the needs of the plants, in particular through the activity of the numerous microorganisms participating in biogeochemical cycles or in root symbioses" (Morel 1989).

Biological fertility includes the activities of earthworms and termites, which participate in the improvement of the physical properties of the soil (aeration, water infiltration, soil water retention, soil erosion, germination, demography and plant growth, greenhouse gas emissions, etc.) by digging galleries in the soil (Binet *et al.* 1996) as well as the distribution of resource availability for other species, through the creation of biopores and biogenic aggregates (Lavelle *et al.* 1997, Jouquet *et al.* 2006). Worms act on plants by releasing the nutrients available to plants (mineral N and P), by modifying the communities of microorganisms and by stimulating their activity, by releasing phytohormones or by stimulating symbioses between plants and microorganisms (rhizobium, mycorrhizae) (Barot *et al.* 2007, Chapuis-Lardy *et al.* 2010, Bernard *et al.* 2012). Earthworms and soil termites also participate in the decomposition of organic residues on the soil surface and soil organic matter as well as the recycling of nutrients (Lavelle and Spain 2001). They are called engineering organisms (Jones *et al.* 1994).

The presence of earthworms in agroecosystems results in an average 25% increase in crop yield and 23% above-ground biomass (Groenigen *et al.* 2014). But not all plants respond to the presence of earthworms the same way. Indeed, some worms are parasites and can cause significant economic losses in agriculture, not only through reduced yields, but also due to the cost of chemicals used to sterilize the soil. So, the positive or the negative impact of earthworms on agriculture depends on the species of worms and plants involved or the characteristics of the soil (Laossi *et al.* 2010).

Thus, the abundance and activity of earthworms and termites impact the functioning of the ecosystem (Lavelle 1988) and depend on the climate. Measuring their populations is quite destructive (Lavelle 1993). Apart from these two groups of organisms, other less widespread species may play a similar role in the regulation of ecosystem functions. This is the case, for example, with dung beetles in South Africa (Brown *et al.* 2010), white grubs, larvae of Scarabéideae Coleoptera (Brown *et al.* 2001, Rabary *et al.* 2008) ants and diplopods (centipedes).

The biological fertility of the soil also includes the activities of mycorrhizae. A mycorrhiza is the result of the symbiotic association between fungi and the roots of plants. These fungi are considered to be major elements of the soil / plant interface. Most plant roots (over 80% of vascular plant species) have or are likely to have mycorrhizal structures. This is due to the fact that the mycorrhizae is a very old phenomenon that appeared about 500 million years ago in the Paleozoic Era, probably at the same time as the first land plants and that it became widespread in all plants in the exception of a few families such as *Brassicaceae*, *Caryophyllaceae*, *Cyperaceae*, *Juncaceae*, *Chenopodiaceae* and *Amaranthaceae* which show very few mycorrhizal associations (Norman *et al.* 1995).

This symbiosis participates in the nutrition of the plant, in the decomposition and in the mineralization of plant organic matter (Gobat *et al.* 2003, Lambers *et al.* 2008). Fungal hyphae improve the water and mineral nutrition of the host plant and the production of various extracellular enzymes (phosphatase, phytase) capable of releasing phosphorus from complex organic and inorganic compounds in the soil. In return, the fungus benefits from

the carbon resources synthesized by the plant, which are essential for its metabolism and its fruiting (Gobat *et al.* 2003). This symbiosis also participates in the reduction or even the inhibition of the negative effect of certain pathogens (Smith and Read 2008) and in a better tolerance of mycorrhizal plants to metallic trace elements or to polycyclic aromatic hydrocarbons (Joner and Leyval 2003). Likewise, this symbiosis promotes the formation of aggregates and thus improves the structure of the soil. Indeed, the colonization of the soil by the extramatricial mycelium and the production of glomalin by the mycorrhizal hyphae lead to the formation of much more stable aggregates (Lovelock *et al.* 2004).

In addition, biological fertility includes the activities of microbial biomass. Microbial biomass is the central and active compartment of most models designed to account for changes in carbon and nitrogen in the soil (Molina *et al.* 1983). For example, cellulolytic bacteria are involved in the decomposition and mineralization of carbon, microorganisms with arylsulfatase activity are involved in the transformation of sulfur, microorganisms with phosphatase activity are involved in the transformation of phosphorus and other microorganisms are involved in the transformation of nitrogen (nitrifying agents, denitrifying agents, microorganisms with protease activity, etc.). Likewise, microbial biomass also participates in nitrogen fixation. For this reason, close to biogeochemical cycles, microbial biomass is an essential component of biological fertility and its measurement is a reliable biological indicator that can help to manage problems related to soil organic matter and certain pollutions (Powlson 1994). Finally, biological fertility includes the activities of protozoa and nematodes, which feed on microorganisms and release the nutrients they contain.

In the overall functioning of the soil, these three aspects of fertility (physical fertility, chemical fertility and biological fertility) are not additive, but act in interaction. That is, no fertility can hardly be approached independently from the others. This is the case with organic matter, which is an essential element in soil fertility. In fact, soil organic matter is involved in all three aspects of soil fertility. It is a reserve of harming elements (organic and mineral) for the plant and for soil microorganisms and provides soil structure (Huber and Schaub 2011).

Likewise, it should be noted that the pH (or hydrogen potential) is very important element in the overall functioning of a soil. Indeed, the indication of the concentration of H^+ ions present in the soil (the pH) induces in particular physicochemical constraints to the development of the plant because the low or high pH levels lead to a deficiency in plant nutrients (the availability of certain nutrients). When the soil pH is close to neutrality (between 6.5 and 7), it is considered the ideal pH and the root absorption of the elements present in the soil solution is optimal. However, ideal pH varies depending on the plant and its needs since plants do not have the same sensitivity to pH (Neina 2019).

In the case of an acidic pH, the concentration of H^+ ions is high and there is an excess of iron, aluminum and manganese which is very harmful for plants and magnesium and molybdenum, their solubility gradually decrease until they generate deficiencies (Neina 2019). Phosphate ions react with aluminum (Al) and iron (Fe) to form less soluble compounds. In addition, microorganisms are less active and therefore, they break down less organic matter. Knowing that nutrients each play a specific role in plant growth, corrective liming is necessary for acidic soils (Flisch *et al.* 2017).

In a soil, it is better to have a slightly acidic pH (for example from 6.5 to 6.8) than a pH above 7.5 because most nutrients (especially micronutrients) tend to be more available optimally at slightly acidic than at slightly basic pH, with the exception of molybdenum (Mo), which varies in an inversely proportional manner (Anonymous 2020).

To conclude, a sufficient soil depth, good soil structure, good drainage, a sufficient quantity of organic matter, sufficient water retention, a pH adapted to the needs of plants (5.5-7), a concentration sufficient quantity of the various nutrients essential to plants in assimilable forms, the presence of microorganisms favorable to plant development and good fertilization practice are the properties which generally contribute to soil fertility. Therefore, the term fertility is not in itself an individual asset but a set of physico-chemical and biological properties that characterize soil fertility.

