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# RELATIONSHIP BETWEEN SOIL COLOR AND SOME PROPERTIES OF IRAQI SOIL UNDER DIFFERENT CLIMATIC CONDITIONS

Omar Alsalam[*1] Y.A.A. Sabry[2] Abdulghafour Ibrahim Hamad[3]
Baqi D.S. Al Maamouri[4] Sawsan Ahmed Mohammed[5]
[1&4] Department of Soil Science and Water Res. - College of Agricultural Engin. Science - University of Baghdad, Baghdad, Iraq.
[2] Department of Soil Science and Water Res. - College of Agricultural Engin. Science - University of -Salahaddin-Erbil, Iraq.
[3&5] Department of Desert. Combat - College of Agricultural Engin. Science - University of Baghdad, Baghdad, Iraq.

## ABSTRACT

**Soil color a basic quality of assessing pedogenesis and climatic effects hence, may provide valuable insight into soil properties and may serve as a distinctive and straightforward measurable climatic indicator. In this study, surface horizons samples were sampled at depth 0-30 cm by using an auger in ten provinces of Iraq where the climate conditions are different. Although the different physicochemical properties such as (Soil Texture pH, EC, O.M. CEC, $CaCO_3$) were identified in the lab section, the Munsell Soil Color Book was applied in the field to identify the soil color. The result showed a rise in (pH, O.M., CEC, $CaCO_3$, $Fe_d$, Clay) based on the color indices BWR, $TR_1$, and $TR_2$ in sub-humid climate areas; however, under the same climatic conditions, EC and $CaSO_4.2H_2O$ levels were lower. While Xanthization was more common in semi-arid areas, the processes of Melanization and Runification were more active in humid environments. Multiple regression analysis indicated a statistically significant relationship between BWR and $CaCO_3$, as well as between $TR_1$ and $CaSO_4.2H_2O$. No significant relationship was detected between $TR_2$ and the soil properties under investigation. Furthermore, linear regression analysis between climate and the BWR soil color index demonstrated a significant association, with value $R^2$ = 0.33 at a significance level of 0.01. Research findings demonstrated that Iraqi soil climate shows direct correlation to the BWR index specifically.**

**Key words: climatic change, color indices, multiple regression, munsell system, pedology.**



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## INTRODUCTION

The assessment of soil color proves essential for pedologists because it discloses vital information about soil developmental phases together with their age and composition (Pegalajar et al., 2020; Pegalajar et al., 2023). Additionally, soil color is essential for differentiating across horizons in a soil profile, which helps pedogenic development assessment (Apon and Sultana, 2024). The hue of soil enables agricultural suitability testing as well as fertility evaluation for potential agricultural purposes. According to (Jyothirmaya et al., 2019), visual soil color assessment provides a quick and simple way to assess soil difference, and using soil color as a guide for inferring many soil processes is a useful strategy. The Munsell Soil Color Charts function as a widespread technique to evaluate soil color for land use and soil classification investigations (Soil Survey Staff, 2014). The Munsell chart contains 238 rectangular color

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chips which all share the same color (Simonson, 1993; Alsalam et al., 2025), Three coordinates organize a color scheme including hue (H), value (V) and chroma (C) (Liu et al., 2020; Pegalajar et al., 2023). Soil experts perform visual color comparisons between soil samples and Munsell color chips even though perception and environmental factors might affect their interpretations (Stiglitz et al., 2016) and Environmental Conditions. Soil quality assessments can use Munsell color evaluation because it proves to be an effective substitute that can be readily assessed (Moritsuka et al., 2019).Therefore, the combined presence of humus (black), iron hydroxides and oxides (red to yellow), and silicates and carbonates (white to gray) frequently result in the hue of the soil (Abdulridha and Essa, 2023; Rutgers, 2024). One of the main factors affecting the genesis, properties, and classification of soil is climate. The difference in soil color between climatic zones is indicative of its influence (Fayyadh and Sindi, 2021 ; Alshamary et al., 2022). Soils containing organic matter usually display lower Value and Chroma measurements according to the Munsell scale because organic matter is commonly found in dark-colored soils. Such soils exist in humid climate types characterized by heavy organic layer cover. The soil surface where vegetation thrives abundantly. The process of organic matter accumulation darkens surface horizons of the soil ranking towards higher total organic carbon (TOC) levels while accelerating heating rates (Silva et al., 2016). On the other hand, reddish-colored soil indicates the existence of free iron oxides, which are indicative of well-drained soil. Higher Hue values (such as 10YR–5YR) show a predominance of yellowish-brown degrees, which are frequently created when iron is mobilized from primary minerals in environments with low temperatures, significant rainfall, and mild acidity (Chen et al., 2010 ; Alsalam et al.,2020). On the other hand, the concentration of salts like Ca, Mg, Na, and K, which precipitate close to the surface and provide deeper soil hues due to the hydrated salt content, influences the dominating color in hot, dry conditions like desert soils (Jorge et al., 2021 ; Demir et al., 2022 ; Saleh et al., 2023). In fact, research on soil color characterization began as early as the 20th century, with a focus on establishing relationships between soil color and dominant soil minerals—particularly iron-bearing minerals such as hematite, goethite, and limonite. Tiruneh et al (2024) examined semi-arid soils in southern India, where red coloration indicated the presence of hematite, which stimulates the Runification process by dissolving iron from primary minerals and depositing it in red quartz-rich coatings. Comparably, (Jorge et al., 2019) determined that hematite, goethite and limonite were the primary factors in which the soil turned yellow and reddish; the formation of which is highly connected to climate. Therefore, it can be concluded that soil color can be used as a measurable and climate sensitive indicator, and it has a promising future in the interpretation of climatic and morphological soil changes. There is a sporadically absent comprehensive research of the relevance of the connection between soil color and its other soil attributes within the climatic regions of Iraq. Soil color, especially concerning the indices of soil color in different parts of Iraq, is a pointer of pedogenic processes and a very vital element in the processes of soil formation. Based on that, this research took a focused approach to define the key factors that affect the variability of soil color in the country. The use of soil samples in the present study has been to sample the surface horizons of all parts of Iraq to understand the degree to which soil

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color depends on the different climatic conditions and thus the reason behind soil formation in the area. The results have shown that soil colors changed depending on other climatic factors such as rainfall, temperature regime, topography, such as elevation and the gradient of the slope. The hypothesis indicated that climate is one of the main natural factors that govern the color of the soil hence the ability to differentiate the soil types in Iraq. Theoretically, soil color might be used as a quick measure of climatic conditions. Moreover, this paper assumes that a strong correlation can be created between the indices of soil color and the physical and chemical properties of soils and wider climatic changes. Therefore, the main purpose of the study was to determine the importance of soil color in estimating the main soil properties under various climatic conditions in Iraq, determine quantitative correlations among soil color indices and determinations of the main soil properties and clarify the essentiality of documenting soil color in accordance with the Munsell Soil Color Charts. Such observations will eventually lead to improved systems of soil classification and interpolation.

