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Investigation of Edaphic and Climatic Factors for Thymus laevigatus in Utmah Natural Reserve, Yemen

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Abstract

In natural habitats of wild plants, growth, and productivity are influenced by various environmental factors, including edaphic and climatic conditions. Yemen has many natural habitats that contain endemic plants. *Thymus laevigatus* is one of these plants distributed in higher mountain areas in the Northern part of the country. Assessment of environmental factors in these areas is still limited. So, this study aimed to analyze the edaphic and climatic factors affecting the growth of wild thyme in the Utmah Natural Reserve. Soils 0-25, and 25-50 cm deep were randomly sampled from the rhizosphere of the thyme. Edaphic factors include soil texture, organic matter, pH, EC, mobile potassium (K_2O) and phosphorous (P_2O_5), Exchangeable (Ca, Mg, Na), Available (Fe, Zn, Mn), and total Calcium carbonate ($CaCO_3$). The meteorological data (precipitation, temperature, and average monthly sunshine duration) for 2015-2022 were obtained from the Water and Environment Center – Sana'a University. Results showed that K_2O, Zn, and Ca concentrations are deficient; Mn is adequate; Mg is near moderate; P_2O_5 is moderate; Fe and organic matter are adequate; Na is high. Soil is without salinity and pH is alkaline. The soil texture is sandy loam. The bioclimatic zone is semi-arid with a temperate winter. Wet periods are months of April, May, mid-July, August, and October with a yearly average rainfall of 377.13 mm. Minimum temperatures are between 6.83-15.01°C, while the maximum is between 23.21-31.16°C. The average sunshine hours during thyme growth season are 10.68 h/ day. The obtained results represent the basic requirements for the growth and productivity of thyme in its natural habitats. Also, it provides preliminary information that can be used to plan conservation projects for this plant and contribute to its domestication and cultivation.

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Bioclimatic zone, Climatic, Edaphic, *Thymus laevigatus*, Yemen

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1. INTRODUCTION

Yemen has rich and diverse natural plant resources due to considerable climatic differences and soil type variation. These resources contain over 3,000 plant species and 10% are endemic [1]. The State of Forest Genetic Resources in Yemen reports that 554 plant species are endangered, including 391 endemic and 115 near-endemic plants [2]. Also, plant species, including medicinal and aromatic plants, are drastically reduced due to drought, desertification, poor agricultural practices, urbanization, road construction, over-exploitation, grazing, and housing expansion. So, conserving natural plant resources is important [1]. Knowing factors affecting the development and adaptation of plant species can aid in efficiently planning the cost and time for rangeland restoration [3]. The productivity and growth of plants are significantly influenced by various environmental factors in ecosystems and natural habitats worldwide [4]. Various recommendations have been developed to conserve medicinal and aromatic natural plant resources. Wild nurseries and natural reserves can be utilized to conserve the medicinal properties of plants in their natural habitats. Seed banks and botanic gardens are crucial in ex-situ conservation and provide a means for future replanting [5]. Most endemic medicinal and aromatic plants derive their medicinal properties from secondary metabolites that respond to stimuli in natural environments, which may not be expressed under culture conditions [6]. The quality of active compounds of medicinal and aromatic plants is affected by various factors such as regional climate, altitude above sea level, geographical location, and soil conditions [7]. Soil condition factors include texture, drainage, bulk density, depth, organic matter, pH, electroconductivity, cation exchange capacity, and nutrients [8]. Wild thyme (*Thymus laevigatus*) is the only species that represents the Thymus genus in Yemen, out of 214 species and 36 subspecies widespread in the Old World [9]. Its morphological features were studied by [10]. It is considered one of the edible medicinal and aromatic plants that grow wild and is endemic in the higher mountainous areas in the Northern part of the country. This species is a characteristic plant of summit ridges, bare stony mountain-sides, moderate to almost flat rocky mountains, on and around the high plateau, and on hills at different elevations beginning from 2174m [10–12]. In Yemen, research on medicinal and aromatic plants (MAPs) is limited [1], and this includes its edaphic and climatic requirements. This led to poor planning by authorities responsible for protecting biodiversity, which was reflected in the reality of MAPs in their natural habitats. Wild thyme is considered an endangered species [2]. Any attempt to conserve, cultivate, and productivity improve this plant, begins with understanding environmental conditions in its natural habitats. Therefore, this study aimed to analyze edaphic and climatic factors affecting the growth of wild thyme in the Utmah Natural Reserve.