2.3 Relationship between Soil Color and Soil Fertility

Although maps are essential tools for agricultural development, when making maps of soil crop suitability, opening soil profiles to describe and interpret soil morphology is a difficult and expensive work method according to the scale and area of the territory to be studied (Walter 2002). This method therefore represents a major constraint for some countries. This is why it is necessary to improve the methods of morpho-pedology by making them simpler and more comprehensive for farmers. For this purpose, soil color can be used as an indicator by establishing important functional relationships between soil color and soil fertility or rather, between soil color and those soil properties characteristic of soil fertility.

However, the color of soils does not usually have agronomic significance, since the same color can be due to different constituents and correspond to soils of different and uneven appearance and properties. Indeed, two soils having the same color as in the surface horizons can have different agronomic properties because of the very variable depths. However, in a region with a limited number of soil types, the color can be specific to a well-defined soil type and therefore involve specific agronomic properties. Thus, we are not talking about the relationship between soil color and soil fertility in general, but rather, a relationship between soil color and soil fertility in a local context.

Iron oxides and iron hydroxides (Sanchez-Maran~on *et al.* 2004, Scheinost and Schwertmann 1999, Schwertmann 1993), organic matter (Schulze *et al.* 1993, Konen *et al.* 2003) and the CaCO_3 are the three soil properties that most affect both soil color and soil fertility.

2.3.1 Soil color as related to iron and its oxides and soil fertility

The relationship between soil fertility and iron and its oxides, through color has been demonstrated by several studies. An analysis between the three fundamental quantities of the Munsell charter (hue, luminosity and chromaticity) and the iron content showed that the soil iron content was positively correlated with the soil luminosity (Courault *et al.* 1988). However, this correlation is much more important in the relationship between soil iron content and chroma. The regression analysis between soil properties and soil color parameters revealed an important relationship between chroma and iron content ($R^2 = 0.58$ for no disturbed soil samples and $R^2 = 0.66$ for disturbed soil samples) (Günel ve Erşahin 2006). The McCracken index, which is the product of hue and lightness, is by far the most significant variable in the model between the red tint of the soil and the iron content (Fe_2O_3) (Soileau and McCracken 1967).

In addition, a study carried out on hyperdystric ferralsol and dystic ferralsol showed that there is a decreasing gradient in soil fertility indicators (clay content, sand, silt, carbon, total nitrogen, total phosphorus, calcium, magnesium and potassium) with increasing yellowing of the shade. Thus, the dynamics of the water and the morphology of the area play a role for the amount of iron in the soil, therefore, in the color of the soil and in the fertility of the soil.

2.3.2 Estimation of the amount of organic matter by color

Organic matter can be estimated from the color of a soil. Moreover, it is accepted that light colored soils are considered less fertile than dark colored soils because they are poor in organic matter. Indeed, the quantity of organic carbon, responsible for the black color of the soil, allows characterizing the fertility of the soil. The variable most closely related to organic carbon is its color: the darker the soil, the richer the soil is in organic matter and therefore, the more fertile the soil.

The relationship between the color of the soil and its organic carbon content has been known for a long time by agriculturists to identify the most fertile soils. It was first described in 1923 (Brown and O'neal 1923). It was in 1951 that this relationship was first determined quantitatively, by the Munsell Color Chart. A significant correlation between the color of the soil and the amount of organic carbon contained ($r = 0.63$) in the soil has been demonstrated (Evans *et al.* 1985).

However, it should be noted that the texture of the soil has an impact on the level of darkening of the soil by organic matter. Indeed, the same amount of organic matter darkens sandy soils more than soils with a finer texture despite the same iron and aluminum content due to the fact that sandy soils have less contact surface to cover (Armson 1977). In addition, sandy particles scatter light less than finer particles (Schulze *et al.* 1993). Thus, the addition of texture as a parameter associated with color allows a more exact model of the fertility of the soil studied (Franzmeier 1988). Similarly, the use of the Munsell chart has an additional constraint when determining the relationship between the color of the soil and its fertility. Indeed, a large difference in organic carbon content results in only a small variation in color (two to three units of light). Thus, the use of the Munsell chart is not recommended to estimate the amount of organic carbon contained in the soil from its color since with the Munsell chart one can obtain an approximate model of the organic carbon content in the mineral soil (Schulze *et al.* 1993). On the other hand, the use of the spectrophotometer is recommended since it allows to assess the color more precisely and

therefore, we have a better estimate of the organic carbon contained in the soil from the color of the soil.

Thus, by taking into account the texture and using the spectrophotometer to define the soil color, significant correlations between luminosity and organic carbon content ($|r| > 0.5$), but of different intensities depending on the type of horizon were found (McKeague *et al.* 1971). In addition, by taking into account the texture of the soil and the characteristics of the study region (bedrock, vegetation and climate, etc.) as a variable, a highly significant correlation between the color of the soil and its fertility ($R > 0.9$) was found (Page 1974, Fernandez *et al.* 1988, Schulze *et al.* 1993). Using a colorimeter, a study that was done on Anatolian soils also had a significant relationship between soil color and soil organic matter content ($R^2 = 0.35$) (Günel ve Erşahin 2006).

However, the influence of organic matter on the soil color depends on the nature of the organic matter, i.e. the ratio between humic acids and fulvic acids. Indeed, depending on the nature of organic matter, the luminosity of the soil is infected by the water content and the concentration of organic matter (Shields *et al.* 1968).

Finally, to establish a model for estimating the organic carbon content of the soil from the color of the soil, the depth of the horizon is a very important variable to take into account. In fact, the color of the soil and the material varies depending on the depth. This reflects well the process of pedogenesis.

Thus, the mathematical expression of the relationships between soil color and soil organic matter can provide significant advantages in the management and sustainable use of soil by creating a model that takes into account all variables.

2.3.3 Relationship between CaCO_3 content and soil color

The amount of CaCO_3 in the soil influences its color. Indeed, there is a positive correlation with the luminosity of the soil and the quantity of CaCO_3 contained in the soil. This correlation of the relationship between soil luminosity and the amount of CaCO_3 is much greater than those with the other two soil color quantities (soil redness and soil yellowing) (Courault *et al.* 1988). Thus, a large amount of CaCO_3 in the soil results in a white coloration of the soil. This relationship is fully justified since in nature limestone is white in color.

3. MATERIALS AND METHODS

3.1 Study Area

3.1.1 Geographic and geological context

The study was conducted on a sloping agricultural landscape, approximately 20 km from Çankırı city center (near the Çankırı-Ankara Road and on the agricultural land of Aşağı Pelitözü). The study area is approximately 100 ha and representing, local soils in terms of topography and soil properties. The study area is located between 55°46'59"- 55°66'55" latitudes and 47°38'34" - 47°70'31" longitudes (Figure 3.1). Wheat cultivation has been practiced on the study area for over 50 years using the conventional tillage practices. Soil sampling took place two weeks after wheat was harvest. The elevation of study area is between 514 and 805 m.

