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Evaluation of Soil Color and Soil Fertility Relations on Cultivated Semi-Arid Sloping Landscapes

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Abstract: Soil color is a critical property, providing important information on soil properties. Soil color highly spatially varies on cultivated semi-arid sloping landscapes, indicating differences in soil properties that affect soil fertility. This study evaluated the relationships between color variables (L*: soil brightness, a*: redness, and b*: yellowness) and some basic soil properties on air dry and wet (around field capacity) soil samples, in a semi-arid sloping landscape having been under wheat cultivation for a long time. The values of color variables and soil properties were graphed and relationships between them were modeled using most proper regression models. The soil properties were poorly related to values of a* and b*, while $CaCO_3$, sand, clay, and K contents and EC were highly significantly correlated with values of L*-wet (L*-values obtained on moist soil samples). Soil EC and $CaCO_3$ content can be safely predicted by L*-wet in the study area. Also, the L*-wet should be preferred over L*-dry in predicting soil properties from soil color components in the study area and similar soils.

Keywords: Soil color, Soil fertility, Soil water content, semi-arid sloping landscapes

Ekili Yarı-Kurak Eğimli Bir Arazide Toprak Rengi ve Toprak Verimliliği Arasındaki İlişkinin Değerlendirilmesi

Öz: Toprak rengi, toprak özellikleri hakkında önemli bilgiler sağlayan kritik bir özelliktir. Toprak rengi, ekili yarı kurak eğimli arazilerde mekansal olarak oldukça değişkendir ve bu, toprak verimliliğini etkileyen toprak özelliklerindeki farklılıkları gösterir. Bu çalışmada uzun süredir buğday ekimi yapılan yarı kurak eğimli bir arazide hava kuru ve ıslak (tarla kapasitesi civarında) toprak örneklerinde renk değişkenleri (L*: toprak parlaklığı, a*: kırmızılık ve b*: sarılık) ile bazı temel toprak özellikleri arasındaki ilişkileri değerlendirilmiştir. Renk değişkenlerinin değerleri ve toprak özellikleri grafik haline getirilmiş ve aralarındaki ilişkiler en uygun regresyon modelleri kullanılarak modellenmiştir. Toprak özellikleri a* ve b* değerleriyle zayıf bir şekilde ilişkiliyken, $CaCO_3$, kum, kil ve K içerikleri ve EC, L*-wet (nemli toprak numunelerinde elde edilen L* değerleri) değerleriyle yüksek oranda anlamlı bir şekilde ilişkili çıkmıştır. Toprak EC ve $CaCO_3$ içeriği, çalışma alanındaki L*-wet ile güvenle tahmin edilebilir. Ayrıca, çalışma alanındaki toprak rengi bileşenlerinden ve benzer topraklardan toprak özelliklerinin tahmin edilmesinde L*-wet, L*-dry yerine tercih edilmelidir.

Anahtar Kelimeler: Toprak rengi, Toprak verimliliği, Toprak su içeriği, yarı kurak eğimli alanlar

1. Introduction

Soil is one of the most important components of agriculture and can have a significant influence on crop yields and quality. Rapid and accurate description of soil properties is critical in environmental and agricultural nexus. Technological solutions developed such as synthesis of fertilizers, site-specific management systems, and mapping and modelling of physicochemical and morphological soil properties provide key information to make proper decisions for sustainable use of soil resources in harmony with other components of environment. However, these technologies are not accessible by majority of farmers as they are expensive and time consuming (Walter 2002).

Soil color, which is one of the most important soil morphological characteristics, can provide information on mineral composition and organic matter (Fang et al. 1999), water, and nutrient contents (Shen et al. 2006; Budak et al. 2018). Soil color is widely used in soil research as it can be determined easily at a low cost (Günal et al. 2008). The light soil color indicates high calcium carbonate content, which suggests low fertility compared to dark brown to black soils, which are rich in organic matter (Shields et al. 1968, Schulze et al. 1993; Bigham et al. 1978, Schwertmann 1993). Soil color can also provide information on chemical processes as a function of the soil moisture regime (Ji et al. 2007).

