Estimating Chilling and Growing Degree Hours Related to Deciduous Fruit Production in Kurdistan Region-Iraq

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Abstract

This study was carried out to estimate the annual chilling and heat accumulation in Kurdistan region-Iraq using three different models; chilling hours (CH), chilling units (CU) and chilling portions (CP), as well as estimating the accumulated growing degree hours (GDH) using the ChillR Package, Version 0.72.8 based on daily maxima and minima temperatures of 170 locations for 40 years (1983-2022) downloaded from NASA. The results showed that in Kurdistan region, the chilling hours with 7 classes ranged from 335 CH in Shahreban (Diyala) to 1083 CH in Amedi, Deraluk, Dinarte, Kani Masi, and Shiladize (Duhok), and Barzan (Erbil), with an average of 886 CH. The chilling units (CU, Utah Model) with 6 classes ranged from 507 CU (Shahreban, Diyala) to 1135 CU (Hizawa, Duhok), with an average of 927 CU. However, the chilling portions with 7 classes ranged from 30.0 CP in Shahreban to 58.3 CP in Ahmad Awa, Khurmal, Penjwin, Sirwan, and Zalm (Salaymaniyah), with an average of 49.5 CP. Growing degree hours with 7 classes ranged from 1136 GDH Choman, Galala, Haji Omaran and Samilan (Erbil) to 8564 GDH in Shahreban, with an average of 3256 GDH. All models were strongly correlated with location parameters, the highest strong correlations were found between each CP and GDH with AAT. The observations emphasized that both CU and CP models are more accurate than CH model for estimation of chilling and growing degree hours (units) in Kurdistan region-Iraq.

Keywords: Chilling hours, chilling units, chilling portions, growing degree hours.

Introduction

Sufficient and accurate climate knowledge is necessary to be available for fruit growers so as to correctly decide the selection of fruit trees for different regions with varied climates and hence getting better productivities (4). Among the climate elements, temperature limits represented as chilling and growing degree hours are most important for deciduous fruit growing (18).

It is well known that temperate-zone deciduous fruit trees enter dormancy during winter, this dormancy is a developmental phase that allows the trees to survive unfavorable conditions during the winter (31). Winter dormancy can be released and growth resumed when the trees receive a certain amount of chill and heat units during winter and late winter-early spring, respectively (13). Inadequate amount of winter chill can strongly decrease both crop yield and crop quality. When chilling requirements are not completely satisfied, irregular flowering occurs resulting in an incomplete crop development. This process eventually results in varying crop sizes and maturity stages at the time of harvest, which can noticeably reduce yield quality and quantity (10 and 17). Breaking winter dormancy in fruit trees is not only the resume of vegetative growth, but also flowering, which require certain amounts of both chill and heat units, these units are varied from species to species and cultivar to cultivar, and when a fruit crop is planted in a given area, it is important to consider those aspects of the environment which may have serious effects on the future success of the fruit crop (33).

Nowadays, several models are available to estimate winter chill accumulation worldwide, among these; Chilling Hours Model (8) which also called with some other names such as 0–7.2 °C Model (12), in which temperatures between 0 and 7.2 °C are expected to have chilling effect, and each hour that temperature ranged between these thresholds during dormant season considered a chilling hour (CH). After then the Utah Model was aroused after observing that the previous model had ignored the negative effects of temperatures above 7.2 °C, Utah Model is characterized by differential weighting of temperature ranges, including negative weights above 15.9 °C (32), the chill amounts accounted by this model are expressed as chill units (CU). The third modelling approach is called Dynamic Model, which is extensively used in practical horticulture, the accumulated chill effects in this model are expressed as chill portions (CP), contributing to fulfillment of chilling requirements (23). Additionally, there are also some other regional models (9, 11, 12, 13, 21 and 22). Among all these models, the Utah Model is the only one that can explain the observed negative effect of high temperatures (29). However, when the majority of the aforementioned models were compared, it was noticed that the Dynamic Model is the best among them (23).

There are very few recent studies on the chilling requirements of deciduous fruit trees available in Iraqi Kurdistan region. In this regard, Al-Khafaji (2) used a mathematical model to calculate chilling hours of different areas of Iraq (Baghdad, Diyala, Karbala and

Nineveh) during two years (1993 and 1994) and concluded that 1000-1200 chilling hours are accumulated in Duhok, Sulaymaniyah and Erbil, while 700-800 chilling hours are accumulated in Kirkuk and Diyala. As a result, the scientific studies on the chilling accumulation in Iraqi Kurdistan are limited. On the other hand, the impact of climate change (7) makes the update of chilling accumulation information a prerequisite for successful fruit production.

Kurdistan region of Iraq has a total area of 52871.52 square kilometers and is located between the latitudes 33.96 and 37.20 N and longitudes 42.57 and 46.18 E (Researcher estimates). It has a very fertile soil, plenty of rainfall and other suitable climatic conditions for growing and producing various fruit trees. It considered a part of the temperate region, and precisely the warm section of the temperate region according to (10) making the region suitable for both deciduous and evergreen fruit trees. The climate of Kurdistan region is governed by orographic precipitation from the mountains, causing high precipitation rates in the northern parts, and a drier climate in the plains (15). The precipitation is concentrated from October to May, while the hotter summer months hold little or no precipitation at all. The average annual precipitation ranges between 200 and 1000 mm (20 and 28). The mean daily temperature for winter is around 5 °C and in summer, the mean temperature is around 30 °C, but can rise to 50 °C in the southern parts (15 and 20) with a strong variability of topography and temperature regimes (4). In Iraq and Kurdistan region, although the directions toward establishing new orchards are increasing, yet crop yields are late and not sufficient for local consumption, because the environmental aspects, especially chill and heat units are not considered due to the ignorance of farmers on one hand and on the other hand, lack of accurate meteorological data to determine if adequate chilling exists for a desired fruit in a given area. Nowadays, internet services and mobile apps play an important role in forecasting weather aspects, NASA, Yahoo Weather, Accuweather, NOAA Weather Radar Live and The Weather Channel are among the examples, each of which could be used as alternatives for lacking meteorological stations and weather data.

