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Original Article

Nutrient Dynamics in Oak Forests of Iraqi Kurdistan Due to Altitudinal and Geospatial Influences

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ABSTRACT

Oak forest nutrient dynamics are mainly affected by altitudinal and geospatial differences. This dynamic creates a great difference in soil nutrient availability and uptake by the trees, which have significant considerations in forest management. This study examined the variability in soil and leaf nutrient contents (nitrogen, phosphorus, potassium, and calcium) in *Quercus aegilops* and *Quercus infectoria* at eleven selected oak forests in the Iraqi-Kurdistan region. The clustering of soil characteristics and altitudinal-geospatial data in principal component analysis (PCA) showed a strong correlation between variables such as $CaCO_3$, organic matter (OM), N, P, and altitude. Strong correlations between electrical conductivity (EC) and K and latitude and altitude were highlighted. Nitrogen content was 2.91%, recorded as the highest value in leaves of *Q. infectoria* at Talwa. However, the lowest value (1.04%) was observed in *Q. aegilops* leaves at Shaqlawa. Phosphorus content variation was significantly recorded, with the highest content of leaves (0.69%) recorded in *Q. aegilops* leaves at Qaradakh and the lowest value (0.33%) in *Q. infectoria* leaves at Barzan. A significant variation in potassium content was observed; the highest value was 1.953% in *Q. infectoria* leaves at Barzan. While, the minimum content was 1.093% of *Q. aegilops* at Shaqlawa. Calcium content also showed a significant variation, with the highest level (0.27%) in *Q. infectoria* leaves at Sarsang compared to a lower level (0.17%) from Shaqlawa. These findings explain the role of topography and climate in nutrient distribution dynamics across the oak forest ecosystems. This could be helpful for the forest management strategies, and enhance the sustainability and afforestation of oak forests in Kurdistan region.

Keywords: Oak, Iraqi Kurdistan forests, Micro Nutrients, Sustainability and Topography.

1 Introduction

Oak (*Quercus* spp.) trees are common around the world and native to Asia, Europe, North Africa, and America, in which different species were originated and adapted to their climate diverse from temperate regions to tropical ones [1]. Besides their valuable timbers, charcoal, wood fuel, animal fodder, and medicinal properties, oaks also act as carbon sinks, utilizing a great rate of atmospheric CO_2 through their high rate of photosynthesis [2]. Oaks are valued as an industrial resource in many countries, in addition to their economic importance and ecological significance, and well known for their tolerance to environmental stress factors [3]. The oak forests in Iraq are mostly found in the northeast, extending from Hurin Sheren near the Iranian border to Zakho near the Turkish border, with latitudes between 34° 40' and 37° 08' and longitudes between 42° 40' and 45° 30', which make up to 4% of the total area of Iraq and are regarded as important natural resources [4]. The altitudinal and geospatial differences of the forests influence soil nutrient dynamics that play a vital role in sustaining forest management, conservation, and productivity enhancement [5]. Geospatial factors, including latitude, longitude, and topography, significantly affect the soil nutrient dynamics in oak forests [6]. Altitude determines the microclimatic conditions of a specific area, which affects soil nutrient content and availability [7]. It has been found that soil organic matter could be affected by climate change (altitude) [8]. Greater elevations and colder Mediterranean temperatures generally produce higher organic carbon levels in cultivated soil [9]. However, the demand for farming in high-altitude regions has recently increased due to the lack of irrigation requirements, creating concerns regarding sustainable soil management [10]. Iraq's rough terrain impacts patterns of soil