Soil color components of a*, b*, and L* can be used as indicators for establishing important quantitative relationships between soil color and soil fertility or rather, between soil color and those soil properties affecting 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. 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 Chart (hue, value, and chroma) and the iron content showed that the soil iron content was positively correlated with the soil chroma (luminosity) (Courault et al. 1988). However, this correlation is much more important in the relationship between soil iron content and chroma. Organic matter can be estimated from the color of a soil. A study, which was conducuted on Anatolian soils also had a significant relationship between soil color and soil organic matter content (R^2 = 0.35) (Günal 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 (Shields et al. 1968). Moreover, it is accepted that light colored soils are considered less fertile than dark colored soils because they are poor in organic matter. The amount of $CaCO_3$ in the soil influences its color. Courault et al. (1988) reported that correlation coefficient between soil luminosity and the amount of $CaCO_3$ was far greater than those with the other two soil color quantities (soil redness and soil yellowing). Also, soil reflectivity measured at a wet condition (e.g., around field capacity) on a soil sample may be different from the one measured on dry condition (e.g., at air dry water content) of the same soil sample, resulting in different correlation magnitudes between a soil property (e.g., pH) and a color component (e.g., a*).

The objectives of this study were 1) to evaluate correlation between some principal soil basic soil properties and soil color components of a*, b*, and L* at wet (around field capacity) and dry conditions (at air dry water content) on an approximately 100-ha sloping landscape, showing color contrasts, under dryland wheat production, and 2) to evaluate differences between correlation coefficients at dry and wet conditions for the purpose of determining the proper soil water state for modeling soil fertility color relations in the study are.

2. Materials and Methods

2.1. Study Area

The study was conducted on a sloping approximately 100-ha cultivated landscape, 20 km from Çankırı city center (near the Çankırı-Ankara Road and on the agricultural land of Aşağı Pelitözü). Rainfed wheat has been grown in the study area for over 70 years using the conventional tillage practices (Fig. 1). Soil sampling was conducted after two weeks wheat was harvested. The elevation of study area is between 514 and 805 m. The study area is located in the Bozkır formation, which is an Upper Miocene geological formation. White colored gypsum is the dominant lithology and there is clay and marl (green-gray in color) as an intermediate bands with gypsum (Sarp 2010). The study area has a semi-arid climate; mean annual temperature is 11.3°C, and the mean annual precipitation is 440.8 mm. 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 (Sünal, 2018).

2.2 Soil sampling

Soil samples were taken at 155 sampling sites from approximately 0-30 cm soil depth (depending on the tillage depth at the sampling site). The sampling sites were discriminated to achieve condition that there were at least three representative samples from each area with a difference in color. The color variability of the study area could be observed with the naked eye Fig.1). For each sampling site, the position was recorded using a GPS. The soil samples were then dried in a room, passed through a 2mm sieve and prepared for analysis.

Figure 1. Location of study area
Şekil 1.*Çalışma alanının konumu*

2.3 Methods

2.3.1 Determination of soil color with a spectrometer

The spectrophotometer or simply 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. Having been used widely since 1976, this system is a benchmark standard for measuring the color objectively. 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).

2.3.2 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 1.