The purpose of the study is to update and redistribute the most important fruit growing regions of Iraqi Kurdistan to different zones based on winter chill accumulation, and to determine the available amounts of chilling and heat units affecting the production of deciduous fruit trees in each area, using different chilling models, so that they are available for fruit growers when they plan to establish new orchard projects, and to substitute the chilling hours (CH) to chill portions (CP) which are considered most accurate.

Materials and Methods

This research was carried out to determine the accumulated chilling; chilling hours CH (8), chilling units CU (32), chilling portions CP (19) and growing degree hours GDH (26) in 170 locations (on the basis of subdistricts, located within 34 Districts) from Erbil (52 locations), Sulaymaniyah (66 locations), Diyala (15 locations), Kirkuk (2 locations), and Duhok (35 locations)

governorates of Iraqi Kurdistan region (Figure 1 and Table 1). Coordinates (decimal degrees) of the locations (1-170) were found from Google Maps; however, the altitudes (m) of the locations were taken from *Elevation Finder (freemaptools.com)* website (16) using the coordinates (latitudes and longitudes). The data of daily maxima and minima temperatures (.csv excel files) of 40 years (January 1, 1983-December 31, 2022) were downloaded from NASA *POWER | Data Access Viewer (nasa.gov)* (30) for all locations under study, and the data were processed for calculating the parameters (CH, CU, CP and GDH) using R (ChillR and ChillModels packages) according to (25).

The coordinates ranged from the latitudes 33.9647 N (Shahreban, Diyala) to 37.2007 N (Darkar, Duhok), and longitudes 42.5717 E (Ibrahim Khalil, Duhok) to 46.1877 E (Awesar, Sulaymaniyah) with the altitudes ranging from 57 m (Shahreban) to 1769 m (Haji Omaran, Erbil) with an average of 698 m. The annual average temperatures (1983-2023) ranged from 13.2 °C (Choman, Galala, Haji Omaran, Qasre, Samilan and Warte) from Erbil, and (Betwata and Sarkapkan) from Sulaymaniyah to 24.2 °C (Shahreban) with an average of 17.9 °C (Table 1). The geospatial analysis tool in ArcGIS 10.8.1 Environment (27) was used to interpolate all field measurements to create the spatial distribution maps of the parameters. The geometric calculator was used for calculating the total area as 52871.52 km^2.

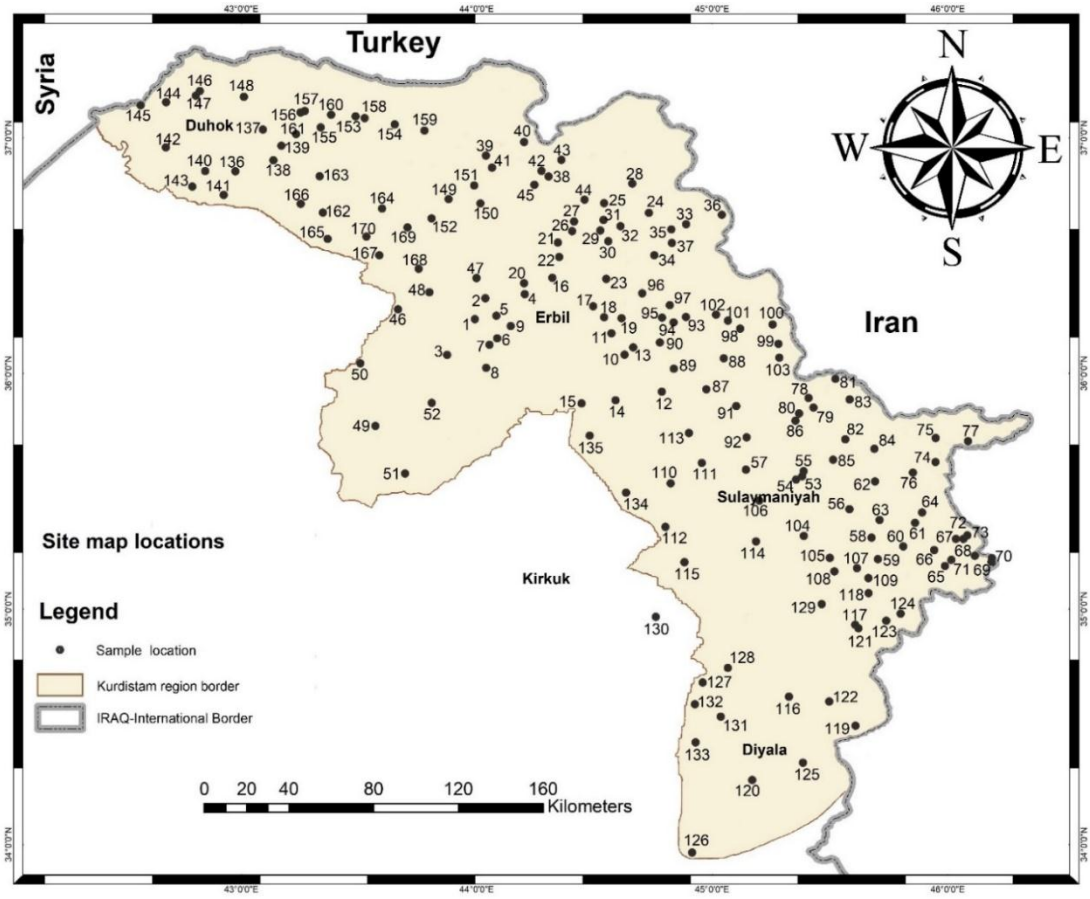

Fig 1. The site map of the studied locations including location series (1-170) as are also arranged in Table 1.