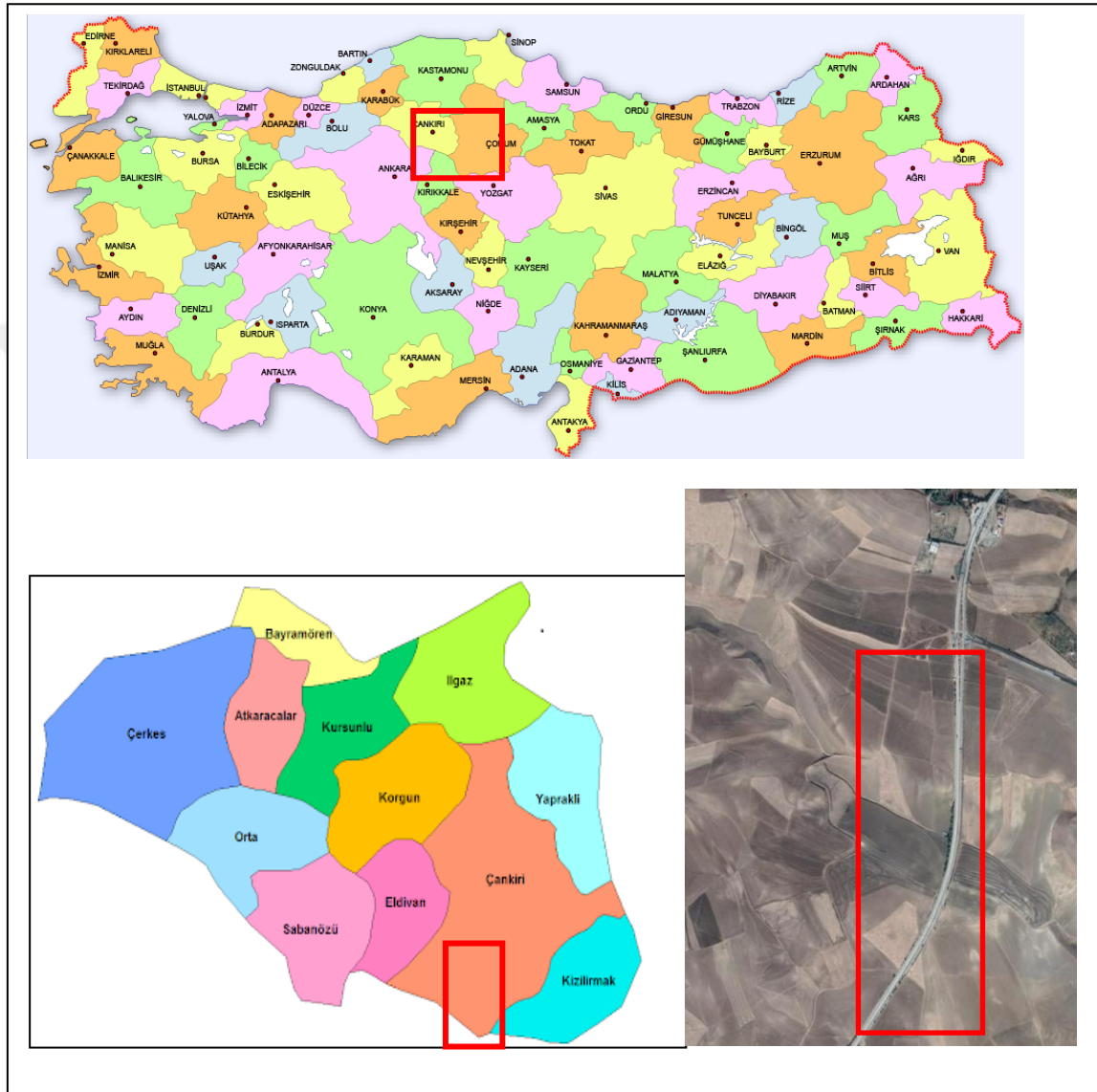


Figure 3.1 Location of study area

The study area is located in the Bozkır formation, which is an Upper Miocene geological formation. Off-white colored gypsum is the dominant lithology and there is clay and marl (green-gray in color) as an intermediate band with gypsum. Bozkır formation took place in a lagoon environment in a hot climate. Under this formation there is Kızılırmak formation in concordance. Kızılırmak formation is a red colored conglomerate composed of sandstone, clay, marl, and siltstone dating from the Upper Miocene. Underneath this geological layer, there is Bayındır formation in discordantly. Bayındır formation is a geological layer that is formed during upper Eosen and lower Miocene. Bayındır formation is composed of gypsum layer with sandstone, siltstone, and marl. Under this layer, there is İncik formation in concordance. İncik Formation is a burgundy-colored conglomerate with sandstone, siltstone, marl and loamy marl. Under this layer, there is the Kocaçay formation. It is a formation that consists of nummulite limestone. Then, in concordance, there is the formation of Sulakyurt dating from the paleosen composed of granite. Then, in unconformity, there is the Mesosoic Eldivano fiyolitly layer which is the oldest layer observed in the region (Şarp 2010) (Figure 3.2).