Table 1. Soil variables and the methods used for their analysis
Çizelge 1. *Toprak değişkenlerinde kullanılan analiz yöntemleri*

Soil property	Methods/device	Reference
Soil color	Colorimeter	
Soil texture	Mechanical analysis	Gee and Bouder 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 *et al.*1999
Soil reaction (pH)	With a pH electrode in 1 / 2.5 soil-water suspension	Rhoades *et al.* 1999
Organic matter content	Walkley-Black method	Nelson and Sommers 1982
$CaCO_3$ content	Scheibler calcimeter	Çağlar 1958
Available P content	Olsen method	Olsen *et al.*1954
Aggregate stability index	Wet sieving	Kemper and Rosenau 1986

2.3.3 Statistical Analysis

The descriptive statistics for soil properties and color components were calculated. The values for L*, a*, b* were graphed against the values of soil properties, and the relationship was modelled using the most proper regression model (linear, exponential, and polynomial). The performance of regression models was evaluated by coefficient of determination (R^2) and the relative mean square error. Some outliers in data sets of some soil variables were trimmed to decrease skewness of data and to improve model fit. 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. In statistical tests, the null hypothesis was rejected at 5% level of significance, unless stated otherwise.

3. Results and Discussion

Descriptive statistics of the soil properties of the study area are given in Table 2. Majority of soils are clay. Sand content varies between 11.2% and 43.7%, with a mean of 25.7%, and clay content varies between 40.5% and 69.7% with a mean of 54.59%. A soil attribute with a CV>40% is considered highly, between 15% and 40% is moderately, and <15% little variable (Mulla and McBratney 2000). A soil variable with a skewness (S) smaller than $|0.5|$ is considered slightly skewed and deemed normally distributed, between $|0.50|$ and $|1.0|$ moderately skewed and greater than $|1.0|$ is considered strongly skewed (Webster 2001). Kurtosis measures weighting of the tails relative to the middle of the distribution (Kleinbaum et al., 2013). Standardized kurtosis for a standard normal distribution is 3, and this value is often subtracted from the calculated value. The resulting statistic can be negative for flat distributions with short tails, approximately zero for a normal distribution, and it is positive for distributions with large tails (Kleinbaum et al., 2013).

Majority of the soil properties are moderately variable. Soil pH exhibited lowest and EC exhibited highest variability. Both of the variables had highly right-skewed distribution. Soil textural components behaved inconsistently in variability, kurtosis, and skewness. The greatest variably among soil textural components occurred for sand and lowest for clay content. The variability of clay content was far lower than those for sand and silt contents.

The mean of $CaCO_3$ content of soils was 17.12%. Soil $CaCO_3$ content had moderately variable, slightly negatively kurtotic, and slightly right-skewed distribution. Organic matter (OM) content of soils ranged from 0.62% to 2.95% with a mean of 2.19% (Table 2). The values of OM content were moderately variable, slightly positively kurtotic, and strongly left-skewed, suggesting presence of some relatively extremely low OM-valued localities in the study area.

Distributions for P and K contents are highly inconsistent in kurtosis, skewness, and coefficient of variation (CV) (Table 2). Witling point and FC had similar variability, while their values for kurtosis and skewness were highly inconsistent. Field capacity of the study soils varied between 19.54% and 42.06%, with a mean of 30.56% and WP 5.56% and 20.59%, with a mean of 15.43%; mean values for both of the variables are in accord with clay soils (Koorevaar et al., 1983). Aggregate stability values in the study area vary between 0.327 and 0.611, with a mean of 0.492 (Table 2), which indicates that the soil are moderately resistance to erosion. Values for AS showed a slightly variable, slightly left-skewed, and slightly positively kurtotic distribution.

Descriptive statistics for soil color components are given in Table 3. 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*) showed a slight variability in wet and dry cases.

The relationship between soil properties and the two parameters a* (soil redness) and b* (soil yellowness) were not adequately strong. The highest correlation coefficient was obtained between brightness (L*) for moist samples (L*-wet) and soil properties in all the cases. Relationships between L* and silt, OM, and P contents and soil pH, FC, WP, and aggregate stability index were not significant. Therefore, relationships between those soil properties and L* were not modeled.

Table 2 Descriptive statistics for properties of study soils
Çizelge 2 *Çalışma alanı topraklarının tanımsal istatistikleri*

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 (µS cm^{-1})	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
$CaCO_3$ (%)	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
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.