Table 1. Governorates, Districts, Subdistricts (locations 1-170) of Kurdistan region-Iraq under study with their altitudes, coordinates and annual average temperatures (1983-2022)

S.	Governorate	District	Subdistrict	Altitude	Latitude	Longitude	Annual Avg. Temp. (°C)
1.	Erbil	Erbil	Ankawa	412	36.2312	43.9926	21.2
2.			Bahirka	466	36.3173	44.0352	20.2
3.			Shamamek	394	36.1439	43.9936	21.2
4.			Bastora	738	36.3370	44.2036	16.9
5.			Shaways	511	36.2478	44.0824	20.0
6.		Bnaslawa	Bnaslawa	468	36.1482	44.0878	20.0
7.			Daratoo	434	36.1229	44.0561	21.2
8.			Qushtapa	405	36.0239	44.0399	21.2
9.			Kasnazan	617	36.2058	44.1423	20.0
10.		Koysinjaq	Koysinjaq	575	36.0790	44.6298	20.0
11.			Siktan	677	36.2368	44.6138	20.0
12.			Ashti	473	35.9218	44.7855	17.9
13.			Chnarok	741	36.1124	44.6664	20.0
14.			Segrdkan	336	35.8732	44.4461	20.0
15.			Taq Taq	340	35.8873	44.5887	20.0
16.		Shaqlawa	Shaqlawa	903	36.4070	44.3216	16.9
17.			Hiran	935	36.2851	44.4948	16.9
18.			Nazanin	767	36.2439	44.5352	20.0
19.			Smaquli	735	36.1710	44.5717	20.0
20.			Pirmam	1105	36.3833	44.2002	16.9
21.			Harir	713	36.5563	44.3449	16.9
22.			Basirma	638	36.4998	44.3484	16.9
23.			Balisan	910	36.3994	44.5501	16.9
24.		Soran	Soran	671	36.6548	44.5419	16.9
25.			Diana	698	36.7227	44.5412	16.9
26.			Khalifan	680	36.6034	44.4037	16.9
27.			Sreshma	828	36.6454	44.4112	16.9
28.			Sidakan	986	36.8063	44.6604	14.2
29.		Rawanduz	Rawanduz	796	36.6079	44.5243	16.9
30.			Akoyan	537	36.5610	44.5594	16.9
31.			Barzewa	635	36.6265	44.6132	16.9
32.			Warte	1001	36.5025	44.7535	13.2
33.		Choman	Choman	1108	36.6335	44.8896	13.2
34.			Samilan	1021	36.6803	44.7318	13.2
35.			Galala	1055	36.6117	44.8264	13.2
36.			Haji Omaran	1769	36.6743	45.0420	13.2
37.			Qasre	1100	36.5573	44.8276	13.2
38.		Mergasor	Mergasor	1145	36.8381	44.3070	14.2
39.			Barzan	753	36.9251	44.0393	15.7
40.			Sherwan Mazin	956	36.9828	44.2014	14.2

41.			Ble	499	36.8737	44.0646	14.2
42.			Goratu	957	36.8605	44.2747	14.2
43.			Piran	842	36.9072	44.3593	14.2
44.			Mazne	688	36.7390	44.4575	16.9
45.			Shanadar	468	36.8009	44.2452	14.2
46.			Khabat	283	36.2711	43.6667	20.2
47.		Khabat	Dara Shakran	416	36.4046	43.9964	20.2
48.			Kawr Gosk	274	36.3496	43.8033	20.2
49.			Makhmour	258	35.7780	43.5704	21.2
50.		Makhmour	Gwer	228	36.0446	43.5040	21.2
51.			Kandenawa	208	35.5584	43.6786	22.0
52.			Dibaga	352	35.8763	43.8099	21.2
53.	Sulaymaniyah		Sulaimani	840	35.5673	45.3821	17.2
54.			Bakrajo	750	35.5507	45.3571	17.2
55.		Sulaimani	Sarchinar	772	35.5830	45.3868	17.2
56.			Arbat	705	35.4263	45.5823	17.2
57.			Bazian	816	35.5928	45.1412	19.2
58.			Zarayan	585	35.3061	45.6768	17.2
59.		Sharazoor	Chnara	651	35.2120	45.7030	20.3
60.			Qalbaza	517	35.2641	45.8113	17.2
61.			Said Sadiq	585	35.3687	45.8582	17.2
62.		Said Sadiq	Barzinja	1231	35.5405	45.6917	17.2
63.			Kani Panka	565	35.3810	45.7085	17.2
64.			Shanadari	571	35.4146	45.8928	17.2
65.			Halabja	704	35.1793	45.9857	14.6
66.			Sirwan	518	35.2515	45.9401	13.5
67.			Khurmal	564	35.2982	46.0354	13.5
68.			Byara	1102	35.2270	46.1154	14.6
69.		Halabja	Tawella	1476	35.2011	46.1858	14.6
70.			Awesar	1680	35.2167	46.1877	14.6
71.			Anab	754	35.2092	46.0162	14.6
72.			Ahmad Awa	659	35.2974	46.0669	13.5
73.			Zalm	800	35.3129	46.0834	13.5
74.			Penjwin	1270	35.6239	45.9478	13.5
75.		Penjwin	Garmk	1235	35.7262	45.9492	13.5
76.			Nalparez	1092	35.5786	45.8522	17.2
77.			Gokhlan	1265	35.7114	46.0867	13.5
78.			Mawat	886	35.8976	45.4088	14.0
79.		Mawat	Dashti Tle	767	35.8572	45.4276	14.0
80.			Wlaghlu	1083	35.8303	45.3688	14.0
81.			Shanakhse	1111	35.9774	45.5239	14.0
82.			Chwarta	1131	35.7208	45.5641	17.2
83.		Chwarta	Siwayil	1560	35.8892	45.5843	14.0
84.			Zalan	972	35.6805	45.6898	17.2
85.			Sitak	1015	35.6377	45.5147	17.2