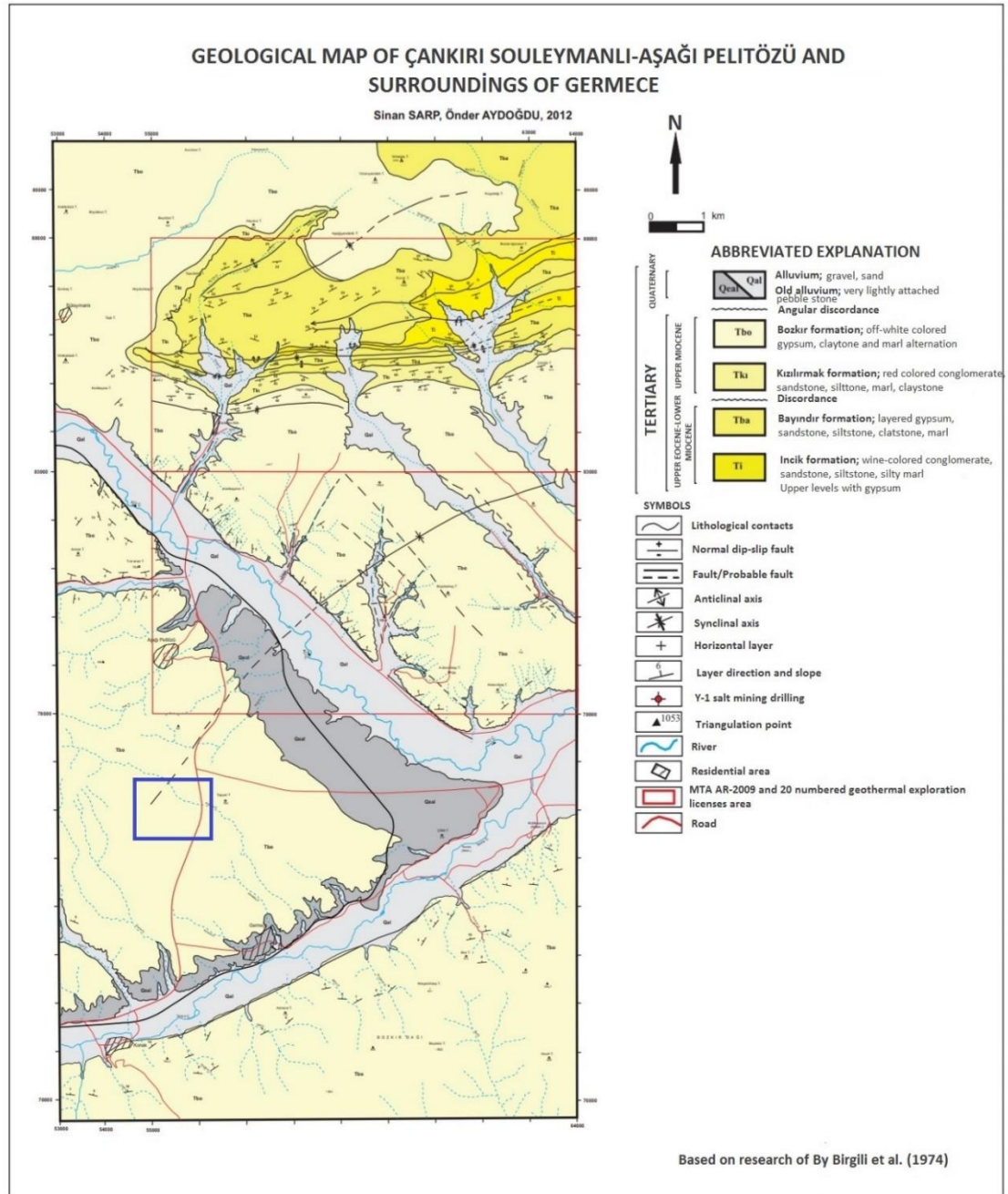


Figure 3.2 Localization of the study area (in blue square) on the Geological Map of region: Çankırı Souleymanlı-Aşağıpelitözü and surrounding Germece (Şarp 2010)

3.1.2 Climate

The study area is located between the steppe climate of central Anatolia and the western Black Sea climate. Thus, the study area has a semi-arid climate. Annual mean temperature is 11.3°C and the mean annual precipitation is 440.8 mm. The rainy period is between April and October (7 months). During this period, the amount of precipitation is 245.0 mm and the annual mean relative humidity is between 67% and 62%. Soil moisture regime is Xeric. Mean soil temperature at 50 cm depth in the center of Çankırı is 14.7°C, thus, soil temperature regime is classified as Mesic (Süenal 2018).

3.1.3 Soil sampling

Sampling took place on August 12 and 13, 2020. Using a shovel, 155 samples were taken from 0-40 cm depth, depending on the tillage depth of sampling sites (depth of topsoil). For each sampling site, the position was recorded using a GPS. During sampling, the samples were chosen not only randomly but also so that there were at least three representative samples from each area with a difference in color. The soil samples were then dried in a room, passed through a 2mm sieve and prepared for analysis. The color variability of the study area could be observed with the naked eye (Figure 3.3 and 3.4).



Figure 3.3 Variability in soil color on the study area



Figure 3.4 A view of the southern part of the study area

3.2 Methods

3.2.1 Determination of soil color with spectrometry

A spectrophotometer or spectrometer captures the intensity of a light beam on a small sample of soil (e.g., 1 cm in diameter) using three photoelectric cells as receptors, then it collects the spectra complete values (for each wavelength) and transform them mathematically (by applying algorithms) to values corresponding to the perception of the human eye.

The spectrophotometer or spectrometer gives numerical values L^* , a^* , b^* using the XYZ system defined by the International Commission on Illumination (CIE). The principle of this system consists in translating the color of an object into a point having X, Y, and Z coordinates (trichromatic values) in the CIELAB color space based on the values of the three primary colors (red, green and blue) and using graphics to define the color. Having been used widely since 1976, this system is a benchmark standard for objectively measuring color.

The numerical values of L^* , a^* , and b^* designate the three quantities, which characterize a color. L^* describes the brightness, which goes from L^* equal to 0 for black to L^* equal to 100 for maximum brightness. The two parameters a^* and b^* express the deviation of the color from that of a gray surface of the same lightness. The point a^* varies between red (values are positive in the range of red) and green (values are negative in the range of green). Point b^* varies between yellow (values are positive in the yellow range) and blue (negative values are in the blue range) (Figure 3.5).

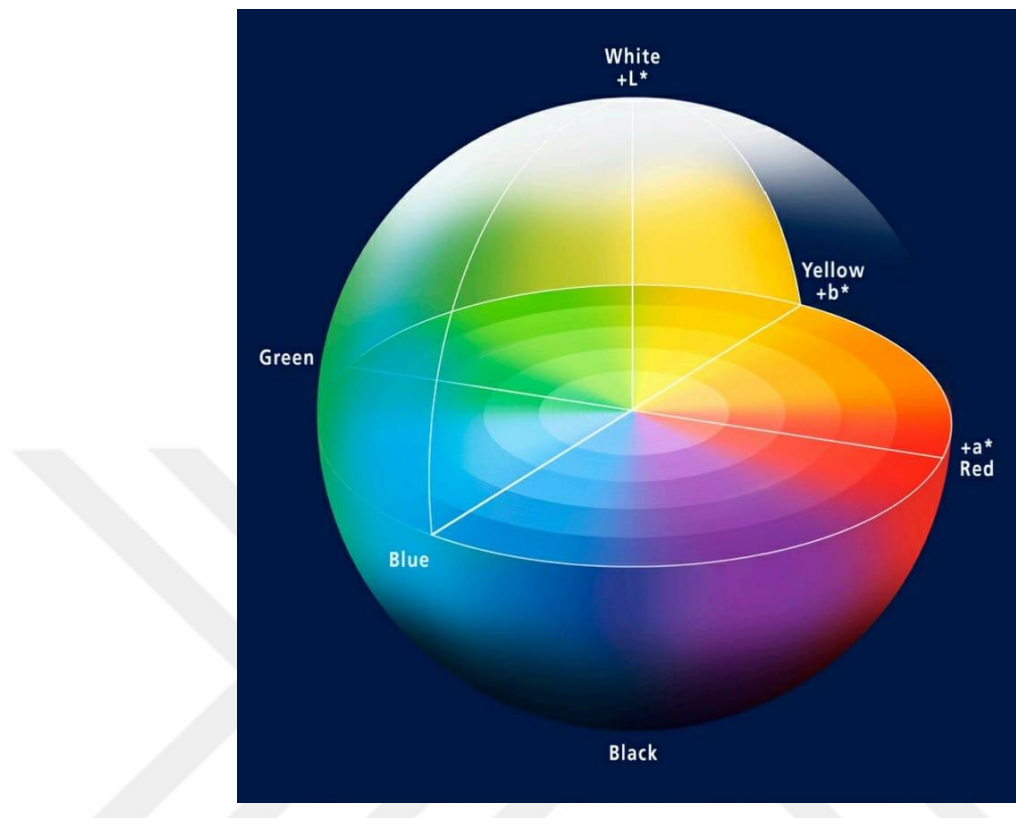


Figure 3.5 $L^*a^*b^*$ quantities in the CIELAB color space (Tobijaszevska *et al.* 2018)

The spectral properties of soils measured using a spectrophotometer are more or less closely related to the data determined using the Munsell color code. The principle of this analysis consists in placing a sample of soil under the colorimeter (Figure 3.6). In this study, the soil samples were sieved through a 2-mm sieve and placed in a cylindrical box having a radius of 1 cm and a height of 2 cm. The soil reflectance is drastically affected by soil water content. Therefore, first, the soil color was measured with air dry samples and then the samples were wetted to approximately field capacity and the measurements were repeated.