## MATERIALS AND METHODS

**Study area:** The sampling of the soil was done on May 8, 2024 to August 10, 2024. Auger was done in different parts of Iraq that have different climatic conditions and vegetation coverings at surface horizons (030 cm depth). The sampling sites were varied in terms of rainfalls, starting at 100mm up to 1100mm per year, and located in the northern, central and southern regions of Iraq. The governorates that were chosen include Duhok, Erbil, Sulaymaniyah, Kirkuk, Mosul, Diyala, Baghdad, Wasit, Dhi Qar, and Basra. Table 1 provided the exact coordinates of all locations where the samplings were conducted. Direct comparison of soil color with Munsell Soil Color Charts was done to determine soil color in the field. All sampling sites were mapped by the GPS in order to create a detailed map that would represent the study areas. After the field collection, the soil samples were put in the labeled plastic bags, and a thorough and correct description of site-specific data was taken to be subjected to the necessary lab tests.

### Climate Zones of the Study Area

The climatic data of study regions such as monthly and annual average of rainfall and maximum and minimum temperatures of the years 2014-2024 was collected through the available records of the meteorological stations affiliated to the Ministry of Agriculture that is, Agricultural Meteorological Center and the Marketing Department, which are part of the same ministry as reflected in Figure 1. These climatic data show that the driest month is July where the rainfall is averaged at 0.44 mm. On the other hand, the highest quantity of rainfall is registered in January, under average of 51.02 mm. The total average annual rainfall in Iraq is estimated at 315.36 mm. The time of the rainy season ranges between September and May and January is the wettest month whereas the dry season lies between June and August. Climatologically, there are three regions in Iraq depending on the amount of rainfall they receive annually. The first one is the semi-humid region, which covers the northern part of Iraq as well, as samples 1 to 7 (Table 1). The climate of this region is cool and wet in the winter season and dry and warm in the summer season, with 500 to 1100mm rainfall. The second one is the semi-arid area, which is depicted in sample 8 to 10 and is shaped by a Mediterranean climate, that is, hot, dry summers and cold, wet winters, and the rainfall is 180 to 500 mm. The third and the largest is the arid zone which is depicted by samples 11-21 and which covers a large part of central and south Iraq. The area is characterized by minimal annual precipitation (less than 180 mm) and high temperatures, summers are characterized by extreme heat and dryness and short and cold winters. The moisture loss through evapotranspiration in

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these regions is far much more greater than the amount of rainfall per year. Figure 1 shows that the lowest temperature was 8.96°C in January and 34.89°C as the highest average temperature in July.

**Laboratory analysis of soil properties**

After collecting soil samples from ten Iraqi provinces, comprising a total of twenty-one samples covering the study areas, the soils were air-dried, crushed, and grinded using a ceramic mortar, then sieved through a 2 mm mesh. The processed samples were stored in plastic containers and transported to the Soil Survey and Classification Laboratory in the Department of Soil and Water Resources, College of Agricultural Engineering Sciences, for the required physical and chemical analyses, as detailed below:

The relative distribution of soil separates was determined using the hydrometer method as described by Day (1965). Soil pH and (EC) were measured in accordance with the guidelines of the Soil Survey Staff (2004). Organic matter was quantified via the wet oxidation method using potassium dichromate, following the procedure outlined by Jackson (1958). Carbonate minerals were assessed using the Calcimeter method as described by the Soil Survey Staff (2004), while free iron oxides were extracted using the dithionite-citrate-bicarbonate (DCB) method described by (Hesse, 1972). Gypsum content was estimated using acetone according to the method (Lagerwerff et al., 1965). Cation exchange capacity (CEC) was determined using the sodium acetate (1*N*) method buffered at (pH=8.2) The soil samples were first saturated with sodium ($Na^+$), after which the excess sodium was removed using 99% ethanol. Subsequently, the sodium ions were replaced with ammonium ions ($NH_4^+$), and the remaining sodium concentration in the final extract was measured using a flame photometer, as described (Page et al., 1982).

**Table 1. Details the climatic conditions, parent material and coordinates for the twenty-one soil samples collected from the study area**

| Province and Region Name | Sample No. | Coordinates East | Coordinates North | Average Annual Total Precipitation (mm) | Climate Type | Base Material |
|---|---|---|---|---|---|---|
| Dohuk - Semel | 1 | 42°51′46″ | 36°51′36″ | 500.2 | Semi humid | Limestone |
| Erbil - Qorato | 2 | 44°27′38″ | 36°56′34″ | 1065.7 | Semi humid | Limestone |
| Erbil - Shirawa | 3 | 44°16′30″ | 36°24′22″ | 1003.9 | Semi humid | Limestone |
| Erbil - Grdarasha | 4 | 44°16′28″ | 36°24′18″ | 650.0 | Semi humid | Limestone |
| Sulaymaniyah - Khalkan | 5 | 44°25′36″ | 35°59′19″ | 747.0 | Semi humid | Limestone |
| Sulaymaniyah - Dokan | 6 | 45°05′03″ | 35°50′03″ | 714.6 | Semi humid | Limestone |
| Sulaymaniyah - Bakira Khtiari | 7 | 45°22′08″ | 35°34′08″ | 548.1 | Semi humid | Limestone |
| Mosul - Faida | 8 | 42°59′12″ | 36°37′59″ | 177.82 | Semi humid | Limestone |
| Kirkuk - Altun Kupri | 9 | 44°07′44″ | 35°46′07″ | 137.53 | Semi humid | Limestone |
| Diyala - Khanaqin | 10 | 45°27′04″ | 34°22′35″ | 178.33 | Semi humid | Limestone |
| Baghdad - Abu Ghraib | 11 | 44°12′26″ | 33°21′43″ | 105.86 | Arid | Limestone |
| Baghdad - Al-Rashidiya | 12 | 44°21′51″ | 33°25′44″ | 122.6 | Arid | Limestone |
| Wasit - Kut | 13 | 45°41′26″ | 32°39′16″ | 80.4 | Arid | Calcareous Alluvium |
| Wasit - Al-Suwaira | 14 | 44°46′27″ | 32°55′01″ | 92.1 | Arid | Calcareous Alluvium |
| Wasit - Sheikh Saad | 15 | 46°35′22″ | 32°46′28″ | 108.2 | Arid | Calcareous Alluvium |
| Dhi Qar - Al-Shatra | 16 | 46°19′36″ | 31°32′45″ | 23.33 | Arid | Calcareous Alluvium |
| Dhi Qar - Al-Jabayish | 17 | 46°57′49″ | 30°57′25″ | 47.2 | Arid | Calcareous Alluvium |
| Dhi Qar - Suq Al-Shuyukh | 18 | 46°26′31″ | 30°55′18″ | 66.46 | Arid | Calcareous Alluvium |
| Basra - Al-Faw | 19 | 48°18′49″ | 30°06′15″ | 125.4 | Arid | Calcareous Alluvium |
| Basra - Abu Al-Khaseeb | 20 | 48°04′54″ | 30°23′37″ | 60.6 | Arid | Calcareous Alluvium |
| Basra - Al-Rumaila | 21 | 47°43′44″ | 30°16′39″ | 67.1 | Arid | Calcareous |