86.			Gapilon	911	35.7988	45.3542	14.0
87.			Dukan	467	35.9334	44.9740	17.9
88.			Bingird	652	36.0656	45.0494	17.9
89.		Dukan	Khidran	544	36.1327	44.7764	17.9
90.			Khalakan	808	36.0193	44.8386	17.9
91.			Surdash	1019	35.8614	45.1032	17.9
92.			Piramagroon	801	35.7301	45.1461	19.3
93.			Ranya	556	36.2407	44.8894	17.9
94.			Chwarqurna	538	36.2158	44.8358	17.9
95.		Ranya	Hajiyawa	574	36.2360	44.7859	17.9
96.			Betwata	999	36.3401	44.7029	13.2
97.			Sarkapkan	678	36.2923	44.8202	13.2
98.			Qaladize	601	36.1907	45.1182	17.9
99.			Hero	1259	36.1248	45.2818	17.9
100.		Pishdar	Halsho	1043	36.2100	45.2560	17.9
101.			Zharawa	551	36.2253	45.0665	17.9
102.			Sangasar	562	36.2499	45.0165	17.9
103.			Esewa	842	36.0661	45.2842	17.9
104.			Qaradagh	882	35.3103	45.3903	17.2
105.		Qaradagh	Sewsenan	783	35.2167	45.4987	20.3
106.			Delezha	787	35.4564	45.1973	19.2
107.			Darbandikhan	568	35.1337	45.6624	20.3
108.		Darbandikhan	Bawakhoshen	630	35.1734	45.6149	20.3
109.			Bani Khelan	421	35.0669	45.6639	20.3
110.			Chamchamal	718	35.5334	44.8238	19.2
111.			Takyay Kakamand	861	35.6209	44.9542	19.2
112.		Chamchamal	Takyay Jabari	791	35.3501	44.8027	19.2
113.			Aghjalar	601	35.7487	44.8979	19.2
114.			Sangaw	847	35.2850	45.1845	19.2
115.			Qadir Karam	385	35.1994	44.8824	20.9
116.			Kalar	218	34.6293	45.3279	21.6
117.		Kalar	Pebaz	328	34.9321	45.6070	20.3
118.			Shekh Taweel	767	35.0207	45.4646	20.3
119.	Diyala		Khanaqin	175	34.3476	45.379	21.6
120.			Gulala	118	34.2743	45.1693	22.9
121.			Maidan	325	34.9186	45.6208	20.3
122.		Khanaqin	Qoratu	275	34.6066	45.4970	21.6
123.			Sartak	797	34.9493	45.7378	20.3
124.			Bamo	815	34.9790	45.7999	20.3
125.			Alwan	182	34.3431	45.3843	21.6
126.			Shahreban	57	33.9647	44.9138	24.2
127.			Kifri	227	34.6897	44.9607	22.9
128.			Sar Qalla	343	34.7437	45.0663	22.9
129.		Kifri	Awa Spi	770	35.1589	45.5207	20.3
130.			Nawjul	336	34.9784	44.7639	20.9
131.			Kullajo	150	34.5430	45.0374	22.9

132.			Jabara	150	34.5956	44.9268	22.9
133.			Qara Tapa	131	34.4345	44.9302	22.9
134.	Kirkuk	Kirkuk	Qara Hanjir	766	35.4940	44.6330	21.5
135.			Shwan	666	35.7374	44.4798	21.5
136.	Duhok	Duhok	Duhok	528	36.8594	42.9759	17.1
137.			Mangesh	959	37.0357	43.0923	17.1
138.			Zawita	898	36.9062	43.1374	17.1
139.			Bagera	898	36.9675	43.1700	17.1
140.		Semel	Semel	464	36.8607	42.8466	17.1
141.			Fayda	405	36.7586	42.9258	17.1
142.			Batel	446	36.9608	42.6809	20.2
143.			Khanke	385	36.7937	42.7921	20.2
144.		Zakho	Zakho	442	37.1529	42.6808	20.2
145.			Ibrahim Khalil	396	37.1387	42.5717	20.2
146.			Darkar	655	37.2007	42.8234	17.1
147.			Hizawa	569	37.1802	42.8070	17.1
148.			Batifa	862	37.1752	43.0120	17.1
149.		Akre	Akre	646	36.7378	43.8814	20.2
150.			Bjeel	617	36.7263	44.0158	20.2
151.			Dinarte	797	36.8002	43.9908	15.7
152.			Grdasen	546	36.6566	43.8092	20.2
153.		Amedi	Amedi	1183	37.0922	43.4871	15.7
154.			Deraluk	625	37.0580	43.6514	15.7
155.			Sarsing	983	37.0453	43.3383	17.1
156.			Chamanke	1095	37.1092	43.2517	17.1
157.			Bamarne	1188	37.1144	43.2689	17.1
158.			Kani Masi	981	37.0853	43.524	15.7
159.			Shiladize	593	37.0309	43.7787	15.7
160.			Qadesh	1073	37.0986	43.3826	17.1
161.			Goramark	1183	37.0170	43.2334	17.1
162.		Shekhan	Shekhan	464	36.6882	43.3483	20.6
163.			Atrush	868	36.8371	43.3338	17.1
164.			Qasrok	418	36.6995	43.5992	20.2
165.			Zilkan	434	36.5731	43.3695	20.6
166.			Baadre	498	36.7210	43.2532	20.6
167.		Bardarash	Bardarash	370	36.5052	43.5845	20.2
168.			Daratu	416	36.454	43.7547	20.2
169.			Rovia	428	36.6237	43.7017	20.2
170.			Kallak	333	36.5843	43.5335	20.2

The R commands from which the parameters were determined were taken according to (25) as followings:

```
require(chillR)
setwd("C:/Users/Dell/Desktop/WeatherData/Erbil")
# Ankawa
weather<-read.csv("Ankawa.csv")
weatherfw <- fix_weather(weather)
```

```
chill <-
chilling(stack_hourly_temps(weatherfw,
latitude=36.2312),
                Start_JDay= 335, End_JDay= 31)
dev.off()
write.csv(chill,
"Ankawa_chill_Dec_Jan_1983-2022.csv",
                row.names=FALSE)
```

After then, to determine the differential zones, the study area was grouped into 6 temperature zones so as to characterize the map using ArcGIS (Figure 2) according to (32).