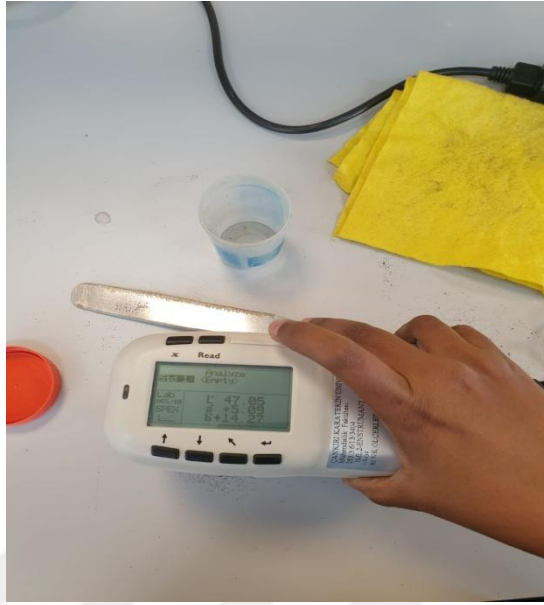


Figure 3.6 Soil color measurement in the Food Engineering Laboratory of Cankiri
Karatekin University

3.2.2 Analyses of basic soil properties

Analyses of 155 soil samples taken from the field were carried out in Soil Laboratory at Forestry Faculty of Çankırı Karatekin University. The soil variables analyzed and the methods used are given in the Table 3.1.

Table 3.1 Analyzed soil variables and the methods used for their analysis

Soil property	Methods/device	Reference
Soil color	Colorimeter	
Soil texture	Mechanical analysis	Gee and Boudier 1986
Available potassium content and available sodium content	Using a flame photometer	Kacar 1994
Field capacity	Pressure chambers	Cassel and Nielsen 1986
Wilting point	Pressure chambers	Cassel and Nielsen 1986
Available water capacity	Difference between field capacity and wilting point	Cassel and Nielsen 1986
Electrical conductivity	With an EC electrode in 1 / 2.5 soil-water suspension	Rhoades <i>et al.</i> 1999
Soil reaction (pH)	With a pH electrode in 1 / 2.5 soil-water suspension	Rhoades <i>et al.</i> 1999
Organic matter content	Walkley-Black method	Nelson and Sommers 1982
CaCO ₃ content	Scheibler calcimeter	Çağlar 1958
Available P content	Olsen method	Olsen <i>et al.</i> 1954
Aggregate stability index	Wet sieving	Kemper and Rosenau 1986

Visuals regarding with some soil analyses are given in Figures 3.7-3.11.



Figure 3.7 Analysis of the soil texture



Figure 3.8 Instruments and apparatus used in analysis of sodium and potassium



Figure 3.9 The pressure chamber and pressure plate used in measurement of field capacity and wilting point



Figure 3.10 Apparatuses used for the analysis of the phosphorus content



Figure 3.11 Apparatuses used in analysis of soil aggregates stability

3.3 Statistical Analysis

Regression equations were used in modeling the relationships between soil properties and soil color variables in Table 1 (Ott 1993). In the modeling, L^* , a^* , b^* values were taken as independent variables and soil properties as dependent variables. After the variables were graphed mutually in the Excel, the type of regression equation (linear, exponential, logarithmic, polynomial, etc.) was determined based on the shape of the graph. The L^* , a^* , b^* values obtained with air-dry and wet measurement of the same soil sample were used in regression analysis to find a more successful regression fit. The fit of the models was determined by considering the coefficient of determination (R^2) and the relative mean square error. Some outliers in data sets were trimmed to improve model fit for the variables. In this regards, 10 data points for EC, 8 for sand content, 5 for of CaCO_3 content, 9 for clay content, and 10 for K content were trimmed. Only the relationships between variables and L^* -wet, which were significant, were modelled. In statistical tests, the null hypothesis was rejected at 5% level of significance.

4. RESULTS AND DISCUSSION

4.1 Descriptive Statistics of Soil Properties

Descriptive statistics of the soil properties of the study area are given in Table 4.1. The majority of soils are clay. Sand content varies between 11.2% and 43.7%, with a mean of 25.7% and the clay content varies between 40.5% and 69.7% with a mean of 54.59%. Soil clay richness is compatible with the geology of this region. Indeed, the clay with the gypsum and the marl constitutes the geological layer of Bozkır formation (Şarp 2010). pH value varies between 6.80 and 7.69, with a mean of 7.15 (Table 4.1) and EC varies between 2.49 and 2630 $\mu\text{S}/\text{cm}$, with a mean of 472.1 $\mu\text{S}/\text{cm}$.

A soil variable with a $\text{CV} > 40\%$ is considered highly variable, between 15% and 40% is moderately variable, and $< 15\%$ is little variable (Mulla and McBratney 2000). Therefore, the soil texture components are moderately variable in the study area. In addition, a soil variable with a skewness (S) $< \text{absolute } 0.5$ is considered slightly skewed and deemed normally distributed, with $\text{absolute } 0.50 \leq S \leq \text{absolute } 1.0$ moderately skewed, and $\text{absolute } 1.0 < S$ is considered strongly skewed (Webster 2001). Thus, clay and sand contents are slightly and silt content is moderately right-skewed.

The mean of CaCO_3 content of soils is 17.12%. The values of CaCO_3 content have a moderately variable and slightly right-skewed distribution. Lime content is classified in five classes (Ülgen and Yurtsever 1974): between 0 and 1%, non-calcareous; between 1 and 5%, slightly calcareous; between 5 and 15%, moderately calcareous; between 15 and 25%, highly calcareous; and $> 25\%$, extremely calcareous. Therefore, the mean of CaCO_3 suggests that the soils are extremely calcareous (Table 4.1). High of CaCO_3 content certainly is originated from the parent material, gypsum and marl, which contain calcium, constitute two of the three lithology of the geological layer of Bozkır formation (Şarp 2010).

Organic matter (OM) content of soils varies between 0.62% and 2.95% with a mean of 2.19% (Table 4.1). Soils are classified in five classes according to their organic matter content (Ülgen and Yurtsever 1974). The first class (very low in OM) corresponds to soils with an organic matter content between 0-1%. The second class (low in OM) corresponds to soils with an organic matter content of between 1 and 2%. The third class (moderate in OM) corresponds to soils with an organic matter content between 2 and 3%, The fourth class (high in OM) corresponds to soils with an organic matter content of between 3 and 4%. The fifth class (very high in OM) corresponds to soils with OM content greater than 4%. Consequently, the OM content of soils was moderate (Table 4.1). The values of OM content are moderately variable and strongly left-skewed, suggesting presence of some extremely low-valued localities for OM in the study area.