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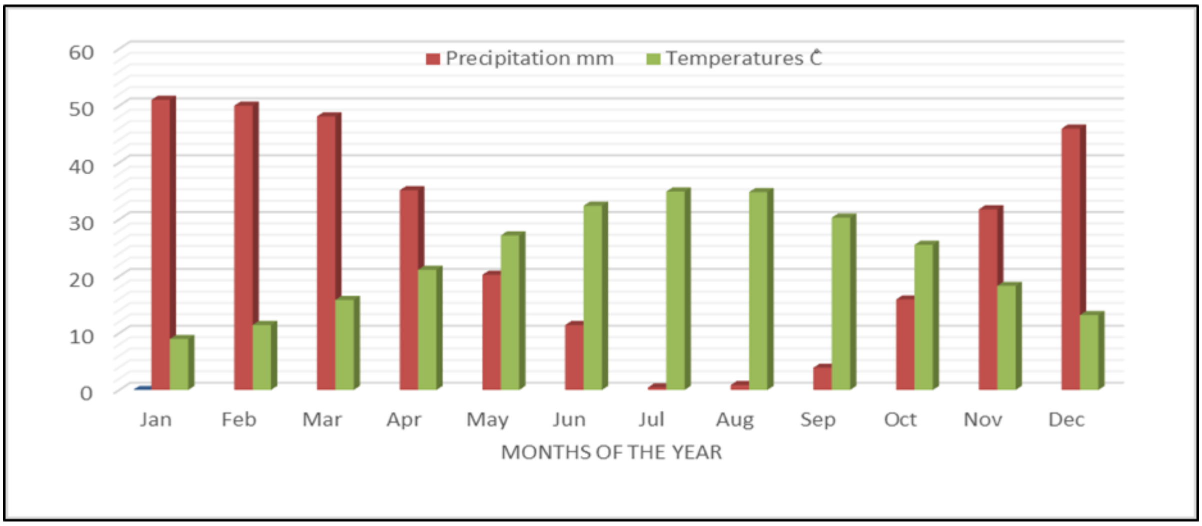


**Figure 1. Annual precipitation and temperature averages by month for the period (2014–2024).**

**Evaluation of munsell color coding**

Soil color descriptions were converted into numerical values using the following equations:

1- Bentley and Westin (1965) equation, and modified by Cordova (2000):

**BWR**= Hue x C …………….(1).

C= Chroma, R=Red, Y = Yellow

Hue, 10R=7, 2.5YR= 6, 5YR=5, 7.5YR=4, 10YR=3, 2.5Y=2, 5Y=1.

2- Torrent *et al.* (1993) equation

**$TR_1$**= (10-H) × C / V ……….(2)

H: Hue

V: Value

C: Chroma

Numeric may be assigned to the Values, such as: 10YR = 4, 7.5YR = 3, 5YR = 2, 2.5YR=1

3- Torrent *et al.* (1983) Equation:

**$TR_2$** = (10 – Hue) x C/V …….. (3)

C= Chroma, V=Value, H= Hue 7.5R=12.5, 10R=10, 2.5YR=7.5, 5YR=5, 7.5YR=2.5, 10YR=0

**Statistical analysis:** The study utilized SPSS 24 for computing descriptive statistics. Also employed analysis of variance (ANOVA) and stepwise multiple linear regression analysis in SPSS version 24.0 to identify the soil properties that significantly influenced the prediction of soil color indices.

**Stepwise regression:** This is one of the primary models of multiple regression. The stepwise regression model involves the inclusion of multiple independent variables, ordered based on a statistical criterion, through a backward selection method. This methodology begins by entering all explanatory variables into the regression model. Then, the process sequentially removes the least significant variables or those with the lowest weights or weakest correlation to the dependent variable, based on the partial F-value, Until only the independent variables with statistical significance remain in the equation, thereby achieving an optimal regression model for predictive purposes. Based on the above, and in general, stepwise regression achieves the following:

1- Reducing the number of independent variables included in the regression model.

2- Eliminating the problems of multicollinearity among independent variables in the estimated model.

Simple linear regression was used to evaluate the relationship between soil color indices and

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their climatic influences using the spss program.

## RESULTS AND DISCUSSION

### Effect of climate on soil properties

(Table 1) indicates clear variability among the soils studied properties due to environmental factors, particularly climatic ones such as rainfall amounts, temperature levels, topographical diversity, types of natural vegetation, and agricultural utilization patterns. These factors have significantly influenced the properties of the soils.