2. MATERIALS AND METHODS

2.1. Study area

The study area (Fig. 1) is in the middle portion of the highland west of Dhamar city. This highland is characterized by land with terraced mountain slopes and non-terraced hills and mountains. According to [13], terraced mountain slopes are a very distinct type of land that was made by man at least 2,000 years ago. The loamy soils on these slopes are suitable for cultivation. Non-terraced hills and mountains are uncultivable land but provide fodder for livestock and firewood for man. The soils are very shallow, very stony, and calcareous. The slopes can be very steep. According to [10], the geographical information of the study site is 14.5251249N, 44.0645764E with an elevation of 2476 m. Natural habitats of *T. laevigatus* are distributed on non-terraced hills and mountain slopes which are natural rangeland.

2.2. Soil sampling and analysis

The natural habitats of *T. laevigatus* are not subject to any agricultural exploitation and are therefore completely homogeneous. ICARDA [14] recommendations state that a soil sample should be composed of several subsamples representing a seemingly uniform area or field with similar cropping and management history. In the current study soil samples were collected at 0-25, and 25-50 cm from 3 localities. The samples of each depth were mixed to form a representative sample of the area. The soil samples were air dried, thoroughly mixed, passed through a 2mm sieve to remove gravel and any debris, and then packed in plastic bags ready for physiochemical analysis. Soil texture was analyzed for the top 25 cm soil samples by pipette method according to [15]. Organic matter (OM) is analyzed by the loss on ignition (LOI) method. Soil pH was determined by pH meter using 1:1 soil to distilled water method. Soil salinity (EC) was determined by an electrical conductivity meter. Mobile Potassium (K_2O) and Exchangeable Calcium (Ca), Magnesium (Mg), and Sodium (Na) were measured using the Ammonium Acetate method. Mobile phosphorous (P_2O_5) was measured using Olsen's method. Available soil micronutrients (Fe, Zn, Mn) were measured using the DTPA extraction method [16]. Total Calcium carbonate ($CaCO_3$) was measured according to [17].

2.3. Climate data collection and analysis

Weather monthly data referred to the period January 2015 to October 2022 were provided by the Water and Environment Center – Sana'a University. Monthly means of precipitation, temperature (Min., Max., and average), and average monthly sunshine duration were calculated. Precipitation, and temperature used for:

i **Determine bioclimatic zone:** according to [18] bioclimatic zone determined using Emberger's Pluviothermic Index (Q2):

$$Q2 = \frac{2000P}{M^2 - m^2}$$

Where $Q2$: Emberger's Pluviothermic Index, P is the total monthly precipitation (mm),M is the average of the maximum temperature of the hottest month (°K), and m is the average of the minimum temperature of the coldest month (°K).

ii. **Drought analysis:** to determine dray and wet periods Bagnouls and Gaussen [19] suggest an ombrothermic diagram using the bioclimagraph (P = 2T) where P: precipitation (mm), T: average of monthly temperature.

MS Excel 2021 software was used to calculate and draw graphs.