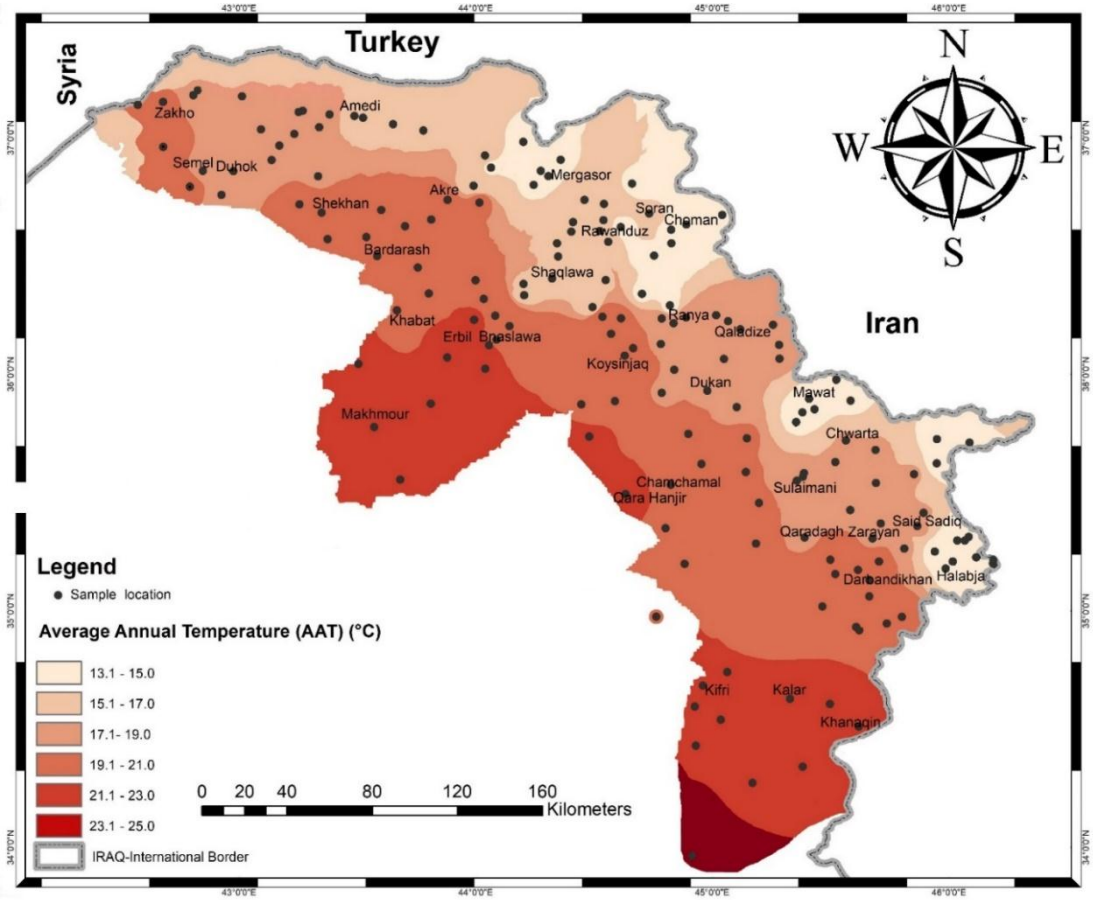

Fig 2. Distribution of studied locations according to annual average temperatures (1983-2022)

Results

Chilling hours (CH)

Figure 3 illustrates that there are 48 Sub-districts located in the range of 1001-1100 chilling hours (CH), including Amedi, Atrush, Bagera, Bamarne, Batifa, Chamanke, Darkar, Deraluk, Dinarte, Duhok, Fayda, Goramark, Kani Masi, Mangesh, Qadesh, Sarsing, Semel, Shiladize and Zawita from Duhok governorate; Ahmad Awa, Betwata, Dashti Tle, Gapilon, Garmk, Gokhlan, Khurmal, Mawat, Penjwin,

Sarkapkan, Shanakhse, Sirwan, Siwayil, Wlaghlu and Zalm from Sulaymaniyah governorate; and Barzan, Ble, Choman, Galala, Goratu, Haji Omaran, Mergasor, Piran, Qasre, Samilan, Shanadar, Sherwan Mazin, Sidakan and Warte from Erbil governorate. However, 50 subdistricts are locating within the range of 901-1000 CH, these include Anab, Arbat, Awesar, Bakrajo, Barzinja, Bingird, Byara, Chwarqurna, Chwarta, Dukan, Esewa, Hajiyawa, Halabja, Halsho, Hero, Kani Panka, Khalakan, Khidran, Nalparez, Qaladize, Qalbaza, Qaradagh, Ranya, Said Sadiq, Sangasar, Sarchinar, Shanadari, Sitak, Sulaimani, Surdash, Tawella, Zalan, Zarayan and Zharawa from Sulaymaniyah; and Akoyan, Ashti, Balisan, Barzewa, Basirma, Bastora, Diana, Harir, Hiran, Khalifan, Mazne, Pirmam, Rawanduz, Shaqlawa, Soran and Sreshma from Erbil. Whereas the coverage of the chilling hours ranging as 801-900 CH includes 23 locations which are Bnaslawa, Chnarok, Kasnazan, Koysinjaq, Nazanin, Segrdkan, Shaways, Siktan, Smaquli and Taq Taq from Erbil; Aghjalar, Bazian, Chamchamal, Delezha, Piramagroon, Sangaw, Takyay Jabari and Takyay Kakamand from Sulaymaniyah; and Batel, Hizawa, Ibrahim Khalil, Khanke and Zakho from Duhok. As for the range of 701-800 CH, there are 26 locations: Akre, Baadre, Bardarash, Bjeel, Daratu, Grdasen, Kallak, Qasrok, Shekhan, Rovia and Zilkan from Duhok; Bani Khelan, Bawakhoshen, Chnara, Darbandikhan, Pebaz, Sewsenan and Shekh Taweel from Sulaymaniyah; Bahirka, Dara Shakran, Kawr Gosk and Khabat from Erbil; and Awa Spi, Bamo, Maidan and Sartak from Diyala governorate. Regarding the range of 601-700 CH, there are 9 locations as Ankawa, Daratoo, Dibaga, Gwer, Makhmour, Qushtapa and Shamamek from Erbil; Qadir Karam from Sulaymaniyah; and Nawjul from Diyala. Meanwhile, the coverage of the range of 501-600 CH includes 7 locations: Alwan, Khanaqin and Qoratu from Diyala, Qara Hanjir and Shwan from Kirkuk; Kandenawa from Erbil; and Kalar from Sulamaniyah. The remainder 7 locations; Gulala, Jabara, Kifri, Kullajo, Qara Tapa, Sar Qalla and Shahreban from Diyala governorate have a chilling hours of less than 500 CH. It is worth mentioning that the average of accumulated CH in Kurdistan region is 886 CH. The highest chilling (1083 CH) accumulates in Amedi, Deraluk, Dinarte, Kani Masi and Shiladize (Duhok) and Barzan (Erbil). At time, the lowest chilling hours per year (335 CH) accumulate in Shahreban (Diyala).