Twenty-one samples were taken from ten Iraqi provinces, classified by their climatic zones:

Sub-humid climate: samples (1–7) from northern provinces

Semi-arid climate: samples (8–10) from central provinces

Arid climate: samples (11–21) from southern provinces

(Table 1) showed that there is indeed a difference in the soils under study, which could be explained by the factors of the environment, especially the aspects of the climatic factors like rainfall amounts, temperature, topographical diversity, the type of prevailing natural vegetation cover, and the land use nature. Twenty-one samples were taken in ten Iraqi provinces and classified according to their climatic zones: semi-humid climate with samples (1-7) in the provinces of north Iraq, semi-arid climate with samples (8-10) in the provinces of central Iraq, arid climate with samples (11-21) in the provinces of the south Iraq. The field results obtained on soils in the area of northern Iraq; these are on the provinces of Erbil, Sulaymaniyah, and Duhok, showed that they had high levels of rainfall than the soils in the central and southern areas. This is directly caused by the current climate which is characterized by increased precipitation and reduction in the annual temperatures. These factors have augmented the degree of leaching actions and have had great effect on the concentration and distribution of vegetation cover and total content of organic matter. These factors have enhanced the developmental phase of such soils by facilitating the decomposition and accumulation of organic matter resulting in attainment of darker color of the soils.The parent material of soils on their nature can be clearly seen in the soil reaction (pH) besides the influence of environmental factors like rainfall. (Table 2) presents the pH of the study soils, which in sample no.3 and sample 18 were 7.1 to 8.03. These results show when a region has arid climatic conditions in the south of Iraq and especially in the marshlands, the soil level of pH reduces because of water presence that accelerates leaching of most cations and allows hydrogen ion to take their place. Also, the existence of carbonate minerals in such soils increases their buffering capacity so that they can keep the pH in the natural range. Semi-humid climatic zones in the north of Iraq such as Erbil where the heavy rain fall and low temperature are predominant, on the contrary, showed higher values of pH. This can be explained by the fact that base cations are dissolved by precipitation of soil water and their absorption by plant roots. When plant residues mineralize their pH values are expected to be high, and this is what (Silva et al., 2016) confirmed.(Table 2) indicates the values of electrical conductivity (EC), which are used to determine the salinity of the soil in the north, central, and south of the country. These values were 0.34 to 114.2 dS $m^{-1}$. The sub-humid northern areas experienced a great reduction of EC, and the values up to 0.34 dS $m^{-1}$ were recorded. This finding is in line with most of the literature in this field as it has been established that the soils of the northern parts of Iraq are not salty by nature since they are subjected to a process

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of soil leaching which in most cases differs in quantity at any given location in the same area. This, together with the fact that the soils have a high level of organic matter due to conducive climatic conditions of growing plants has added to the dense vegetation cover. It is no secret that the north parts of Iraq are the places where there is the greatest amount of organic material, which, consequently, has not allowed salt to accumulate in these soils. On the contrary, soils of the southern part of Iraq, which have arid climates, had the largest electrical conductivity measurement, which is 114.2 dS $m^{-1}$. This outcome can be compared to the current situation in the region to be almost entirely dry with the low utilization rate and uneven distribution of irrigation systems that led to the elevation of the water table above the natural level. This increased groundwater then flows up through the capillary process and the salts dissolved by it accumulate over time in the higher horizons, specifically at the surface levels, because of elevated evaporation rates and intensive heat. It is worsened by the fact that the region has sparse vegetation cover, minimal rainfall, and persistent drought.

**Table 2. Soil properties in the study area.**

| Province and Region Name | Sample No. | Class Tex. | Clay g $kg^{-1}$ | PSD Sand g $kg^{-1}$ | Silt g$kg^{-1}$ | CEC cmol+$kg^{-1}$ soil | $CaSO_4.2H_2O$ g $kg^{-1}$ | $CaCO_3$ g $kg^{-1}$ | $Fe_d$ g $kg^{-1}$ | O.M. g $kg^{-1}$ | EC dS $m^{-1}$ | pH 1:1 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Dohuk – Semel | 1 | CL | 301 | 311 | 388 | 43.07 | 5.1 | 286.0 | 4.34 | 42.50 | 0.34 | 7.7 |
| Erbil – Qorato | 2 | C | 512 | 116 | 372 | 44.02 | 2.76 | 123.0 | 4.36 | 35.90 | 0.58 | 7.8 |
| Erbil – Shirawa | 3 | CL | 334 | 301 | 365 | 41.95 | Nill | 109.8 | 7.38 | 22.50 | 0.64 | 8.0 |
| Erbil – Grdarasha | 4 | C | 479 | 264 | 257 | 18.81 | Nill | 298.0 | 6.86 | 13.50 | 0.40 | 7.61 |
| Sulaymaniyah - Khalkan | 5 | CL | 312 | 285 | 403 | 42.36 | 3.12 | 98.6 | 3.012 | 33.96 | 0.78 | 7.3 |
| Sulaymaniyah - Dokan | 6 | C | 499 | 139 | 362 | 38.14 | Nill | 149.0 | 4.25 | 37.10 | 0.87 | 7.4 |
| Sulaymaniyah - Bakira Khtiari | 7 | C | 621 | 57 | 322 | 37.01 | 4.23 | 386.1 | 3.56 | 33.60 | 0.92 | 7.8 |
| Mosul – Faida | 8 | SiCL | 344 | 143 | 513 | 15.6 | 79.08 | 189.6 | 5.89 | 21.60 | 0.43 | 7.8 |
| Kirkuk - Altun Kupri | 9 | SiCL | 360 | 178 | 462 | 19.96 | 88.36 | 214.56 | 1.10 | 12.60 | 0.60 | 7.8 |
| Diyala - Khanaqin | 10 | CL | 299 | 303 | 398 | 18.68 | 21.89 | 164.3 | 2.65 | 11.36 | 2.60 | 7.4 |
| Baghdad - Abu Ghraib | 11 | CL | 298 | 299 | 403 | 28.6 | Nill | 322.0 | 0.89 | 24.93 | 4.60 | 7.3 |
| Baghdad - Al-Rashidiya | 12 | L | 115 | 486 | 399 | 17.02 | 1.43 | 243.0 | 0.73 | 14.63 | 2.12 | 7.7 |
| Wasit – Kut | 13 | C | 749 | 38 | 213 | 42.07 | 21.06 | 229.1 | 3.67 | 24.60 | 55.31 | 8.0 |
| Wasit - Al-Suwaira | 14 | SiCL | 389 | 119 | 492 | 24.02 | 28.65 | 287.3 | 3.85 | 22.90 | 114.2 | 7.2 |
| Wasit - Sheikh Saad | 15 | CL | 295 | 348 | 357 | 17.65 | 47.67 | 298.95 | 3.35 | 31.07 | 74.01 | 7.2 |
| Dhi Qar - Al-Shatra | 16 | CL | 394 | 285 | 321 | 31.81 | 23.29 | 206.8 | 2.26 | 20.21 | 39.45 | 7.3 |
| Dhi Qar - Al-Jabayish | 17 | SiC | 445 | 78 | 477 | 33.15 | 33.91 | 280.01 | 2.35 | 18.60 | 38.21 | 7.1 |
| Dhi Qar - Suq Al-Shuyukh | 18 | SiC | 481 | 46 | 473 | 37.54 | 32.09 | 352.4 | 4.22 | 35.78 | 16.85 | 7.8 |
| Basra - Al-Faw | 19 | SL | 169 | 587 | 244 | 15.87 | 73.60 | 255.6 | 0.09 | 13.50 | 15.69 | 7.7 |
| Basra - Abu Al-Khaseeb | 20 | SL | 186 | 658 | 156 | 17.93 | 217.82 | 78.21 | 0.05 | 8.59 | 16.85 | 7.4 |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Basra - Al-Rumaila | 21 | SL | 152 | 681 | 167 | 13.82 | 236.62 | 71.69 | 0.08 | 1.01 | 4.72 | 7.6 |