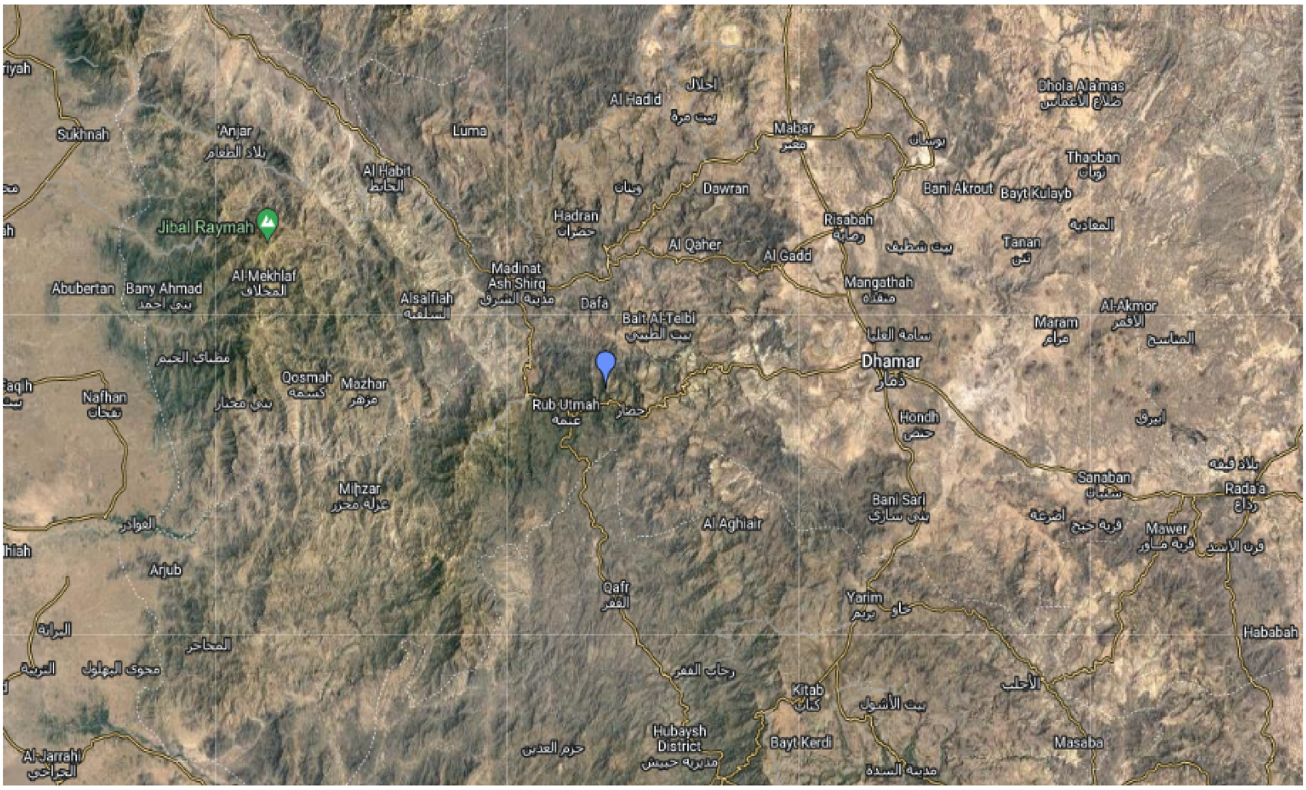

Figure 1. Dhamar governorate map showing the study area (blue balloon)

3. RESULTS

3.1. Soil characteristics

The Physio-chemical properties are shown in Table 1. A depth of 0-50 cm is the appropriate depth for thyme growth, but the effective depth is 0-25 cm. Based on [17] and [14], the results indicate a high concentration of Na, a deficient concentration of K_2O, Zn, and Ca, an adequate concentration of Mn, a low to moderate concentration of Mg, a moderate concentration of P_2O_5, an adequate concentration of Fe, and adequate organic matter. EC (0.78 and 0.85) refers to the soil without salinity. According to [20], the results of soil pH (7.15 and 7.11) refer to soil being alkaline and most nutrients being available. The proportion of sand, silt, and clay (Table 1) refers to soil texture as sandy loam. It was observed that the upper surface of the soil is mostly gravel and stones.

3.2. Climate factors

It is apparent in Table 2 average of climate factors from 2015 to 2022. It includes precipitation, temperature (minimum, maximum, average), and average monthly sunshine duration.

3.2.1. Precipitation (mm)

The results of this study for the monthly average of the period 2015-2022 indicated that rainfall is distributed throughout the year and that the highest rates are in April, May, and August with a yearly average of 377.13 mm (Fig. 2). It is observed that rainfall differ on each year during the period study. The rainy season runs from mid-March to late May. From June to mid-July, rainfall decreases and increases during August. The dry period begins in September and runs until mid-March. However, it was observed to increase rainfall in October (288 mm in 2018 and 74 mm in 2019). This explains the increase in the October monthly average.