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erosion and deposition. Higher erosion rates on steeper slopes can cause the topsoil to lose vital nutrients. The region's varied terrain makes nutrient dynamics even more challenging; valleys and flat areas exhibit higher nutrient buildup because of decreased erosion and increased deposition of organic materials [11]. The climate, including temperature and precipitation patterns, is determined by the region's latitude, which also controls the dynamics of soil nutrients [7]. Latitude-dependent variations in Iraqi Kurdistan's climate affect the types of plant and soil properties in various forested regions. Studies in comparable mountain forest ecosystems have demonstrated that spatiotemporal and altitudinal changes can produce unique nutrient profiles in comparatively short geographic areas. For instance, a study on Himalayan oak forests revealed notable variations in the amount of phosphorus and nitrogen in the soil at various elevations and slope profiles [12]. Likewise, research conducted in the Mediterranean area has emphasized how temperature and terrain affect the availability of nutrients in the soil [13]. Digital Elevation Models (DEMs) offer crucial topographical information affecting nutrient distribution and other soil characteristics [14]. DEMs provide useful data on aspect, slope, and elevation—all of which are important factors in the formation of soil and the distribution of nutrients. For example, because of the heavier rainfall and lower temperatures at higher elevations, the soil may be more acidic, impacting nutrient availability. Additionally, slopes affect patterns of deposition and erosion. Higher rates of erosion on steep slopes can transport or loss of nutrient-rich topsoil and transfer it to lower regions, possibly resulting in fertile valleys [15]. Heavy rainfall increases water infiltration which impact on nutrient availability, soil formation and erosion while intense rainfall led to runoff surface. The impact of altitude and geographic location on soil nutrient content in Kurdistan's oak forests is investigated in this study, and how nutrient dynamics, such as soil and foliar nutrient concentrations, vary across various altitudinal gradients and geographic locations in Iraq's oak woodlands. Furthermore, comprehend how altitude and geography affect the availability and uptake of nutrients in oak trees, and adding to our understanding of how ecosystems function and guiding conservation and management plans.

2 Material and methods

2.1 Study area

The Kurdistan region and the northern portion of the Republic of Iraq are included in the study area. The area is located between longitudes 42° 25' and 46° 15' and between latitudes 34° 42' N and 37° 22' N. Kurdistan Provinces in the region are Sulaimani, Halabja, Erbil, and Duhok (which includes the towns of Shekhan and Akre) encompassing around 51520.76 km^2 (Figure 1) [5]. The average temperature is approximately 35–40 °C, with the low temperature of approximately -1 °C. According to the official website of Kurdistan Regional Government, the annual precipitation ranges from 375 to 1200 mm, indicating an extremely hot and dry summer and a wet and chilly winter. Eleven forest sites were selected: the oak forests of Sarsang, Solav, Talwa, and Barzan in Duhok province; Qaradax, Sharbazher, Halabja, Penjwen, and Ranya in Sulaimania province; and Shaqlawa and Soran in Erbil province. Those two oak species were abundant, *Quercus aegilops* and *Quercus infectoria*.