As per its results, organic matter content was between 1.01-42.5g $kg^{-1}$. It was 42.5g$kg^{-1}$ in the sub-humid northern soils of Iraq. Based on the findings, it is clear that the content of organic matter is higher in the north because of the richness of natural and permanent vegetation in those areas like forests. Also, due to relatively low temperatures throughout the year, the oxidation rate of organic material is low and, thus, the material is accumulated in the surface horizons. Overall, the organic matter content of Iraqi soils decreases from north to south because of the semi-arid and arid climate, the low rainfall, the poor amount of moisture, and the high annual temperatures, which contribute to the rise in the rate of oxidation and decomposition. The content of organic matter in the south where there was an arid climate was only 1.01 g $kg^{-1}$. The obvious decline of organic matter in the south in comparison to the north is probably explained by environmental factors that are unfavorable to soil-forming activities especially the climatic factors that cause greater rates of decomposition and oxidation by high temperatures and low moisture. (Table 2) results also indicated that the crystalline iron oxide content ($Fe_d$) in the soils under study varied between 0.05 and 7.38 g $kg^{-1}$. Observable increase of $Fe_d$ was found in soils of the sub-humid northern areas, probably because the parent material had been subjected to severe weathering over a long period of time. Due to the intensities of weathering, more iron is produced out of the mineral structures and thus concentration of crystalline iron oxides is augmented. Conversely, they found that soils of the southern area possessed lower crystalline iron oxide making sense in light of variability in parent material composition. The level of soil development is directly connected with the quantity of free iron oxides and their crystallinity, as well as the environment factors, including the depositional environment, temperature, rainfall, land use, and vegetation cover. (Table 2) indicates that the total carbonate level in the soils of the study area varied between 98.6-386.1 g $kg^{-1}$ in the sample soils of the sub-humid areas in the north. The relatively high amounts of carbonates are discussed by relatively high levels of calcareous nature of the parent materials, as such soils are formed by limestone. When the leaching of carbonates takes place in the surface of the soils as a result of the prolonged and intense rainfalls, the dissolved $CO_2$ in the water forms carbonic acid which promotes the leaching. With time, the rainfall and irrigation cycles are reoccurring with interspersed dry periods and lead to the vertical and lateral movement of the carbonate minerals redistributing them across the soil profile. The early formation and development of calcareous soils are therefore regulated by dissolution and leaching of the carbonates through the action of moisture. The amount of carbonate in soils of arid southern region on the contrary was between 71.69-352.4 g $kg^{-1}$ showing reduced carbonate mineral content. This could be related to the gypsiferous nature of those soils since there is a negative connection between the content of gypsum and the content of carbonates; the higher the content of gypsum in the soil, the lower the content of carbonates in the soil. As it can be seen, the results of (Table 2) indicate that the gypsum levels in the soils found in the northern parts of Iraq, where there was a sub-humid climate, varied between 0 and 88.36 g $kg^{-1}$. These results show a noticeable reduction in gypsum levels in the studied soils from northern Iraq, which can be attributed to the high content of carbonate minerals in those soils. The accumulation of carbonate minerals

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is typically accompanied by a reduction in gypsum levels due to the strong competition between sulfate and carbonate ions for calcium ions, which governs the onset of gypsum or lime formation in the soil depending on the prevailing dominance of either ion (Alsalam et al., 2020 ; Alshamary et al., 2022). Gypsum formation and buildup are also significantly influenced by soil moisture content and the physiographic location of the soil. In contrast, soils from southern Iraq, which represents arid climatic zones, have gypsum contents ranging from 0 - 236.62 g $kg^{-1}$. These results suggested that the distribution of gypsum was irregular. Different parent material types and general equilibrium conditions affecting soil formation are the causes of the observed diversity in gypsum concentration among the study area's soils. This is the most pronounced across the broad physiographic range that extends north to south in Iraq. The significant differences in gypsum content observed in the soils of the different sites in Iraq are due to the corresponding diversity in local conditions, level of rainfall and amount of precipitation. The results in (Table 2) indicate the cation exchange capacity (CEC) values of the studied soils, which ranged from 13.82 to 44.02 cmol $kg^{-1}$ soil. In the northern regions of Iraq, characterized by a sub-humid climate, the highest value recorded 44.02 cmol $kg^{-1}$soil. The increase in the CEC of the northern soils based on the existing climatic conditions may be due to weathering processes that occur on various levels but varying over time. These soils have a greater percentage of clay following weathering processes that took place. In contrast, CEC values in southern Iraq, characterized by an arid climate, ranged from 13.82 to 42.07 cmol $kg^{-1}$soil. According to the statistics, most soils in the middle and southern regions had lower CEC values overall than those in the northern ones. Variations in the soil's texture, clay fraction, organic matter concentration, and degree of humification and decomposition are probably the cause of this drop. The type of vegetation cover and farm practices strongly relate to these properties because they sustain changes due to climatic factors including extreme droughts and temperatures and heavy rainfalls. These factors affect the breakdown and persistence of organic matter in the soil, and ultimately its contribution to either increasing or decreasing the soil's cation exchange capacity (Demir et al., 2022). (Table 2) reveals a significant variation in textures of the soils, which can be naturally explained by the characteristics of the parent materials, on which the soils were formed, and by the existing climatic conditions in the different regions, and its impact on the processes of leaching, depletion, accumulation, calcification, decalcification, removals of gypsums, and by the transporting and deposition processes. seven different textures of the soils were observed. It was seen that (C) and (CL) textures existed in the northern parts of Iraq in which the climate is a sub-humid. The parent material, prevailing climate, and physiographic location are more important in these areas because they influence the activity of the process of both depletion and accumulation. The dominance of pedogenic processes, especially continual leaching fueled by increased rainfall, is confirmed by the existence of fine (clay) texture in these locations. In contrast, the soil texture in arid southern regions varied from (C) to (SL), most likely as a result of depositional and transport mechanisms. These soils are typically alluvial in origin, underdeveloped and relatively young, and show stratification from movement from other places. High levels of clay (over 621 g $kg^{-1}$soil) were found in the northern sub-humid soils, whereas sand (above 658 g $kg^{-1}$ soil) was

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found in the desert southern soils. At 513 g $kg^{-1}$soil, the maximum silt content was found in central regions with semi-arid conditions. It is possible to ascribe this rise in clay content to geography, parent material, and rainfall (Alsalam et al., 2025).