Table 4.1 Descriptive statistics for properties of study soils

Soil property	N	Min.	Max.	Mean	SD	S	K	CV (%)
pH (1:2.5)	155	6.80	7.69	7.15	0.23	1.70	1.49	3.21
EC ($\mu S/cm$)	144	2.49	2630	472.1	521.31	3.16	9.31	110.43
Sand (%)	144	11.2	43.7	25,7	7,52	0.20	-0,68	29,28
Clay (%)	144	40.5	69.7	54.59	6.13	0.13	-0.25	11.23
Silt (%)	155	5.45	47.05	20.18	5.61	0.96	3.00	27.80
CaCO₃ (%)	150	4.65	32.76	17.12	6.22	0.38	-0.34	36.32
OM (%)	155	0.62	2.95	2.19	0.54	-1.10	0.64	24.65
N (%)	155	0.13	0.37	0.20	0.13	-0.77	-0.65	63.55
Na (mg/kg)	155	5.90	37.69	15.78	15.78	0.70	2.57	75.91
K (mg/kg)	144	13.51	65.1	38.94	12.98	- 0.008	-0.92	33.33
P (mg/kg)	155	0.123	2.082	0.245	0.209	6.161	44.993	85.23
FC (%)	125	19.54	42.06	30.56	4.53	0.21	-0.126	14.85
WP (%)	93	5.56	20.59	15.43	2.36	-1,02	2.75	15.34
AS (%)	155	0.327	0.611	0.492	0.055	-0.211	0.204	11.16

N: Number of samples, EC: Electrical Conductivity, OM: Organic Matter, N: Nitrogen, Na: Sodium, K: Potassium, P: Available Phosphorus, FC: Field capacity, WP: Wilting point, SA: Aggregate stability, Min: Minimum, Max: Maximum, SD: Standard deviation, S: Skewness, K: Kurtosis, CV: Coefficient of variation.

Potassium content varies between 13.51 and 65.1 mg/Kg and with a mean value of 38.94 mg/Kg (Table 4.1). The critical threshold of potassium in soil depends on several factors (Karamanos and Flore 2000).

The phosphorus content varies from 0.123 to 2.082 mg/Kg and its mean is 0.245 mg/Kg (Table 4.1). The phosphorus content in the soil is between 0.1 and 3.7 kg/ha (Sharpley *et al.* 1996). Phosphorous content of soils is highly variable in the study area. Also, its distribution is strongly right-skewed and highly positively kurtotic, indicating presence of a few extremely high-valued localities in the study area.

Soil aggregate stability analysis is a measure of the ability of soil aggregates to resist against degradation when exposed to external forces (water and wind erosion, shrinkage processes and swelling and tillage). Soil with high aggregate stability is more resistant to precipitation and water movement. Thus, stable aggregates are desirable. Analysis of the stability of soil aggregates allows decisions to be made about soil management because the stability of aggregates is an indicator of soil quality (Doran and Parkin 1996). The aggregate stability values in the study area vary between 0.327% and 0.611%, with a mean of 0.492% (Table 4.1), which indicates that the resistance of soils to erosion is not adequate.

Field capacity (FC) of the study soils varies between 19.54% and 42.06%, with a mean of 30.56 % (Table 4.1) and wilting point (WP) is between 5.56% and 20.59%, with a mean of 15.43% (Table 4.1). Texture has a great influence on water retention. Clay soils contain a large amount of water compared to sandy soils.

Descriptive statistics for soil color components are given in Table 4.2. Most prominent difference between values obtained on moist and air-dry samples occurred for L. The values for all three components (a^* , b^* , and L^*) show a slight variability in all the cases.

Table 4.2 Descriptive statistics of soil color variables

SMS	CC	N	Minimum	Maximum	Mean	SD	CV%
Dry	L*	155	36.13	63.26	47.85	5.92	12.38
	a*	155	2.86	7.86	5.19	0.86	16.61
	b*	155	11.05	19.93	14.68	1.50	10.22
Wet	L*	155	28.82	50.48	37.12	4.32	11.65
	a*	155	4.15	7.99	6.23	0.83	13.26
	b*	155	11.42	21.74	15.58	1.81	11.59

SMS: Soil moisture status, CC: color component, N: Number of samples, L: Brightness, a+: Redness, b+: Yellowness, SD: Standard deviation, CV: Coefficient of variation.

4.2 Relationship Between Soil Color Components (L*, a*, b*) and Soil Properties

The relationship between soil properties and the two parameters a* (soil redness) and b* (soil yellowness) are not very strong. The highest correlation coefficient was obtained between brightness (L*) for moist samples (L*-wet) and soil properties. Therefore, the regression models obtained between soil properties and L*-wet values were given hereafter.

4.2.1 Relationship between brightness (L-wet) and other soil variables

Relationships between pH, silt content, organic matter content, P content, FC, WP, and aggregate stability index and L* were not significant. Therefore, relationships between those soil properties and L* were not modeled.

A significant negative correlation occurred between sand content and L*-wet in study soils (Figure 4.1). The relationship was explained best by an exponential regression equation. The measurements of L*-wet associated to sand content more strongly than those obtained on air-dry soils (L-dry). Guo *et al.* (2012) found a stronger relationship between soil brightness and sand content ($r = 0.76$). A relatively lower relationship would be attributed to high clay content of the soils, which would mask the effect of sand content on soil brightness.

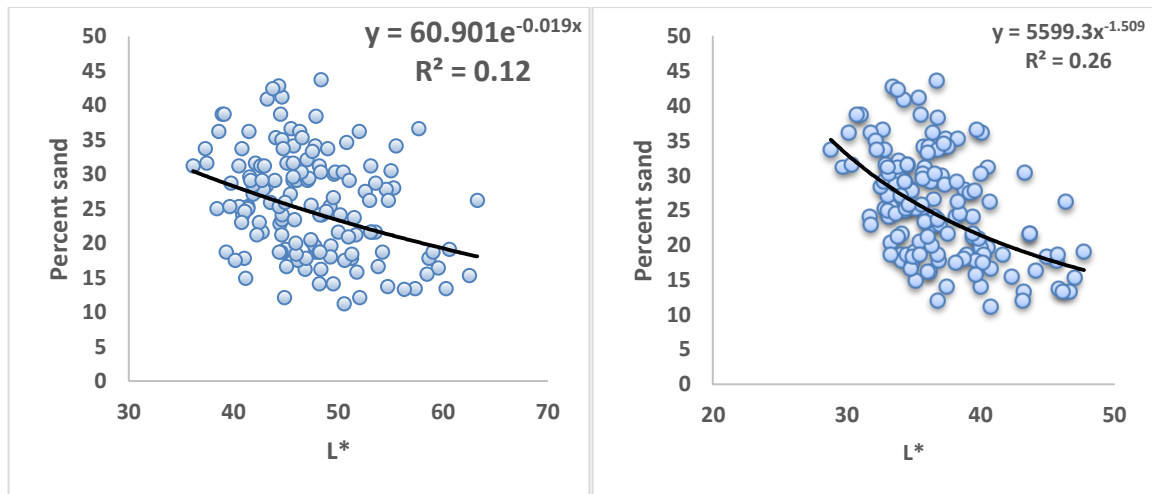


Figure 4.1 Relationship between sand content and L*: Dry soil (left) and Wet soil (right)