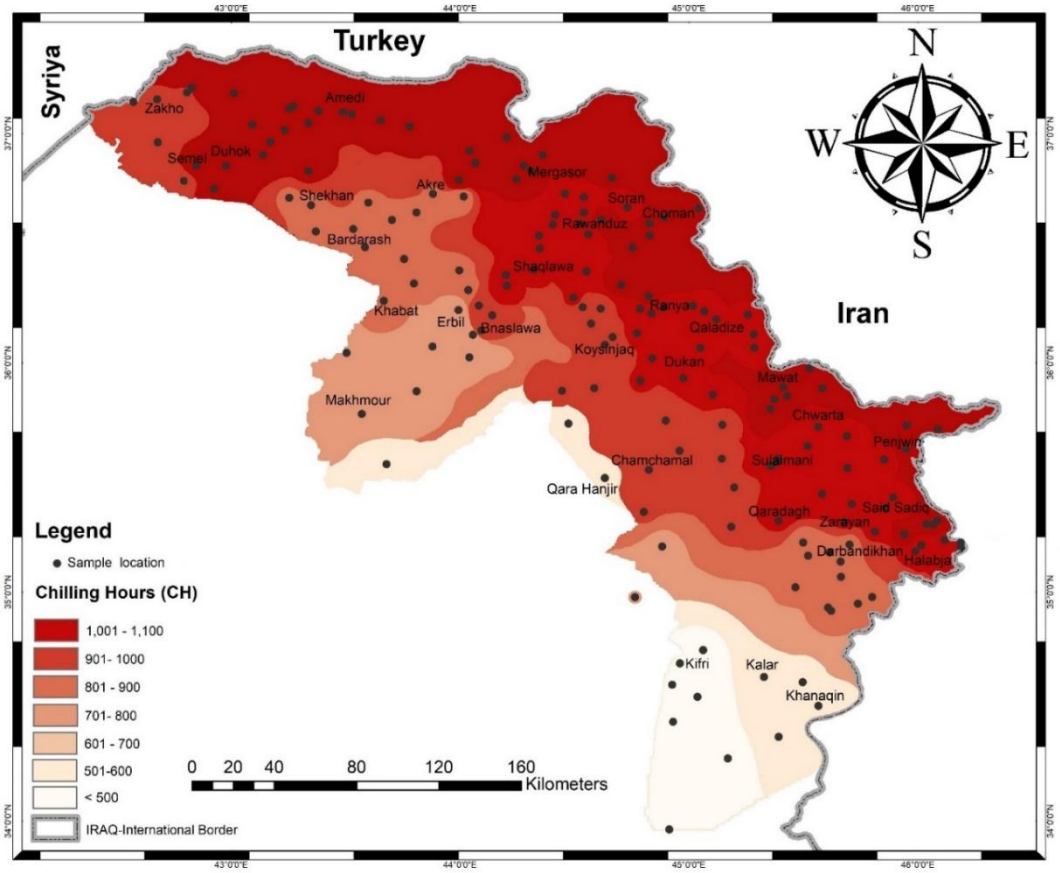

Fig 3. Distribution of studied locations according to chilling hours (1983-2022)

Table 2 below is a little review about distributing the studied locations according to chilling hours and their suitability for producing different fruit crops.

Table 2. Distribution of the suitability of studied locations for production of different fruit trees in accordance to their accumulated chilling hours

CH Range	Location	Fruits and Nuts	References
1001-1100	Ahmad Awa, Amedi, Atrush, Bagera, Bamarne, Barzan, Batifa, Betwata, Ble, Chamanke, Choman, Darkar, Dashti Tle, Deraluk, Dinarte, Duhok, Fayda, Galala, Gapilon, Garmk, Gokhlan, Goramark, Goratu, Haji Omaran, Kani Masi, Khurmal, Mangesh, Mawat, Mergasor, Penjwin, Piran, Qadesh, Qasre, Samilan, Sarkapkan, Sarsing, Semel, Shanadar, Shanakhse, Sherwan Mazin, Shiladize, Sidakan, Sirwan, Siwayil, Warte, Wlaghlu, Zalm and Zawita.	Apple, European pear, European plum, nectarine, peach, persimmon, pistachio, sweet cherry, walnut.	(6), (24), (34)