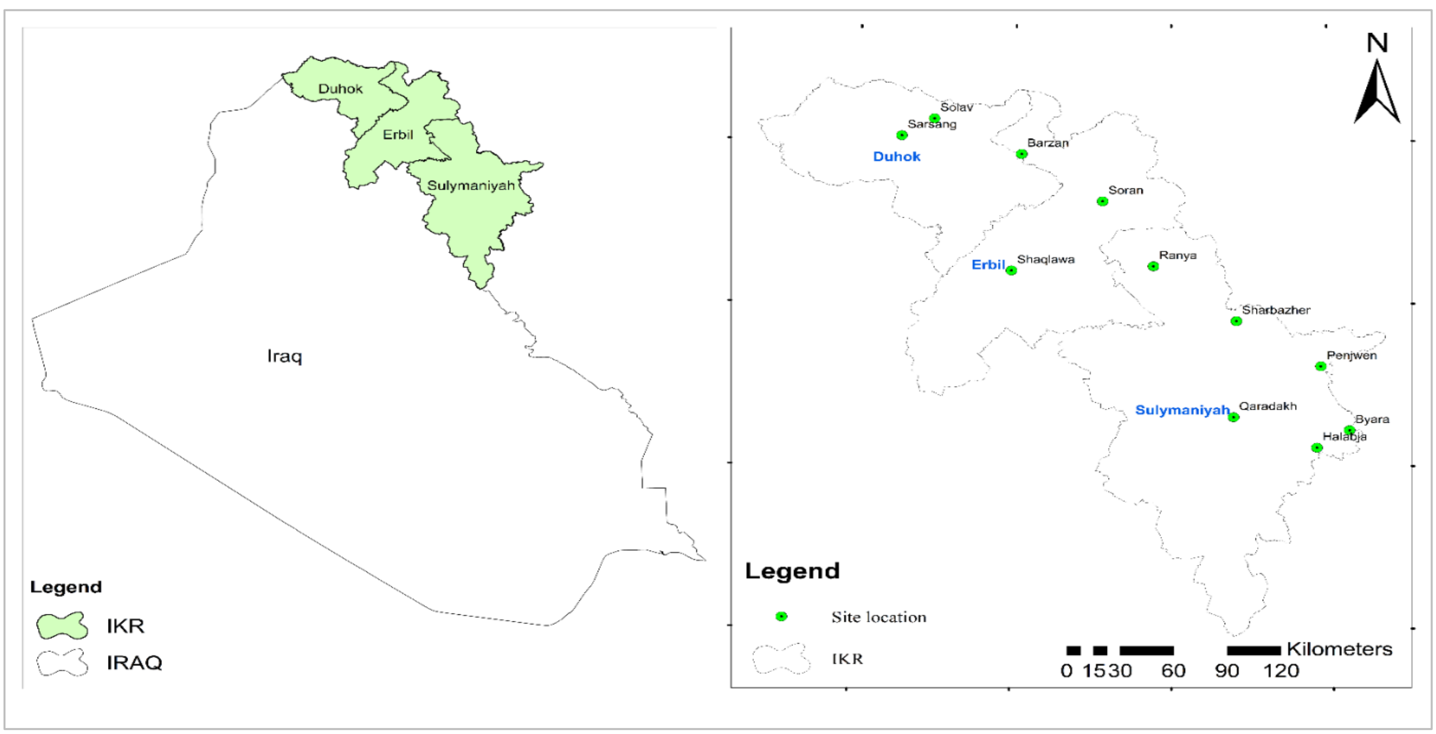
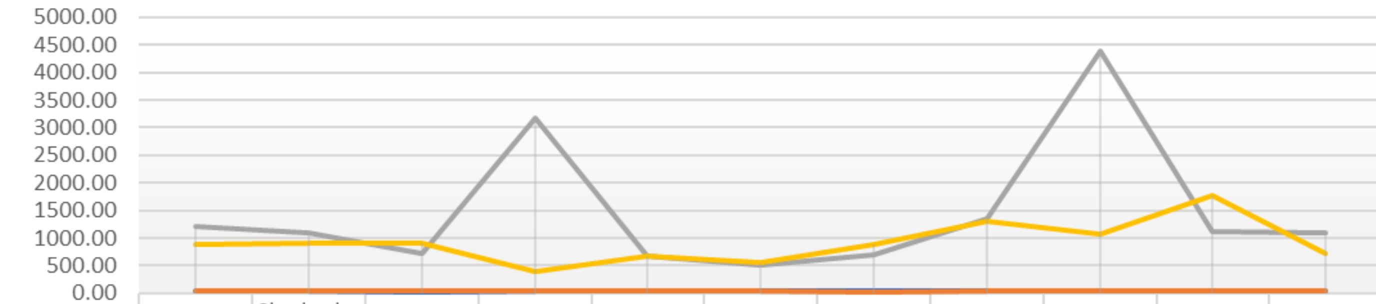


Figure 1: Geographical description of oak forests in the North Iraqi-Kurdistan Region.

2.2 Geospatial variations of oak forests

The north of Iraqi Kurdistan region, placed in the northeastern part of Iraq, is characterized by diverse altitudes and geospatial variations that significantly impact its ecosystems, particularly soil nutrients and oak forest growth. Iraqi Kurdistan spans from the Hurin Sheren region on the Iranian border to the Zakho region close to the Turkish border. The region's topography varies, with altitudes ranging from lowland valleys to high mountain peaks [5]. The eleven selected oak forest locations and their geographical descriptions were shown in Figure 2.



	Qaradakh	Sharbazher	Sarsang	Shaqlawa	Soran	Ranya	Halabja	Penjwen	Talwa	Solav	Barzan
Longitude	45.39	45.41	43.35	43.99	44.56	44.89	45.97	45.94	46.12	43.48	44.04
Latitude	35.31	35.90	37.05	36.21	36.64	36.24	35.19	35.62	35.23	37.10	36.93
Altitude (m)	1220.00	1100.00	726.00	3169.00	680.00	508.00	701.00	1341.00	4400.00	1120.00	1100.00
DEM (mm)	879.00	912.00	906.00	401.00	682.00	553.00	882.00	1294.00	1082.00	1775.00	729.00

Figure 2: Geospatial data of selected oak forests in Iraqi Kurdistan Region.