**Climate influence on soil color (munsell system) and color indices (BWR, $TR_1$, $TR_2$)**

Regarding soil color and its indicators Munsell color notation and the derived indices (BWR, $TR_1$, $TR_2$) (Table 3) provides detailed insight. In Semi humid northern regions, there was a clear reduction in both Value and Chroma levels. These subdued colors indicate higher organic matter content in the soils of these areas, which is likely due to denser vegetation cover that enriches the soil with greater biomass in response to moist conditions. This results in a higher total organic carbon content and intensifies the Melanization process, darkening the surface horizons. The increase in 7.5YR Hue values, which is dark brown to dark reddish brown, is explained by the oxidation of iron oxides (Azuka et al., 2015 ; Sinclair et al., 2024), which represents the change of soil color in the well-drained grounds (Jyothirmaya et al., 2019). The reddish colors are suggestive of rubification process whereby the formation of red color is preferred under high humidity, low to medium temperatures, and quick organic matter turnover (Barbosa et al., 2015). In the governorates like Mosul, Kirkuk and Diyala, which were moderate in respect of humidity, the color of the soil changed and became yellowish-brown (10YR-7.5YR). This is because of the process of yellowing called Xanthization which is preceded by the dissolution of hematite spontaneously in moderately moisture climate under certain microorganisms and organic matter. This increases the relative content of goethite, and the color becomes yellowish-brown (Seibert et al., 2007 ; Barbosa et al., 2015).Southern regions, with arid climates, are marked by minimal rainfall and high temperatures, resulting in elevated Value levels and lighter soil colors due to the dominance of carbonate minerals, which obscure the effect of organic matter (Isa and Sulaiman , 2020 ; Djama et al., 2023). The BWR index exhibited an increasing trend ranging from 8.0 to 20 in Semi-humid climates but gradually declined to 6.0–12 in arid climates and showed irregular behavior in semi-arid conditions. The $TR_1$ index values (Torrent et al., 19893) ranged from 7.40 to 10.7 in sub-humid climates, reaching 12.0 in semi-arid zones characterized by 10YR hues. The $TR_2$ index (Torrent et al., 1983), although similar to $TR_1$, was relatively higher—peaking at 20.0 in semi-arid climates. $TR_2$ exhibited irregular patterns in Semi-humid areas but rose significantly in arid zones, ranging from 4.0 to 13.4. The BWR index corresponds with more reddish soils where the 5YR and Chroma exceed 4. Samples from Semi-humid climates were characterized by darker red hues when compared to other SYR-based color readings.

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**Table 3. Summarizes the influence of climate on soil color and related indicators**

| Province and Region Name | Samples No. | Color Moist | BWR | $TR_1$ | $TR_2$ |
|---|---|---|---|---|---|
| Dohuk – Semel | 1 | 7.5YR4/4 | 16.0 | 7.0 | 7.5 |
| Erbil – Qorato | 2 | 5YR4/4 | 20.0 | 8.0 | 5.0 |
| Erbil – Shirawa | 3 | 5YR3/4 | 20.0 | 10. 7 | 6. 7 |
| Erbil – Grdarasha | 4 | 7.5YR3/2 | 8.0 | 4. 7 | 5.0 |
| Sulaymaniyah - Khalkan | 5 | 5YR3/2 | 10.0 | 5. 4 | 3. 4 |
| Sulaymaniyah – Dokan | 6 | 5YR3/3 | 15.0 | 8.0 | 5.0 |
| Sulaymaniyah - Bakira Khtiari | 7 | 7.5YR3/2 | 8.0 | 4. 7 | 5.0 |
| Mosul – Faida | 8 | 10YR6/4 | 12.0 | 4.0 | 6. 7 |
| Kirkuk - Altun Kupri | 9 | 10YR5/4 | 12.0 | 4.8 | 8.0 |
| Diyala – Khanaqin | 10 | 10YR3/6 | 18.0 | 12.0 | 20.0 |
| Baghdad - Abu Ghraib | 11 | 10YR3/4 | 12.0 | 8.0 | 13. 4 |
| Baghdad - Al-Rashidiya | 12 | 10YR4/3 | 9.0 | 4.5 | 7.5 |
| Wasit – Kut | 13 | 10YR4/3 | 9.0 | 4.5 | 7.5 |
| Wasit - Al-Suwaira | 14 | 10YR4/4 | 12.0 | 6.0 | 10.0 |
| Wasit - Sheikh Saad | 15 | 10YR4/4 | 12.0 | 6.0 | 10.0 |
| Dhi Qar - Al-Shatra | 16 | 10YR5/2 | 6.0 | 2.4 | 4.0 |
| Dhi Qar - Al-Jabayish | 17 | 10YR5/4 | 12.0 | 4.8 | 8.0 |
| Dhi Qar - Suq Al-Shuyukh | 18 | 10YR5/2 | 6.0 | 2.4 | 4.0 |
| Basra - Al-Faw | 19 | 10YR5/2 | 6.0 | 2.4 | 4.0 |
| Basra - Abu Al-Khaseeb | 20 | 10YR5/3 | 9.0 | 3.6 | 6.0 |
| Basra - Al-Rumaila | 21 | 10YR6/3 | 9.0 | 3.0 | 5.0 |

**Multiple regression between soil properties and soil color indices:** (Table 4) illustrates the correlation coefficient (R) between the dependent variable (BWR) and the independent variables (soil properties) as follows: In the first regression model, the correlation coefficient was 0.70, indicating a moderate linear relationship between all independent variables and the dependent variable, with an $R^2$ value (0.495), representing the proportion of variance explained by the independent variables in the dependent variable. In the second model, after excluding EC the correlation coefficient remained 0.70, and $R^2$ stayed at 0.495. In the third model, after excluding EC, pH, the correlation coefficient remained 0.70, and $R^2$ slightly decreased to 0.494. In the fourth regression model, after excluding EC, pH, and O.M., the correlation coefficient remained 0.70, and $R^2$ was 0.493. In the fifth model, after excluding EC, pH, O.M., and CEC, the correlation coefficient dropped slightly to 0.69, and $R^2$ decreased to 0.484. In the sixth model, after excluding EC, pH, O.M., CEC, and clay, the correlation coefficient remained 0.69, with $R^2$ falling to 0.481. In the seventh model, after excluding EC, pH, O.M., CEC, Clay, and $Fe_d$, the correlation coefficient dropped to 0.66, and $R^2$ was 0.445. Finally, in the eighth regression model, after excluding EC, pH, O.M., CEC, Clay, $Fe_d$, Silt, the correlation coefficient decreased to 0.61, and $R^2$ dropped to 0.373, reflecting the variance explained by the remaining independent variables in the model.