901-1000	Akoyan, Anab, Arbat, Ashti, Awesar, Bakrajo, Balisan,Barzewa, Barzinja, Basirma, Bastora, Bingird, Byara, Chwarqurna, Chwarta, Diana, Dukan, Esewa, Hajiyawa, Halabja, Halsho, Harir, Hero, Hiran, Kani Panka, Khalakan, Khalifan, Khidran, Nalparez, Qaladize, Qalbaza, Qaradagh, Ranya, Said Sadiq, Sangasar, Sarchinar, Shanadari, Shaqlawa, Sitak, Soran, Sreshma, Sulaimani, Surdash, Tawella, Zalan, Zarayan, Zharawa, Mazne, Pirmam and Rawanduz.	Apple, apricot, European pear, European plum, nectarine, peach, persimmon, pistachio, sweet cherry, walnut.	(6), (24), (34)
801-900	Aghjalar, Batel, Bazian, Bnaslawa, Chamchamal, Chnarok, Delezha, Hizawa, Ibrahim Khalil, Kasnazan, Khanke, Koysinjaq, Nazanin, Piramagroon, Sangaw, Segrdkan, Shaways, Siktan, Smaquli, Takyay Jabari, Takyay Kakamand, Taq Taq and Zakho.	Apple, apricot, European pear, European plum, nectarine, peach, persimmon, pistachio, sweet cherry, walnut.	(6), (24), (34)
701-800	Akre, Awa Spi, Baadre, Bahirka, Bamo, Bani Khelan, Bardarash, Bawakhoshen, Bjeel, Chnara, Daratu, Dara Shakran, Darbandikhan, Grdasen, Kallak, Kawr Gosk, Khabat, Maidan, Pebaz, Qasrok, Rovia, Sartak Sewsenan, Shekhan, Shekh Taweel and Zilkan.	Apple, apricot, European pear, European plum, nectarine, peach, persimmon, sweet cherry, walnut.	(6), (24)
601-700	Ankawa, Daratoo, Dibaga, Gwer, Makhmour, Nawjul, Qadir Karam, Qushtapa and Shamamek.	Apple, almond, apricot, European pear, nectarine, peach, persimmon, sweet cherry, walnut.	(6), (24)
501-600	Alwan, Kalar, Kandenawa, Khanaqin, Qara Hanjir, Qoratu and Shwan.	Almonds, Apricots, nectarine, peach, persimmon, sweet cherry, walnut	(6)
< 500	Gulala, Jabara, Kifri, Kullajo, Qara Tapa, Sar Qalla and Shahreban	Almond, apricot, fig, grape, nectarine, peach, persimmon, pomegranate, quince, walnut, evergreen fruits (dates, lime,	(6), (24)

		orange, lemon, citron, banana, papaya, guava, mango, …etc.).	

Chilling units (CU)

Figure 4 shows that the chilling units (CU) accumulating in Kurdistan region-Iraq ranged between 1135 in Hizawa from Duhok which is the only location within the range class of 1101-1150 CU, and 507 CU in Shahreban, Diyala governaorate, with an average of 927 CU. The range class (1001-1100 CU) includes 33 locations: Atrush, Bagera, Bamarne, Batel, Batifa, Chamanke, Darkar, Duhok, Fayda, Goramark, Ibrahim Khalil, Khanke, Mangesh, Qadesh, Sarsing, Semel, Zawita and Zakho from Duhok; Bingird, Chwarqurna, Dukan, Esewa, Hajiyawa, Halsho, Hero, Khalakan, Khidran, Qaladize, Ranya, Sangasar, Surdash and Zharawa from Sulaymaniyah; and Ashti from Erbil. However, the range class (901-1000 CU) includes 73 locations: Akoyan, Bahirka, Balisan, Barzan, Barzewa, Basirma, Bastora, Ble, Bnaslawa, Chnarok, Dara Shakran, Diana, Goratu, Harir, Hiran, Kasnazan, Kawr Gosk, Khabat, Khalifan, Koysinjaq, Mazne, Mergasor, Nazanin, Piran, Pirmam, Rawanduz, Segrdkan, Shanadar, Shaqlawa, Shaways, Sherwan Mazin, Sidakan, Siktan, Smaquli, Soran, Sreshma and Taq Taq from Erbil; Aghjalar, Arbat, Bakrajo, Barzinja, Bazian, Chamchamal, Chwarta, Delezha, Kani Panka, Nalparez, Piramagroon, Qalbaza, Qaradagh, Said Sadiq, Sangaw, Sarchinar, Shanadari, Sitak, Sulaimani, Takyay Jabari, Takyay Kakamand, Zalan and Zarayan from Sulaymaniyah; and Akre, Amedi, Bardarash, Bjeel, Daratu, Deraluk, Dinarte, Grdasen, Kallak, Kani Masi, Qasrok, Rovia and Shiladize from Duhok. Meanwhile, the range class (801-900 CU) covers 43 subdistricts: Ahmad Awa, Anab, Awesar, Bani Khelan, Bawakhoshen, Betwata, Byara, Chnara, Darbandikhan, Dashti Tle, Gapilon, Garmk, Gokhlan, Halabja, Khurmal, Mawat, Pebaz, Penjwin, Sarkapkan, Sewsenan, Shanakhse, Shekh Taweel, Sirwan, Siwayil, Tawella, Wlaghlu and Zalm from Sulaymaniyah; Choman, Dibaga, Galala, Gwer, Haji Omaran, Makhmour Qasre, Samilan and Warte from Erbil; Awa Spi, Bamo, Maidan and Sartak from Diyala; and Baadre, Shekhan and Zilkan from Duhok. In time, the range class (701-800 CU) covers 12 subdistricts: Ankawa, Daratoo, Qushtapa and Shamamek from Erbil; Alwan, Khanaqin, Nawjul and Qoratu from Diyala; Kalar and Qadir Karam from Sulaymaniyah; Qara Hanjir and Shwan from Kirkuk. However, the coverage of the class (601-700 CU) includes only Kandenawa from Erbil. Finally, the coverage of the class (501-600 CU) is Gulala, Jabara, Kifri, Kullajo, Qara Tapa, Sar Qalla and Shahreban from Diyala governorate.