3.2.2. Temperature (°C)

Results of this study indicated that the average monthly minimum temperatures for the period 2015-2022 (Fig. 3) were between 6.83-15.01℃. While the average monthly maximum temperatures were between 23.21-31.16℃. January is the coldest month of the year and June is the hottest. The temperature of the same month varies in different years. The lowest temperature (5.2℃) was recorded in December 2017 and the highest temperature (31.8℃) was recorded in June 2022. Temperature data for the study period indicated that the temperature increase continues until July and then begins to decrease until the end of the year. Wang et al. [21] defined spring as a transition from winter to summer with increasing temperature, while autumn is the transition from summer to winter with decreasing temperature. Based on temperature data, the spring season begins in February and runs to April. At this period, it was observed plants started flowering and the weather started to become warmer. The months of May, June, and July are the hottest (summer season). Moderate temperature runs

Table 1. Physio-chemical properties of the study area

Physio-chemical properties	Sample depth (cm)	
	0-25	25-50
pH	7.15	7.11
EC (dS.m^{-1})	0.78	0.85
TDS (ppm)	499.97	541.63
Na (ppm)	356.96	577.99
K_2O (ppm)	82.15	73.25
Fe (ppm)	5.67	7.24
Zn (ppm)	0.02	0.02
Mn (ppm)	514.06	369.74
Ca (ppm)	420.84	400.80
Mg (ppm)	164.16	194.56
P_2O_5 (ppm)	9.39	8.70
$CaCO_3$ (%)	9	11
Organic matter (%)	7.52	6.2
Organic carbon (%)	4.37	3.6
Sand (%)	65	-
Silt (%)	21	-
Clay (%)	14	-
Soil texture	sandy loam	-

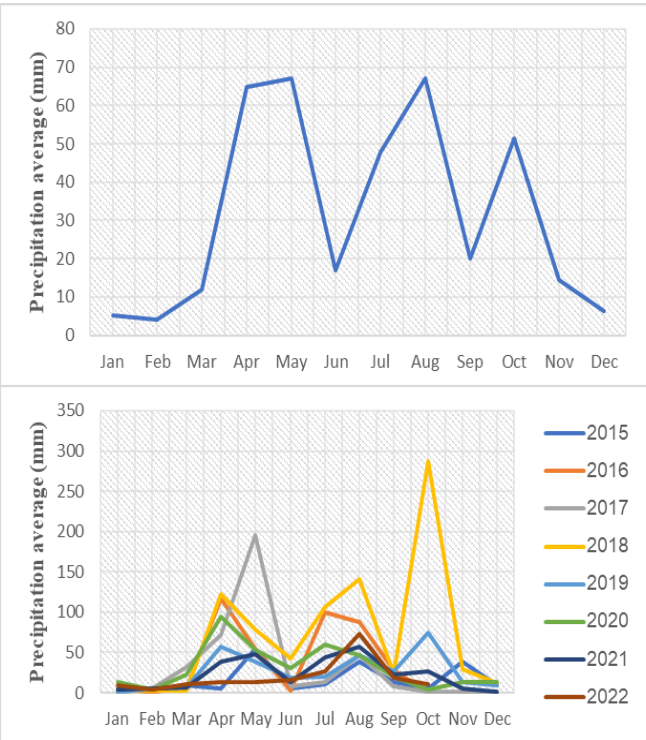

Figure 2. Monthly precipitation average of 2015-2022

from August to October (autumn season). Starting from November, the temperature tends to become colder until January (winter season).

Drought analysis

Using monthly rainfall and temperature for the period 2015-2022, the Bagnouls and Gaussen Ombro-Thermal Diagram was constructed (Fig. 4). The Bioclimatic zone was determined using Emberger's Pluviothermic Index (Table 3). Fig. 4 reveals that the period from November to April and the months of June, mid-July, and September are dry-thermal periods. Months of April, May, second mid-July, August, and October are wet periods. The dry period is distributed over the seasons to include the winter, half of the spring, the last third of the summer, and the middle third of the autumn. It observed that in the study area, the agricultural season starts in April when the rate of rainfall and temperature is optimal (wet period). During this period wild thyme inflorescences start to appear. The recurrence of flowering is a common occurrence during the growth season. Results of calculated Emberger's Pluviothermic Index (Q2) indicated that the bioclimatic zone of the study area from 2015 to 2022 is semi-arid with temperate winter.

3.2.3. Sunshine duration (h)

It is apparent from Table 2 that from April to September the average sunshine hours were 10.68 h/ day. Full flowers occur at the end of April and the first of May when the average of sunshine hours is between 10.4-11.1 h/ day. It observed that wild thyme grows well in areas without shading.