**Table 4. Represents the regression model between the dependent variable (BWR) and the independent variables (soil properties), (n=21).**

| Model | R | $R^2$ | F |
|---|---|---|---|
| 1 | $0.703^a$ | 0.495 | 1.197 |
| 2 | $0.703^b$ | 0.495 | 1.469 |
| 3 | $0.703^c$ | 0.494 | 1.814 |
| 4 | $0.702^d$ | 0.493 | 2.266 |
| 5 | $0.696^e$ | 0.484 | 2.813 |
| 6 | $0.693^f$ | 0.481* | 3.703 |
| 7 | $0.667^g$ | 0.445* | 4.544 |
| 8 | $0.610^h$ | 0.373* | 5.347 |

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a. Properties: pH, $CaCo_3$, CEC, Silt, EC, $Fe_d$, Clay, $CaSo_4$, O.M.
b. Properties: pH, $CaCo_3$, CEC, Silt, $Fe_d$, Clay, $CaSo_4$, O.M.
c. Properties: $CaCo_3$, CEC, Silt, $Fe_d$, Clay, $CaSo_4$, O.M.
d. Properties: $CaCo_3$, CEC, Silt, $Fe_d$, Clay, $CaSo_4$
e. Properties: $CaCo_3$, Silt, $Fe_d$, Clay, $CaSo_4$
f. Properties: $CaCo_3$, Silt, $Fe_d$, $CaSo_4$
g. Properties: $CaCo_3$, Silt, $CaSo_4$
h. Properties: $CaCo_3$, $CaSo_4$

It is observed that for the sixth model, the value (F= 3.703) with a significance level (Sig = 0.026), which is less than 0.05, and (F = 4.544) indicating statistical significance for the seventh model, with a (Sig = 0.016) significance level, also below 0.05. In the eighth model, the (F = 5.347) with a (Sig = 0.015) significance level, again less than 0.05. Therefore, we reject the null hypothesis and accept the alternative hypothesis, concluding that the regression is statistically significant and not equal to zero. This confirms the presence of a significant relationship between the independent variables (soil properties) and the dependent variable (BWR). In other words, there exists a significant positive correlation between BWR and the properties $CaCO_3$ and $CaSO_4.2H_2O$. As the soil color index BWR increases, the levels of $CaSO_4.2H_2O$ and $CaCO_3$ also increase. (Table 5) shows the regression model coefficients, which are used to formulate the linear regression equation between the independent variables (soil properties) and the dependent variable (BWR). From the sixth regression model, it is evident that the independent variable $CaCO_3$ is statistically significant (Sig = 0.01) and influences the regression model. From the foregoing, it is confirmed that there is a statistically significant regression relationship between the soil color index BWR and $CaCO_3$. Soils in arid and semi-arid regions tend to contain large amounts of carbonates due to the calcareous nature of the parent material, derived from limestone. These carbonates often mask the effect of organic matter. This result aligns with the conclusions of (Ibanez et al., 2013).

**Table 5. The estimated parameters of the statistical model for the multiple linear regression equation.**

| Model | | Unstandardized Coefficients | | Standardized Coefficients | | |
|---|---|---|---|---|---|---|
| | | B | Std. Error | Beta | t | Sig. |
| 6 | (Constant) | 12.701 | 4.397 | | 2.888 | 0.011 |
| | Silt | .012 | .009 | .296 | 1.411 | 0.177 |
| | $CaSO_4$ | -.018- | .016 | -.286- | -1.117- | 0.280 |
| | $CaCO_3$ | -.028- | .010 | -.609- | -2.932 | 0.010 |
| | $Fe_d$ | .456 | .435 | .228 | 1.049 | 0.310 |

(Table 6) presents the results of the ANOVA test for the significance of the regression model. From the seventh model, the F-value is 3.726 with a significance level of Sig = 0.032, which is less than 0.05, indicating statistical significance. In the eighth model, the F-value is 5.645 with a significance level of Sig = 0.013, also below 0.05. Accordingly, the null hypothesis is rejected, and the alternative hypothesis is accepted — meaning that the regression is statistically significant and not equal to zero. Therefore, a relationship exists between the independent variables (soil properties) included in the regression model and the dependent variable ($TR_1$). In other words, there is a significant positive correlation between TR1 and $CaCO_3$ and $CaSO_4.2H_2O$, such that as the soil color index TR1 increases, so do the values of $CaCO_3$ and $CaSO_4.2H_2O$.

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**Table 6. ANOVA results between $TR_1$ color index and soil properties.**

| Model | | Unstandardized Coefficients B | Unstandardized Coefficients Std. Error | Standardized Coefficients Beta | t | Sig. |
|---|---|---|---|---|---|---|
| | (Constant) | 9.939 | 2.271 | | 4.377 | .000 |
| 6 | Clay | -.003- | .004 | -.185- | -.776- | 0.449 |
| | $CaSO_4$ | -.025- | .010 | -.631- | -0.432- | 0.027 |
| | $CaCO_3$ | -.013- | .006 | -.448- | -1.992- | 0.064 |
| | $Fe_d$ | .206 | .307 | .168 | .670 | 0.512 |
| 7 | (Constant) | 10.554 | 2.043 | | 5.166 | .000 |
| | Clay | -.002- | .004 | -.121- | -.564- | 0.580 |
| | $CaSO_4$ | -.028- | .009 | -.708- | -3.098- | 0.007 |
| | $CaCO_3$ | -.014- | .006 | -.486- | -2.272- | 0.036 |

(Table 7) displays the regression model coefficients used to construct the regression line between the independent variables (soil properties) and the dependent variable $TR_1$. It is evident from regression models six and seven that the independent variable$CaSO_4.2H_2O$ has statistical significance and influences the regression model. Based on this, there is a statistically significant regression relationship between the soil color index $TR_1$ and $CaSO_4.2H_2O$.