Table 3 Descriptive statistics of soil color variables obtained with air dry and wet (around field capacity) samples
Çizelge 3 *Hava kuru ve ıslak (tarla kapasitesi civarında) numunelerle elde edilen toprak rengi değişkenlerinin tanımlayıcı istatistikleri*

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.

Values for L* obtained with air dry soil samples (L*-dry) associated less strongly to soil properties compared to those obtained for L*-wet in all cases. A significant negative correlation occurred between sand content and L*-wet in study soils (Fig. 2). The relationship was explained best by an exponential regression equation. Guo et al. (2012) found a stronger relationship between soil brightness and sand content (r = 0.76) compared one obtained in this study.

Contrary to sand content, a stronger and positive correlation occurred between the values of L* 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* in either cases, which would be attributed to high clay content of the study soils, which be offsetting the effect of organic matter on soil reflectance.

An exponential relationship was found between potassium (K) content and L*-values in both cases (wet and dry cases) (Figure 4). 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, similarly to clay content, the relationship between L*-wet and K content is a little stronger than the relationship between L*-dry and K content.

A third-degree polynomial regression equation successfully described the relationship between L* and EC of soils. Expectedly, increased EC resulted in increased L* values. The relationship is stronger in the wet soils. The influence of EC on L* is more pronounced between the range 700 and 2500 mS cm^{-1} in both cases (Fig. 5).

A positive association occurred between $CaCO_3$ content and L* values and a linear regression equation could successfully describe this raltionship (Fig. 6). Also, degree of association occurred between L* and CaCO3 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).

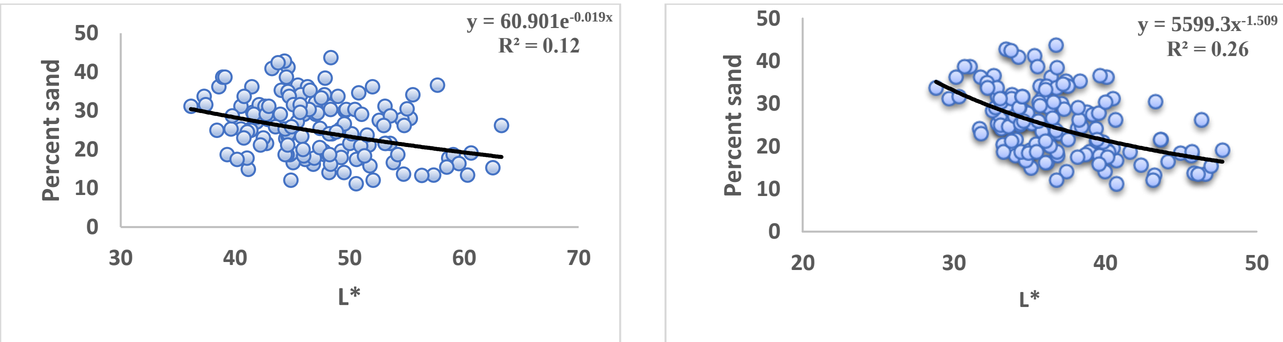

Figure 2. Relationship between sand content and L*: In dry soil (left) and Wet soil (right)
Şekil 2*. Kum içeriği ve L*: arasındaki ilişki Kuru toprakta (solda) ve Islak toprakta (sağda)*