2.3 Soil sampling and analysis

Soil samples taken from oak woodlands at 0 to 25 cm depth to measure the soil's texture, composition, and physical characteristics. Using the international pipette method, particle size fractionation and analysis were performed, and the textural classes were defined by using the soil texture triangle as recommended by Black et al. [16]. The EC value of the soil was estimated employing the portable/laboratory EC-meter (model conductivity meter) VARIO® Cond WTW, according to Rhoades [17]. In accordance with Gupta [18], the pH was determined on a 1:2.5 ratio soil/distilled water suspension using a portable pH meter (model WTW 330i/Germany). The percentage of organic carbon (OC) in soil samples was initially ascertained using the wet oxidation method, or Walkley-Black method, as explained by Estefan et al. [19]. Using 0.01 N EDTA2Na, soluble Ca ions were measured in saturated paste soil extract titrimetrically in accordance with the technique described by Estefan et al. [19]. The percentage of total calcium carbonate equivalent was determined as mentioned by Bremner and Mulvaney [20]. The Kjeldahl digestion-distillation method examined total nitrogen content in soil [20]. The Olsen method was used to calculate the amount of available phosphorus (ppm) [21].

2.4 Leaf sampling and analysis

Leaf samples were taken in the forest sites in late spring 2020, when vegetative growth was at its peak. Five healthy trees of the two species were selected from each plot to measure the leaf traits. At least two branches with mature and fully grown leaves were selected that received the maximum light exposure. The samples were wrapped in plastic bags, they were shipped to the lab in a cool and dark container. They were kept at 15ºC in the dark with the stem bases submerged in water for at least 12 hours to completely dehydrate the leaves. The leaves were cut into small pieces and baked at 70°C until they reached a constant weight to ensure complete drying [22]. Then, several macronutrients were analyzed:

2.4.1 Nitrogen content (%)

The Kjeldahl method involves high-temperature digestion of finely ground material in concentrated H_2SO_4 with the help of a metal catalyst. Plant N is transformed to NH_4, which is subsequently measured using a colorimetric or titration technique [20].

2.4.2 Total phosphorus content (%)

By extracting the materials using 0.5 M $NaHCO_3$, the available phosphorus concentration was ascertained [21].

2.4.3 Potassium content (%)

Determination of K by flame photometer started by taking 1 to 5 grams of dried powdered plant material and prepare its ash solution by heating it up to 600 °C in a furnace, dissolving it in 10 ml of HNO_3, and heating for 30 minutes to reduce the volume to about 2 ml. Then add deionized or distilled water, filter through a Whatman No. 1 filter paper, and check it by flame photometer [23].

2.4.4 Ca content (%)

Calcium content ascertained by the use of an atomic absorption spectrometer [23].

2.5 Statistical analysis

Principal Component Analysis (PCA) is used to detect groups and attributes that contributed significantly to the variance among the geospatial data and soil chemical and physical characters, based on the rotation method using quartimax with Kaiser normalization. The leaf macronutrient data was analyzed based on a combination of two factors: 11 different locations in the Kurdistan region's oak forests, including Qaradax (L1), Sharbazher (L2), Sarsang (L3), Shaqlawa (L4), Soran (L5), Ranya (L6), Halabja (L7), Penjwen (L8), Talwa (L9), Solav (L10), and Barzan (L11), along with the two predominant oak species in these areas, Quercus aegilops (S1) and Quercus infectoria (S2). The analysis of variance (ANOVA) was conducted using the SPSS software (version 25). Duncan's test was employed to evaluate the variations among the mean values of the studied parameters at the 1% significance level.