**Table 7. The statistical model parameters for the multiple linear regression equation**

| Model | | F | Sig. |
|---|---|---|---|
| 1 | Regression | .915 | 0.546[b] |
| 2 | Regression | 1.123 | 0.413[c] |
| 3 | Regression | 1.375 | 0.294[d] |
| 4 | Regression | 1.711 | 0.191[e] |
| 5 | Regression | 2.174 | 0.112[f] |
| 6 | Regression | 2.817 | 0.061[g] |
| 7 | Regression | 3.726 | 0.032[h] |
| 8 | Regression | 5.645 | 0.013[i] |

**Simple linear regression between climate and soil color indices:**

(Table 8) presents the results of the linear regression between the soil color indices and precipitation (representing Iraq's climate). The BWR index showed a statistically significant correlation, with $R^2 = 0.33^{**}$. The $TR_1$ index showed a weaker statistical significance compared to BWR, with $R^2 = 0.25^*$. However, the $TR_2$ index did not show any statistically significant relationship with precipitation. The BWR index demonstrated a strong correlation with climate, showing a linear relationship with $R^2 = 0.33^{**}$. Thus, BWR can be used to predict Iraqi soils based on climate, particularly precipitation. Both BWR and $TR_1$ color indices derived from Munsell data can serve as quantitative indicators of soil properties and can be used across all climatic zones in Iraq.

**Table 8. Linear regression values between soil color indices and climate**

| Amount of Rainfall / Soil Color Indices | $R^2$ | Unstandardized Coefficients | Standardized Coefficients |
|---|---|---|---|
| BWR | $0.338^{**}$ | 0.002 | 0.581 |
| TR1 | $0.255^{*}$ | 0.002 | 0.505 |
| TR2 | 0.079 | 0.002 | 0.282 |

and ** represent correlation is Significant at the 0.05 and 0.01 level

## CONCLUSIONS

This study confirmed the effectiveness of the relationship between soil color and its properties under various climatic conditions in Iraq. Relationships were established between color indices and soil characteristics, and the variation between precipitation (as a climate indicator) and color indices was analyzed. In Iraq, the potential for employing soil color as a predictor of soil genesis and attributes turned out to be encouraging. A positive and

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statistically significant correlation was found in the linear regression between precipitation and the color indices (BWR, $TR_1$). Thus, the use of soil color indices (BWR, $TR_1$) derived from Munsell color data holds potential as a quantitative indicator of soil properties in all Iraqi climates. Such a method could improve classification systems that depend on diagnostic horizons and provide useful information about soil horizons, help with the actual mapping of soil color throughout Iraq.

## CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

## AUTHOR/S DECLARATION

We confirm that all Figures and Tables in the manuscript are original to us. Additionally, any Figures and images that do not belong to us have been incorporated with the required permissions for re-publication, which are included with the manuscript.

Author/s signature on Ethical Approval Statement.

Ethical Clearance and Animal welfare

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## AUTHOR'S CONTRIBUTION STATEMENT

Omar ALSALAM: Conceptualization; Study design; Field sampling; writing; Project and administration. Y.A.A. Sabry: Field sampling.

Abdulghafour Ibrahim Hamad: Calculation of BWR, TR1, TR2.

Abdul Baqi D.S. Al Maamouri: Performing statistical analysis and writing-review.

Sawsan Ahmed Mohammed: Laboratoory coordination (pH, EC, O.M., CEC, PSD, CaSo4, Fed). composed the manuscript with contributions from all authors.

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The Second author (**A. I. Hamad**) serves as an editor for Iraqi Journal of Agricultural Sciences but was not involved in the peer review process of this manuscript beyond their role as an author. The authors declare no other conflict of interest.

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# العلاقة بين لون التربة وبعض صفات الترب العراقية تحت ظروف مناخية مختلفة

عمر طارق السلام[1] يحيى عبد المنعم عبد صبري[2] عبدالغفور إبراهيم حمد[3]

عبد الباقي داود سلمان[4] سوسن احمد محمد[5]

قسم علوم التربة والموارد المائية ، كلية علوم الهندسة الزراعية ، جامعة بغداد ، العراق.[4&1]

قسم علوم التربة والموارد المائية ، كلية علوم الهندسة الزراعية ، جامعة صلاح الدين ، أربيل ، العراق.[2]

قسم مكافحة التصحر ، كلية علوم الهندسة الزراعية ، جامعة بغداد ، العراق. [5&3]

**المستخلص**

**يعد لون التربة صفة أساسية في تقييم عمليات تكوين التربة والعوامل المناخية، لذلك يمكن ان يوفر معلومات قيمة حول صفات التربة ، وبهذا يستعمل كدليل مناخي جديد يسهل قياسه. جمعت نماذج من الافاق السطحية بواسطة الاوكر وعلى عمق 0−30سم من عشر محافظات مختلفة من العراق في ظل ظروف مناخية مختلفة ، تم تقدير لون التربة حقلياً بواسطة كتاب الألوان Munsell لعينات التربة وقدرت الصفات الاتية مختبرياً ($pH$, $EC$, $O.M.$, $CEC$, $CaCO_3$, $CaSO_4.2H_2O$, $Fe_d$, Soil Texture). حسبت مؤشرات لون الترب $BWR$, $TR_1$, $TR_2$. أظهرت النتائج زيادة كمية ($pH$, $O.M.$, $CEC$, $CaCO_3$, $Fe_d$, Clay) في المناطق ذات المناخ شبه الرطب ، بينما انخفضت كمية $EC$, $CaSO_4.2H_2O$ نفسه للمناخ. نشاط عملية الاسوداد و الاحمرار الترب في مناطق ذات المناخ الرطب بالمقابل نشطت عملية الاصفرار الترب في المناطق ذات المناخ شبه الجاف. أظهرت نتائج الانحدار المتعدد العكسي وجود علاقة ذو دلالة أحصائية معنوية بين مؤشر BWR و $CaCO_3$ ، أيضاً وجود علاقة معنوية بين $TR_1$ و$CaSO_4.2H_2O$ ، ولم تكن هناك علاقة معنوية للانحدار المتعدد بين مؤشر $TR_2$ وصفات التربة. كشفت نتائج تحليل الانحدار الخطي بين المناخ ومؤشرات لون التربة BWR أن هناك علاقة معنوية اذ كانت قيمة $R^2$=0.33 عند مستوى معنوية أقل من 0.01. وبهذا أرتبط مؤشر BWR ارتباطاً وثيقاً بالمناخ في الترب العراقية.**

**الكلمات المفتاحية: الانحدار المتعدد، بيدولوجي، تغير المناخي، مؤشرات اللون، نظام منسل.**