Climate change in the study area

Climate change can be observed using Bagnouls and Gaussen's ombre-thermal diagram for each year during the period 2015-2022 (Fig. 5). It observed that most of 2015 is a dry-thermal period. The highest precipitation is 55 mm in May (wet period) and the yearly total of 199 mm. In 2016 dry-thermal period ran from January to March and from September to December. The highest precipitation (117, 100, 88 mm) was in April, July, and August, respectively with a yearly total of 401 mm. In 2017 wet period runs from April to the first third-June with 196 mm in May and a yearly total of 386 mm. In 2018 dry-thermal period runs from January to mid-March and from mid-November to December and the highest precipitation is 288 mm in October with 853 mm yearly total precipitation. In 2019 wet period was in April (57 mm) and October (74 mm) and a yearly total of 315 mm. In 2020 wet period runs from the last third of March to May and from July to mid-August with a yearly total of 374 mm. In 2021 wet period was in mid-May and from mid-July to last August with a yearly total of 272 mm. In 2022 wet period was in August (73 mm) with a yearly total of 196 mm. The bioclimatic zone of the study area in most years is semi-arid with temperate winter except in 2015 (arid with temperate winter), 2018 (sub-humid with

Table 2. Average of climate factors during the period of 2015-2022

Month	Climate factors				
	Min. Temp. (°C)	Max. Temp. (°C)	Avg. Temp. (°C)	Precipitation (mm)	Sunshine duration (h/day)
Jan	6.83	25.11	15.97	5.13	9.8
Feb.	8.16	28.33	18.24	4	10.2
Mar.	10.13	28.65	19.54	12	10.3
Apr.	11.64	28.2	19.92	64.88	10.4
May.	12.98	28.89	20.93	67.13	11.1
Jun.	13.53	31.16	22.34	17	11.6
Jul.	15.01	27.56	21.29	47.63	10.7
Aug.	14.56	27.15	20.86	67.13	9.6
Sep.	13.74	28.74	21.24	20.13	10.7
Oct.	11.28	25.55	18.41	51.38	10.4
Nov.	9.47	23.79	16.63	14.43	10
Dec.	7.54	23.21	15.38	6.29	9.7