3 Results and Discussions

The relationships among soil chemical and physical properties and altitudinal-geospatial data of the forest soils are visually represented by the Principal Component Analysis (PCA) (Figure 3). The variables in the plot that are near one another are correlated and have comparable loads. For example, $CaCO_3$, OM, N, P, and altitude all cluster together, indicating that the dataset's patterns of variance are comparable for these variables. A variable's contribution to the principal components can be determined by measuring its distance from the origin. The influence is greater for variables that are farther from the origin. The closeness of latitude and altitude reveals a potential relationship between them. Longitude may not be strongly correlated with latitude and altitude since longitude is located separately with them. The relationship between soil parameters such as pH, EC, K, and DEM is suggested by their clustering. $CaCO_3$, OM, N, and P near spots suggest their variance patterns.

Table 1 shows the correlation coefficients between the soil studied characters, altitude, and geospatial data with their components. The highest positive value in the first component was Altitude (0.392), P (0.319), and $CaCO_3$ (0.365), which indicated their significant correlation. This implies that altitude might be affecting P and $CaCO_3$ soil content, which frequently vary because of variation in soil content and weathering processes at different location altitudes [15]. The highest negative value of the second component was longitude (-0.491), and the high positive value was latitude (0.448). This suggests a considerable spatial variation along these axes; the positive and negative signs of latitude and longitude imply that soil characteristics may differ spatially [24], showing distinct patterns along the east-west and north-south axes. Whereas, the highest positive variable values in the third component were EC (0.502) and K (0.424), indicates the significant positive correlation between EC and K. DEM (0.543). This likely points to areas with higher conductivity also having elevated potassium [25], which may be relevant for understanding soil salinity or mineral content. This probably indicates that places with higher soil conductivity also have higher potassium, which could be important information for figuring out the mineral composition or salinity of the soil. DEM was a significant variable within component 4, as evidenced by its greatest positive correlation (0.543). This suggests that topography, as shown by DEM, may greatly influence other soil characteristics [26]. The maximum significant value in the fifth component was pH (0.633), indicates that pH is a significant variable in this component. Since soil pH is a key factor in both biological activity and nutrient availability in the soil, this correlation may indicate differences in soil chemistry of the studied locations [27].

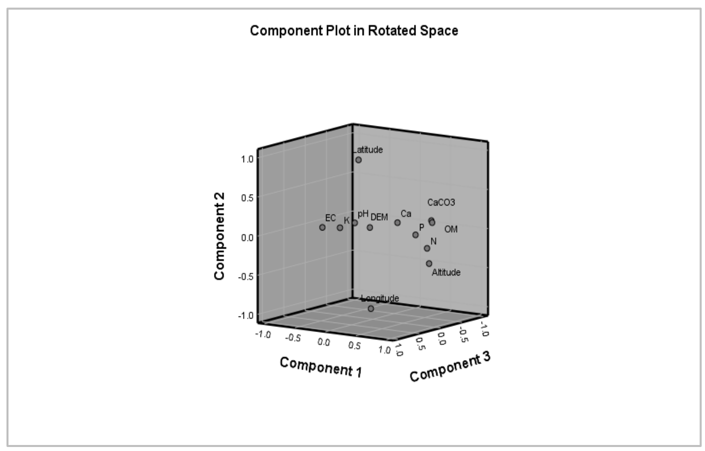


Figure 3: Principal Component Analysis of various environmental and soil characteristics of oak forests in the Kurdistan region based on the rotation method using quartimax with Kaiser normalization.

Table 1: Component score coefficient matrix based on rotation method using quartimax with Kaiser normalization

Characters	Components				
	1	2	3	4	5
Longitude	0.018	-0.491	0.126	-0.035	0.072
Latitude	0.028	0.448	0.018	0.084	-0.002

Altitude	0.392	-0.150	0.110	0.205	0.167
DEM	0.080	0.065	0.022	0.543	-0.030
pH	0.093	-0.010	-0.029	-0.042	0.633
EC	0.117	-0.034	0.502	-0.147	0.104
Ca	0.008	0.095	0.050	-0.247	-0.365
N	0.211	-0.027	-0.015	0.218	-0.168
P	0.319	-0.006	0.211	-0.291	0.072
K	0.216	0.008	0.424	0.300	0.105
$CaCO_3$	0.365	0.104	0.085	-0.018	0.070
OM	0.125	0.097	-0.410	0.011	0.370