A positive linear relationship occurred between the values of L^* and clay content in both of moist and air-dry cases (Figure 4.2). Contrary to sand content, a positive relationship was obtained between L^* -values and clay content. This is consistent with the study by Li *et al.* (2001) who reported that sandy soils had lower reflectance than clay soils. In this study, no significant correlation was found between OM content and values of L^* , which was attributed high clay content and relatively low organic matter content of the study soils. High clay content of the soils would be weakening the relationship between OM content and L^* values. The same amount of organic matter darkens sandy soils more than soils with a finer texture despite the same iron and aluminum content due to the fact that sandy soils have less contact surface to cover (Armson 1977). In addition, sand particles scatter light less than finer particles (Schulze *et al.* 1993). Others (Günel ve Erşahin 2006) reported a significant relationship ($R^2 = 0.35$) between spectrophotometer-measured soil reflectance and soil organic matter content. Also, the influence of organic matter on the soil color depends on the nature of the organic matter, i.e. the ratio between humic acids and fulvic acids (Shields *et al.* 1968).

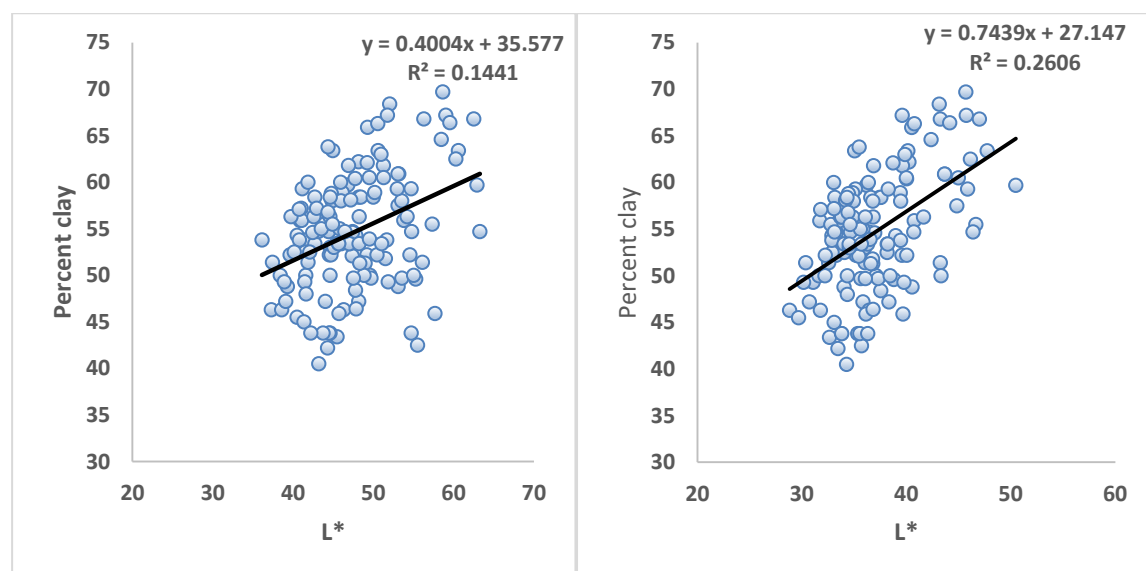


Figure 4.2 Relationship between clay content and L^* : Air-dry soil (left) and wet soil (right)

An exponential relationship was found between potassium (K) content and L* values in both of L*-wet and L*-dry (Figure 4.3). There is an inherent relationship between K content and clay content. However, contrary to clay content, K content was negatively associated with L*, which is highly interesting. Also, the relationship between L*-wet and K content is stronger than the relationship between L-dry and K content. This is related to the sensitivity of the soil color to humidity (Poss *et al.* 1991). In addition, the study carried out by Kone *et al.* (2016) which showed a positive linear correlation between the soil redness and K content. In fact, this study was carried out on ferralsols on the Ivory Coast, although red soils (2.5 YR) have a higher potassium content than yellow soils (7.5 YR and 10 YR) in the topsoil (Kone *et al.* 2016). However, for the soils in the study area, no correlation was found between the soil redness and K content. This can be explained by the low OM content of these soils which is responsible for the low K content because organic matter is responsible for the release of potassium in the soil and potassium is a low mobility nutrient (Hem 1992).

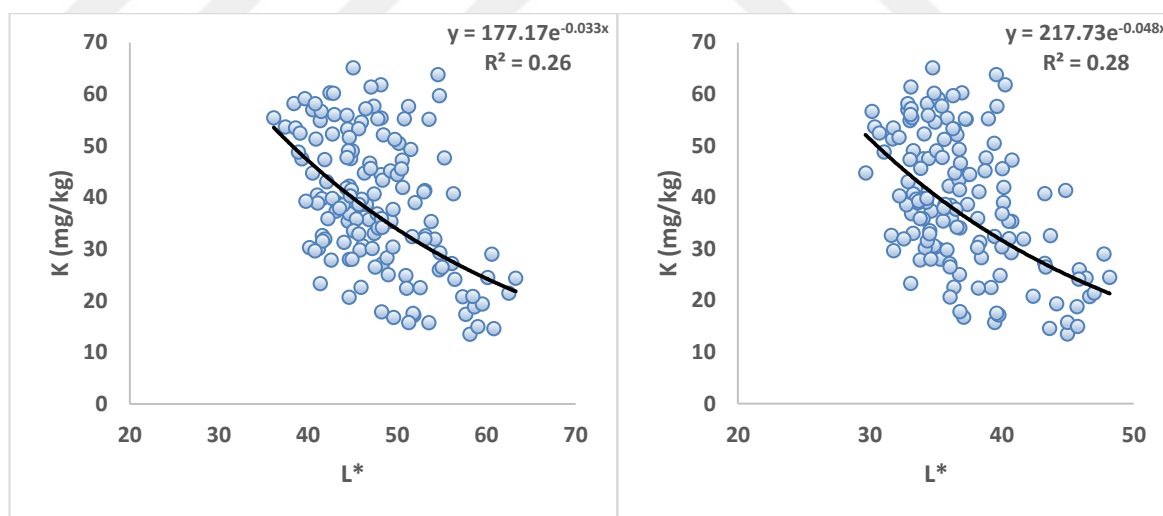


Figure 4.3 Relationship between potassium content and L*: Air-dry soils (left) and wet soils (right)

A third-degree polynomial regression equation described well the relationship between L* and EC of soils (Figure 4.4). Expectedly, increased EC resulted in increased L* values.