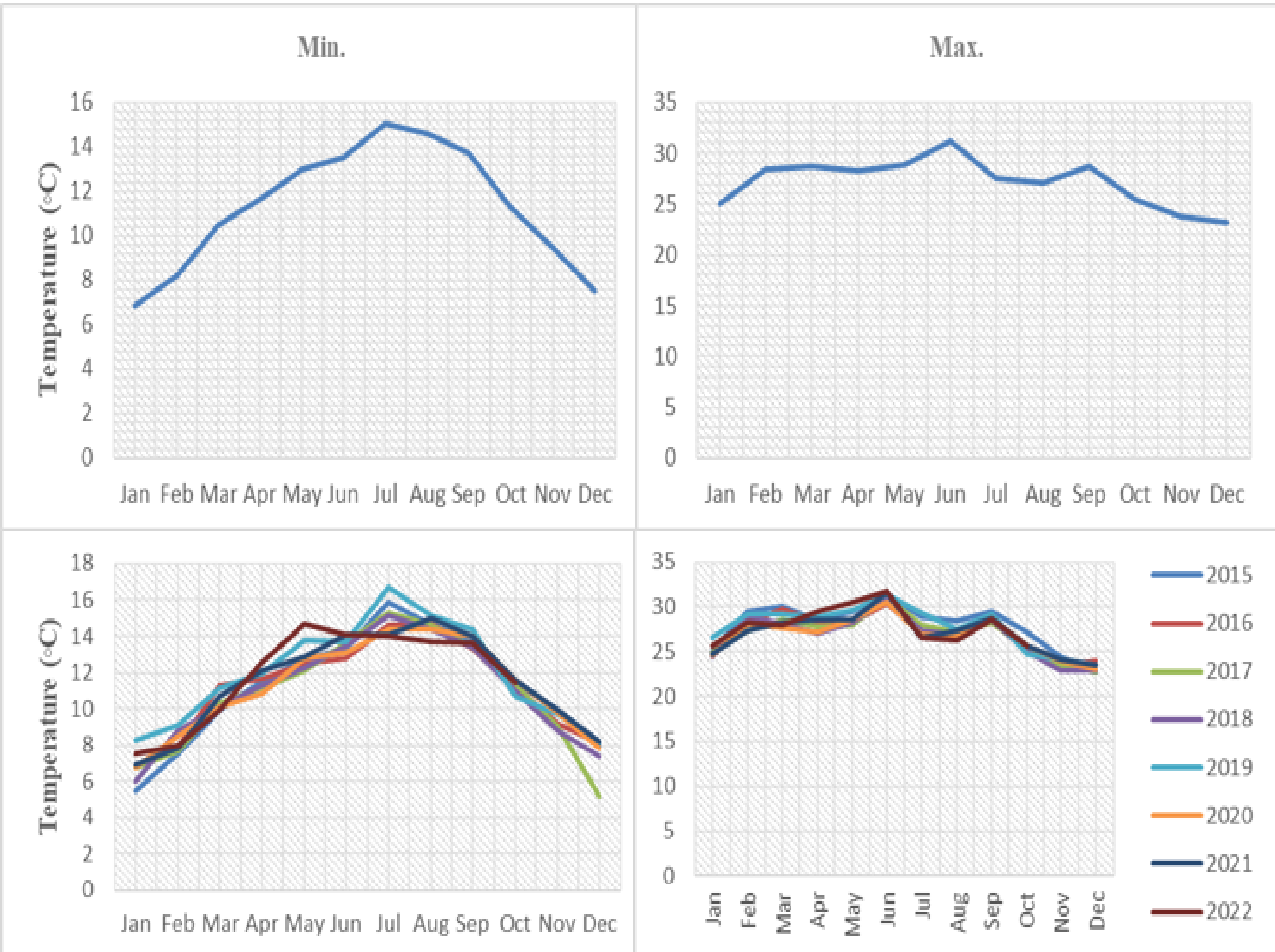

Figure 3. Monthly temperature average of 2015-2022

Table 3. Bioclimatic zone

Period	Q2	Min. temperature (°C)	Climatic type
Average of 2015-2022	53.06	6.83	Semi-arid with temperate winter
2015	26.24	5.5	Arid with temperate winter
2016	58.24	6.8	Semi-arid with temperate winter
2017	51.16	5.2	Semi-arid with temperate winter
2018	117.48	6	Sub-humid with temperate winter
2019	46.16	8.1	Semi-arid with warm winter
2020	53.84	6.8	Semi-arid with temperate winter
2021	37.66	6.9	Semi-arid with temperate winter
2022	27.55	7.5	Arid with warm winter

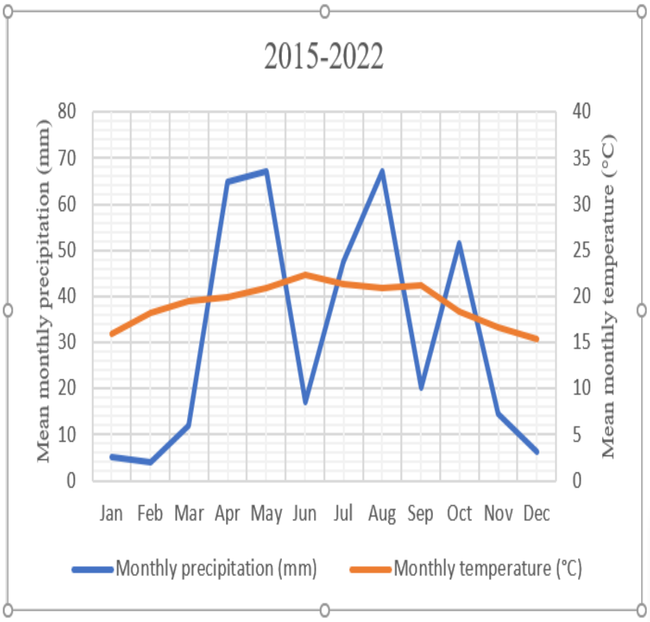

Figure 4. Bagnouls and Gaussen ombro-thermal diagram. Distribution of monthly precipitation and temperature. The region under the red line indicates the dry-thermal period and the region above the red line indicates the wet period.

temperate winter), 2019 (semi-arid with warm winter), and 2022 (arid with warm winter).