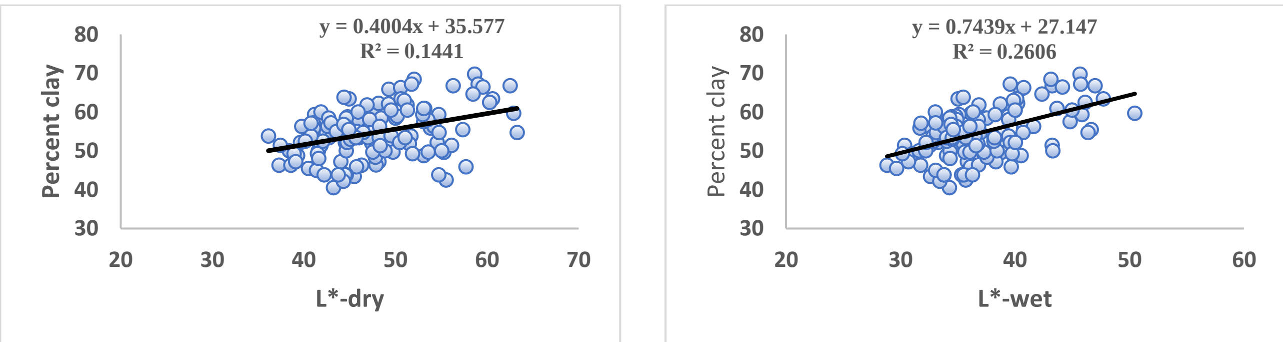

Figure 3 Relationship between clay content and L*: In air-dry soil (left) and wet (around field capacity) soil (right)
Şekil 3*. Kil içeriği ve L*: arasındaki ilişki Hava-kuru toprakta (solda) ve ıslak (tarla kapasitesi civarında) toprakta (sağda)*

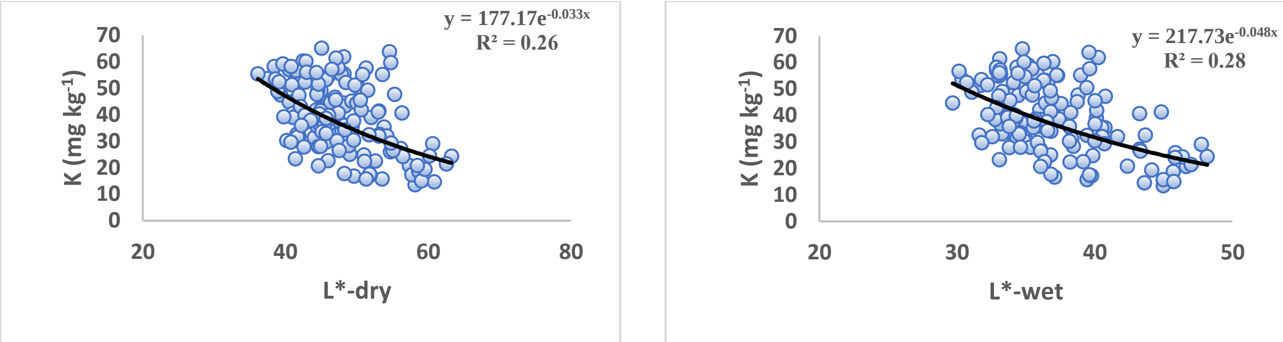

Figure 4. Relationship between potassium content and L*: In air-dry soils (left) and wet soils (right)
Şekil 4. *Potasyum içeriği ile L*: arasındaki ilişki Hava-kuru topraklarda (solda) ve ıslak topraklarda (sağda)*