The relationship is more evident in the wet soils. The influence of EC on L^* is more pronounced between the range 700 and 2500 mS/cm in both cases (Figure 4.4).

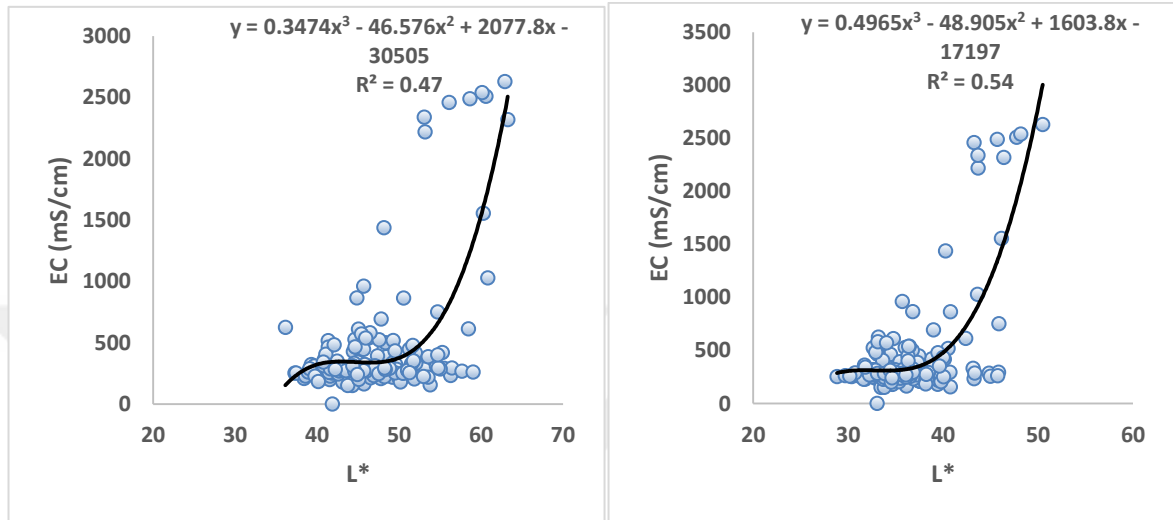


Figure 4.4 Relationship between EC and L^* : Air-dry soils (left) and wet soils (right)

A positive association occurred between CaCO_3 content and L^* values and a linear regression equation could successfully describe this association (Figure 4.5). Also, degree of association occurred between L^* and CaCO_3 was the greatest compared to those occurred between L^* and other soil properties. The results obtained in this study agree to those reported by Courault *et al.* (1988). The amount of CaCO_3 in the soil influences its color; there is a positive correlation between the luminosity of the soil and the quantity of CaCO_3 content. This correlation between soil luminosity and the amount of CaCO_3 is much greater than those with the other two soil color quantities (soil redness and soil yellowing) (Courault *et al.* 1988).

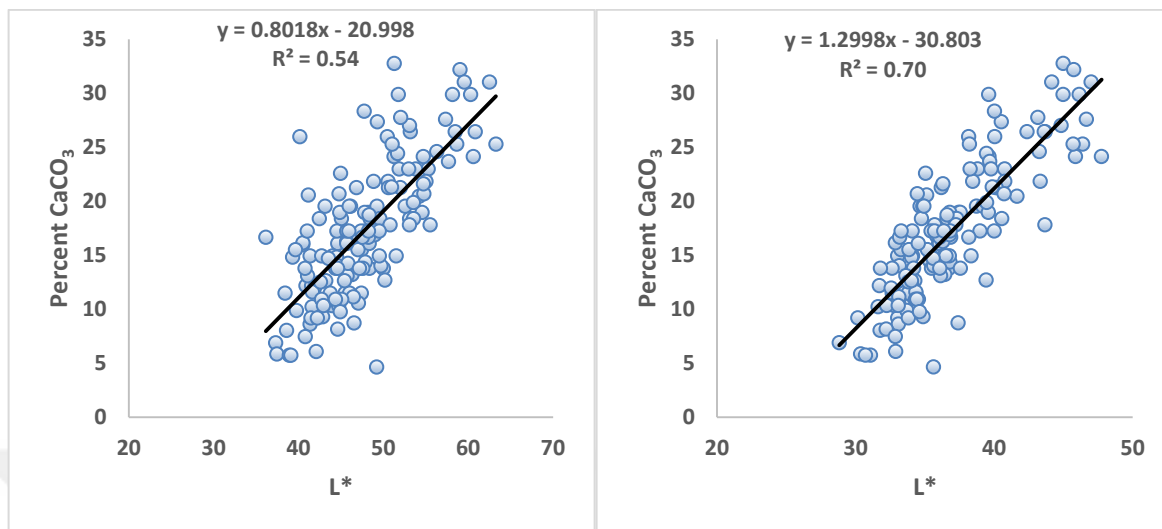


Figure 4.5 Relationship between lime CaCO₃ and L*: Air-dry soils (left) and wet soils (right)

5. CONCLUSION AND RECOMMENDATIONS

The relationship between spectrophotometer-measured soil color variables (L^* , a^* , b^*) and some soil properties were investigated. Soil samples were collected from a semi-arid sloping landscape under long-term dryland wheat cultivation. The correlation between L^* and some of soil properties were stronger than those between soil properties and either of a^* or b^* . In addition, the relationships between soil properties and L^* values of moist (approximately field capacity) (L^* -wet) soil samples were stronger than those obtained on the air-dry water soil samples (L^* -dry). Electrical conductivity (EC), clay content, sand content, potassium content, and CaCO_3 content were significantly correlated with both L^* -wet and L^* -dry, while silt content, OM content, FC, WP, and aggregate stability index were correlated insignificantly.

Soil CaCO_3 content appeared the most significant factor associated to L^* in study soils. A strong significant positive correlation was found between L^* values and CaCO_3 content. A first-degree linear regression equation could successfully describe the relationship between L^* and CaCO_3 content. Similar, to CaCO_3 content, EC was positively associated to L^* -wet and L^* -dry. However, relationship between L^* and EC was described the best by a third-degree polynomial equation. The relationship between L^* and EC is more noticeable in the EC range between 700 and 2500 mS/cm.

Unexpectedly, none of a^* , b^* , and L^* was significantly correlated with OM content in study soils. Extremely high CaCO_3 content and clay content would be masking the influence of OM content on L^* . Also, relatively weak association found between sand content and L^* values would be attributed to high clay content of the soils. High clay content would mask the relationship between sand content and L^* values. Interestingly, K content was correlated negatively with L^* , while clay content was correlated positively; while an inherent positive relationship is generally the case between clay content and K content of soils.

The results show that it is difficult to reach to a conclusion on fertility status of soils using their color in the study area. High CaCO_3 content of the soils is thought to be the main obstacle limiting prediction of soil fertility from color parameters. However, given that high CaCO_3 content restricts the growth of many crops, an idea can be drawn about the local areas with lighter color where high CaCO_3 is a problem by looking at the relationship between CaCO_3 and L^* in the study area. Also, the results showed that the measurement of L^* is sensitive to water content of the soil samples, which should be considered in future studies.

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