A notable difference in Nitrogen concentration was observed in both *Q. aegilops and Q. infectoria* trees across locations in the Kurdistan region (Figure 4). The highest content of nitrogen was 2.91% in *Q. infectoria* at Talwa (L9 S2). Conversely, the lowest nitrogen content was 1.43%, recorded in *Q. aegilops* leaves at Shaqlawa (L4 S1). This finding implies that the amount of nitrogen in oak leaves varies greatly and is affected by both species and location. Talwa's soil is richer in organic matter (5.80%), which may be the reason for the noticeably increased nitrogen content in *Q. infectoria*. It increases the availability of nitrogen through mineralization processes. As well as increased soil organic matter can enhance microbial activity, soil structure, and water retention, all of which help plants absorb nitrogen more effectively [28]. Talwa's elevation of 4400 m in Figure 2 may offer a more temperate climate with ideal temperatures for the absorption and assimilation of NH_4. Higher elevations with cooler temperatures can enhance the availability of nitrogen in the soil and reduce the volatilization of the element [29]. These findings clarify the positive correlation between both species-specific traits and environment and their effect on the nutrient's dynamic in forest ecosystems. Since it greatly affects tree growth and development, which may have a major role in forest management strategies.

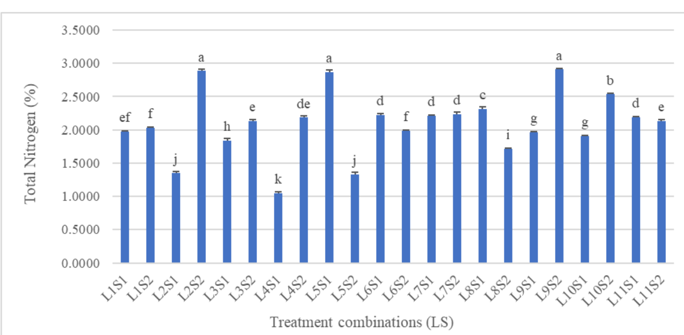


Figure 4: Variation within nitrogen content (%) of Q. aegilops and Q. infectaria leaves at different oak forests in the Kurdistan region.

The total phosphorus content of leaves was significantly different. The highest value was 0.69%, recorded by *Q. aegilops* leaves at Qaradakh (L1S1). While the lowest value was 0.330%, recorded by *Q. infectora* leaves at Barzan (L11S2) illustrated in Figure 5. This difference may be related to the weathering processes, soil chemical composition and organic matter content had great effect on phosphorus concentration in plants which are higher at high elevations like Qaradakh (1220 m) as compared to the lower elevation of Barzan, which was 1100 m (Figure 2). Soil total mineral content, including phosphorus in the soil greatly affected by the weathering at higher elevations [30]. Weathering of apatite is the phosphorus primary source in the soil which can be found in the minerals in the rocks. In this process phosphorus slowly release into soil and tends to bind to the soil strongly [31].

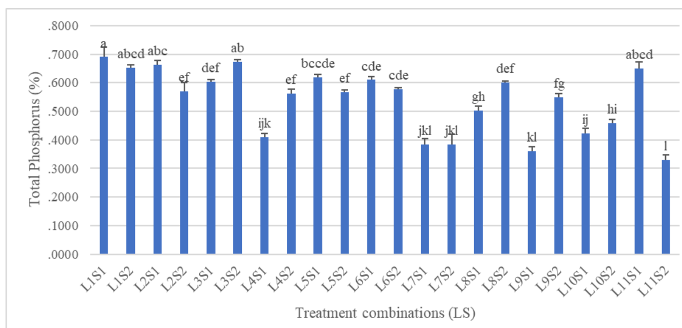


Figure 5: Variation within total phosphorus content (%) of *Q. aegilops* and *Q. infectoria* leaves at different oak forests in the Kurdistan region.