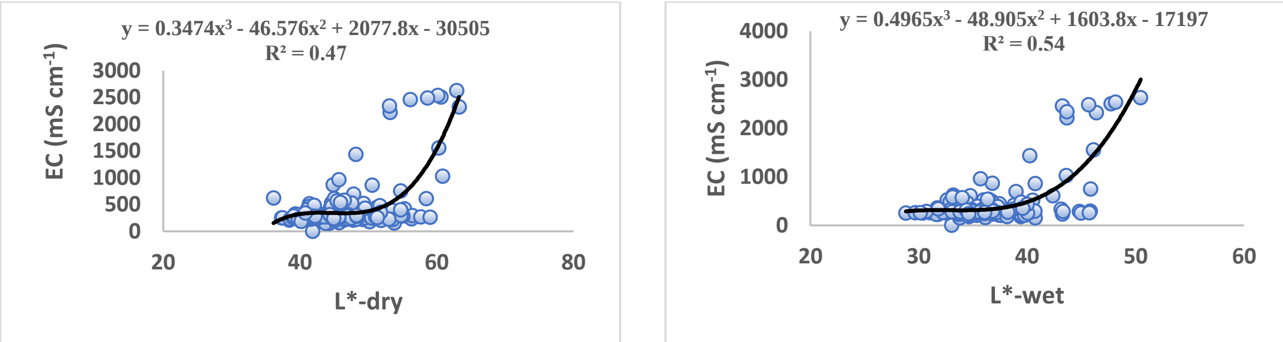

Figure 5 Relationship between EC and L*: In air-dry soils (left) and wet soils (right)
Şekil 5. *EC ve L* arasındaki ilişki: Hava-kuru topraklarda (solda) ve ıslak topraklarda (sağda)*

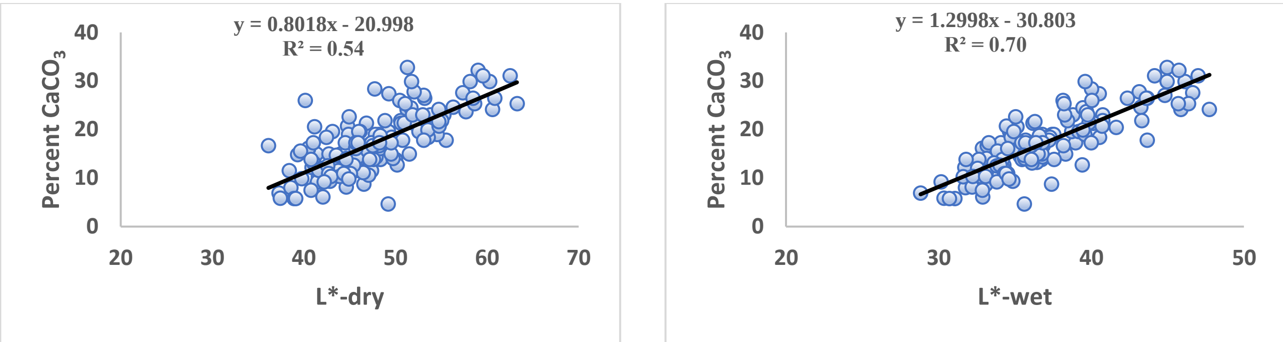

Figure 6 Relationship between lime $CaCO_3$ and L*: In air-dry soils (left) and wet soils (right)
Şekil 6. *Kireç $CaCO_3$ ve L*: arasındaki ilişki Hava-kuru topraklarda (solda) ve ıslak topraklarda (sağda)*

4. Conclusions

Limited number of soil attributes were adequately correlated with soil color component of L*. Most of the soil attributes were correlated to color components of a* and b* either insignificantly or significantly but weakly. The L*-values obtained on wet soil samples (L*-wet) were correlated more strongly with soil properties in all the cases. Clay, sand, K, and $CaCO_3$ contents and EC were significantly and adequately strongly associated to values for L*-wet and L*-dry. The most strong association occurred between CaCO3 content and L*-wet. A linear regression equation could successfully describe the relationship between $CaCO_3$ and L* in both cases. Also, a relatively high association occurred between EC and L*-wet. A three-degree polynomial regression equation could successfully model the relationship between the two attributes. Soil textural components of sand and clay content were significantly moderately correlated with both of L*-wet and L*-dry. Similarly, to soil textural components soil K content was moderately significantly correlated with L* in both cases. The L*-wet can be used to predict soils rich in $CaCO_3$ high in EC. Also, that high $CaCO_3$ content and EC restrict the growth of many crops, an idea can be drawn rapidly and easily on the local areas with lighter color that rich in $CaCO_3$ and high in EC. It was concluded that the measurement of L*-wet should be preferred over L*-dry in modeling soil color-soil properties relations.

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