4. DISCUSSION

In the current study, the results of soil characteristics indicated that wild thyme, in its natural habitats, grows in gravel sandy loam soil with a pH that allows cation exchange capacity near 100%. Because the plant is grown wild, nutrient amounts are determined by the interaction of the soil with other environmental factors, which explains why the soil content of these elements varies from low to sufficient. Levels of pH, K_2O, and P_2O_5 of this study are somewhat similar to those obtained for the Menakhah region (2200–2600 m above sea level) mentioned by [22]. Soil conditions are a determinant of wild plant diversity that naturally occurs in an area. Soil electroconductivity, organic matter, total nitrogen, pH, Ca, K, Cu, and Mn are major soil factors that affect the natural occurrence of wild edible plant species. Also, cation exchange capacity, bulk density, P (available), Fe, Na, and Mg have a strong effect [8]. Thymus species prefer to live on rocks or stones and in well-drained loamy to sandy soils with a pH of 5 to 8 [9, 23, 24]. However, each species requires very different substrata. *T. carnosus* lives on dunes near the sea, *T. lacaitae* on gypseous soils, and *T. vulgaris* usually on calcareous soils [9]. *T. kotschyanus* grows rapidly in sandy loam, light textured, high nitrogen content, rich in organic matter, and non-calcareous soil [4]. In *T. pubescens* natural habitats, pH ranges between 6-8 [25]. Most soils where *T. laevigatus* grows are on slopes steeper than 25%. Alluvial deposits of newly formed soil materials (entisol) are only suitable for pastures and shallow-rooted crops. Organic matter decreases uniformly with depth [26]. Rainfall is the primary climate variable to determine the onset and length of the wet or rainy season [27]. Wild thyme is shallow-rooted, so it is affected by the amount of rainfall. The amounts of rainfall distributed during the growth season promote regular growth and its spread area. Little amounts cause the plant to flower to maintain its existence while high amounts can lead to soil erosion. Asfawa et al. [28] reported that excessive rainfall is not necessarily useful or desirable at all times. The rate or amount it is received at a time could be too much for the environment. Some of it is unavoidably wasted while some may even be destructive. A minimal amount of water is needed to activate biological processes such as reproduction and seed germination. If rainfall is concentrated in time over a certain region, this minimum amount of soil water is intermittently exceeded and vegetation cover can persist. If rainfall is uniformly spread and soil