The potassium content of the two species of oak ranged from 1.953 to 1.093; the highest value was 1.953% presented by *Q. infectoria* leaves in Barzan (L11S2). However, the lowest value was 1.093%, recorded by *Q. aegilops* leaves at Shaqlawa (L4S1), shown in Figure 6. The increased potassium content in *Q. infectoria* leaves at Barzan would suggest that the soil in this area offers superior conditions for potassium uptake or it is especially rich in potassium, as seen by 557.33% potassium content in Figure 3. DEM defines the topography of the earth surface, which has a significant effect on the distribution of nutrients in the soil as previously found by Wang et al. [32] and [33]. This is in accordance with our finding that the soil's nutrient profile at a lower DEM location like Shaqlawa which was 401.0 mm and differed from the higher DEM of Barzan (729 mm) due to different rates of weathering and soil organic content.

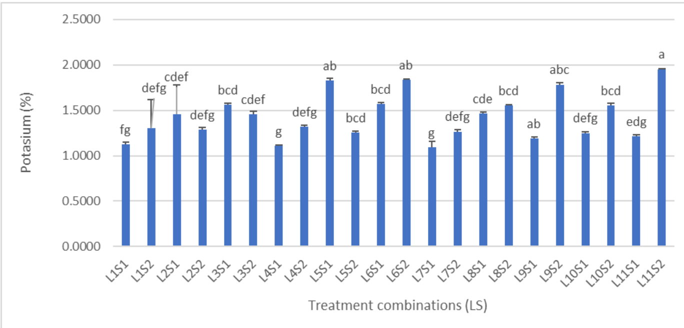


Figure 6: Variation within potassium (K) content of *Q. aegilops* and *Q. infectaria* at different oak forests in the Kurdistan region.

The data related to calcium content in the leaves showed a significant variation between the two oak species, especially *Q. infectoria*, across the studied locations. The highest calcium percent was 0.27% in *Q. infectoria* leaves in Sarsang, while the lowest content was 0.17% in *Q. infectoria* leaves in Shaqlawa (Figure 7). The variation in the calcium content of the oak species in the different locations might be related to the availability of calcium in the soil of these locations. Sarsang soils likely richer in calcium $CaCO_3$ (1.28%) as compared to Shaqlawa soil which had a lower $CaCO_3$ content (0.58%) (Figure 2). This can be due to the parent dominant rock materials like calcite ($CaCO_3$) and gypsum ($CaSO_4{\cdot}2H_2O$) [34]. These release calcium into the soil after weathering. In addition, the different DEM values of the two locations (Figure 2) might be another reason for the difference in leaf calcium content. Sarsang DEM was 906 mm which was higher than Shaqlawa (401 mm). Since elevation affects the climatic conditions of each location, like temperature, amount, and precipitation, this affects the weathering of the rocks [35].

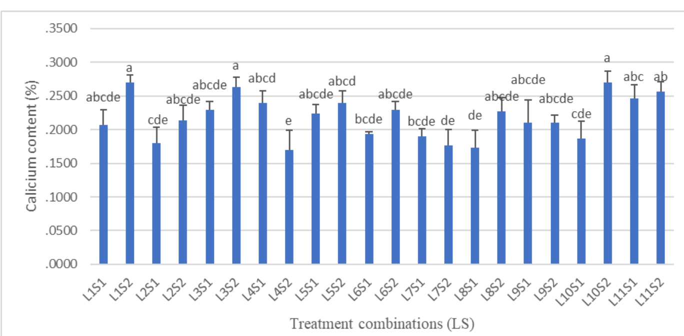


Figure 7: Variation within calcium content (%) of *Q. aegilops* and *Q. infectaria* at different oak forests in the Kurdistan region.

Conclusion

Nutrient dynamic variation of oak species might be related to differences in the soil physical and chemical characters, variations in altitude, and geographical aspects of oak forests in Kurdistan. Qaradakh has a high elevation that reflected the higher phosphorus content in the soil and leaves. More potassium in *Q. infectoria* leaves was correlated with the rich potassium soils of Barzan. Oak leaf calcium concentration was due to local soil calcium availability, which is affected by elevation variations (DEM). The study emphasized how important topography and climate are in controlling nutrient dynamics in oak ecosystems, offering information on the spatial variability of the soil nutrients that is essential for conservation and ecosystem management plans.

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Authors contribution

The first author conducted the experiment and collected the data. The second author guided the development of the research paper by reviewing and providing critical feedback on the manuscript. The third author performed the data analysis and contributed to writing the manuscript.

Conflict of interests

None

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