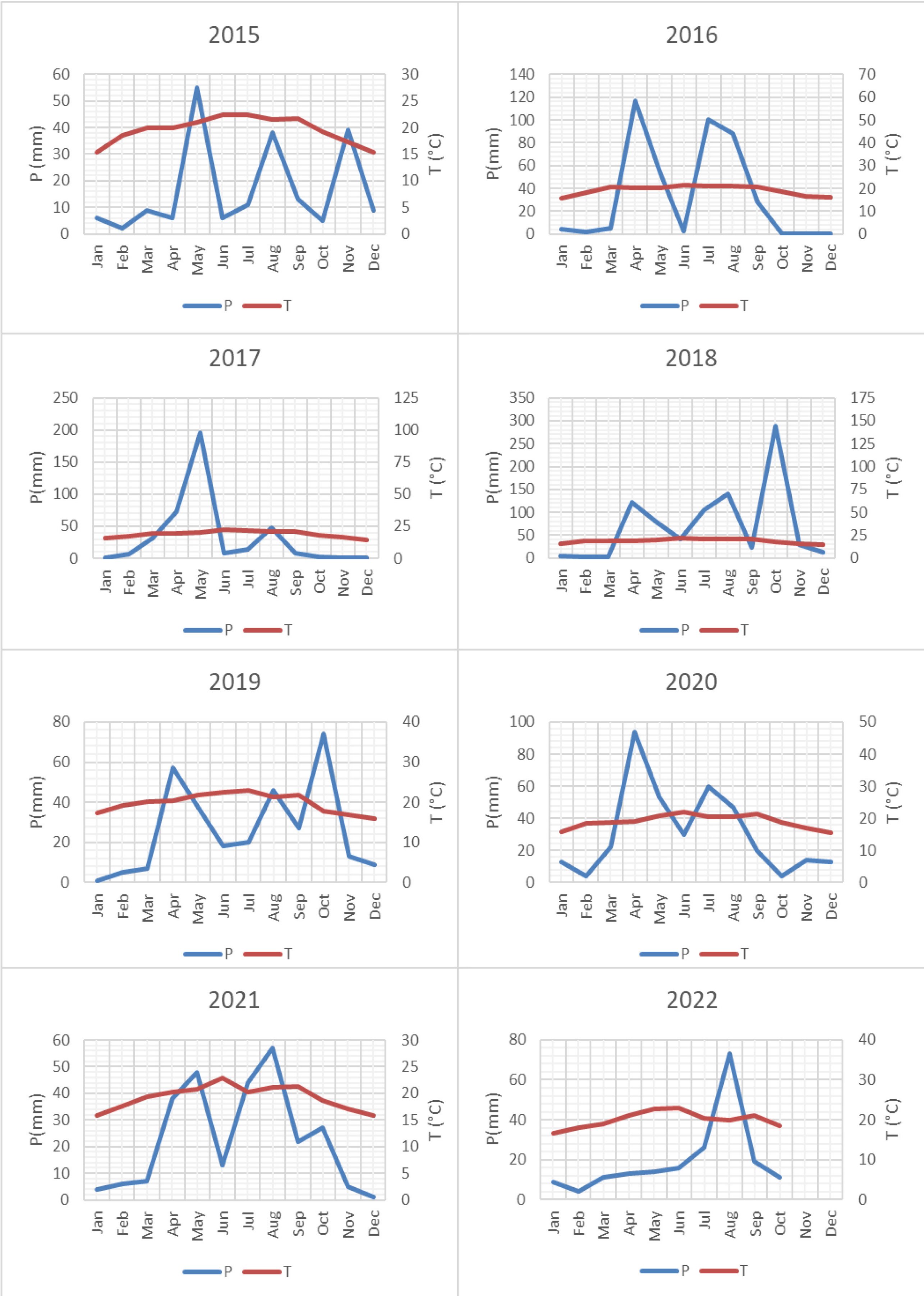

Figure 5. Bagnouls and Gaussen ombro-thermal diagram of the years 2015-2022. P= Precipitation, T= Temperature.

moisture never exceeds the threshold needed to activate plant reproduction, germination, and vegetation cover tend to disappear. The Bagnouls and Gaussen ombrothermal diagram (Fig. 5) provides a sufficient indicator to support reports that considered wild thyme is an endangered species, with the added effects of harvesting, overgrazing, and logging. Plants have a characteristic optimal growth temperature, above or below which, growth and development can be strongly affected but the plant can still survive [29]. The reason for the early appearance of inflorescences might be attributed to the effect of cold on the stems, especially since the generative shoots develop in the areas of last year's growth. Repeated periods of drought during the growth season can stimulate flowering. Mewes and Pank [30] indicated that low temperatures during winter are an absolute requirement for inducing the full flowering of thyme plants. Early flowering and a shorter vegetative phase are means of drought stress escaping as the plant completes its life cycle before an impending drought event [31]. Thymus species grow well in a temperate to warm, dry, and sunny climate. They are very resistant plants, which allows them to live under extreme climatic conditions concerning temperature and water supply [23, 24]. *T. laevigatus* is frost tolerant and its prostrate habit is well adapted to exposed conditions [26]. Light is a crucial environmental factor in the growth and development of plants [32]. Thymus species are heliophilous plants like the sun and their best potential appears in full sun [9, 23]. *T.vulgaris* needed 16 hours of lighting for the optimal development of the full flowers [30].

5. CONCLUSION

Natural habitats of *T. laevigatus* are located in sloping mountainous areas with high altitudes and a bioclimatic zone of semi-arid with a temperate winter. Soil texture is sandy loam derived from newly formed alluvial deposits, superficial in most places, and containing the basic elements in proportion favoring the growth of herbaceous plants. Variations in nutrient concentrations can be attributed to natural habitat changes resulting from the interaction of edaphic and climatic conditions. The growing season begins with the onset of the rainy season and rising temperatures from late March. Average annual precipitation does not exceed 400 mm and average sunshine during the growing season is more than 10 hours daily. Climate change is greatly affecting the natural habitats of plants, including thyme, and this is evident in years of drought, which negatively affect growth and spread, especially if associated with logging, overgrazing, and in years of heavy rains, which lead to soil degradation, erosion, especially in light of the deterioration of agricultural terraces established hundreds of years ago without paying attention to their maintenance. Taking edaphic and climatic conditions into account could help to conserve, domesticate, and introduce thyme into productive agricultural systems. It is important to carry out studies to improve the edaphic condition of thyme natural habitats by using agricultural practices with a high degree of safety to conserve the biodiversity of these habitats.

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