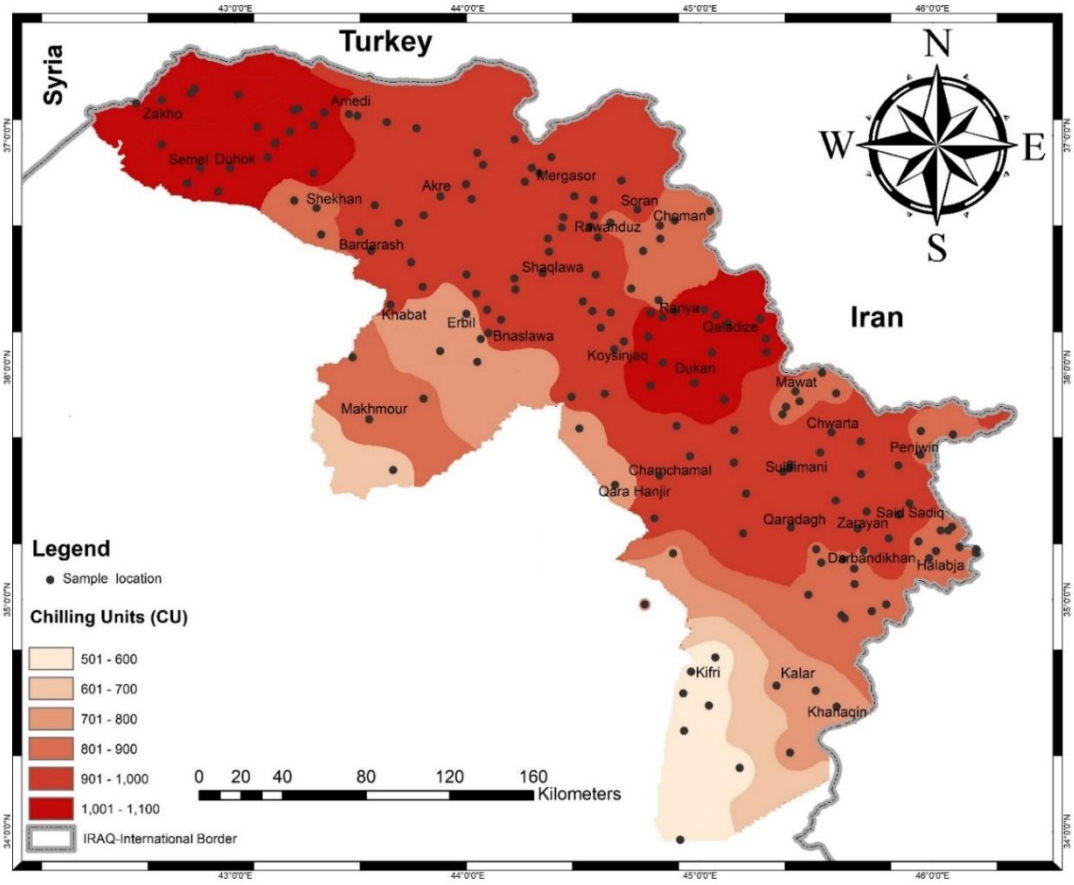

Fig 4. Distribution of studied locations according to chilling units (1983-2022)

Chilling portions (CP)

Figure 5 is clarifying that the range of chilling portions (CP) in Kurdistan region locates between 58.3 CP which is accumulated in Ahmad Awa, Khurmal, Penjwin, Sirwan and Zalm from Sulaymaniyah governorate; and 30.0 CP in Shahreban, Diyala, with an average of 49.5 CP. Generally, the studied area distributed among 7 classes. The first class (55.1-60.0 CP) contains 28 subdistricts: Ahmad Awa, Betwata, Dashti Tle, Gapilon, Garmk, Gokhlan, Khurmal, Mawat, Penjwin, Sarkapkan, Shanakhse, Sirwan, Siwayil, Wlaghlu and Zalm from Sulaymaniyah; and Ble, Choman, Galala, Goratu, Haji Omaran, Mergasor, Piran, Qasre, Samilan, Shanadar, Sherwan Mazin, Sidakan and Warte from Erbil. However, the second class (50.1-55.0 CP) contains 71 subdistrict locations: Anab, Arbat, Awesar, Bakrajo, Barzinja, Bingird, Byara, Chwarqurna, Chwarta, Dukan, Esewa, Hajiyawa, Halabja, Halsho, Hero, Kani Panka, Khalakan, Khidran, Nalparez, Qaladize, Qalbaza, Qaradagh, Ranya, Said Sadiq, Sangasar, Sarchinar, Shanadari, Sitak, Sulaimani, Surdash, Tawella, Zalan, Zarayan and Zharawa from Sulaymaniyah; Amedi, Atrush, Bagera, Bamarne, Batifa, Chamanke, Darkar, Deraluk, Dinarte, Duhok, Fayda, Goramark, Hizawa, Kani Masi, Mangesh, Qadesh, Sarsing, Semel, Shiladize and Zawita from Duhok; and Akoyan, Ashti, Balisan, Barzan, Barzewa, Basirma, Bastora, Diana, Harir, Hiran,

Khalifan, Mazne, Pirmam, Rawanduz, Shaqlawa, Soran and Sreshma from Erbil. Whereas, the third class (45.1-50.0 CP) contains 34 locations including Bahirka, Bnaslawa, Chnarok, Dara Shakran, Kasnazan, Kawr Gosk, Khabat, Koysinjaq, Nazanin, Segrdkan, Shaways, Siktan, Smaquli and Taq Taq from Erbil; Akre, Bardarash, Batel, Bjeel, Daratu, Grdasen, Ibrahim Khalil, Kallak, Khanke, Qasrok, Rovia and Zakho from Duhok; and Aghjalar, Bazian, Chamchamal, Delezha, Piramagroon, Sangaw, Takyay Jabari and Takyay Kakamand from Sulaymaniyah. Meanwhile, the fourth class (40.1-45.0 CP) includes 14 locations: Bani Khelan, Bawakhoshen, Chnara, Darbandikhan, Pebaz, Sewsenan and Shekh Taweel from Sulaymaniyah; Awa Spi, Bamo, Maidan and Sartak from Diyala; and Baadre, Shekhan and Zilkan from Duhok. However, the fifth class (35.1-40.0 CP) covers 15 locations which are Ankawa, Daratoo, Dibaga, Gwer, Makhmour, Qushtapa and Shamamek from Erbil; Alwan, Khanaqin, Nawjul and Qoratu from Diyala; Kalar and Qadir Karam from Sulaymaniyah; and Qara Hanjir and Shwan from Kirkuk. The sixth class (30.1-35.0 CP) involves 7 subdistricts: Gulala, Jabara, Kifri, Kullajo, Qara Tapa and Sar Qalla from Diyala; and only Kandenawa from Erbil. The last class (25.1-30 CP) contains only Shahreban from Diyala.

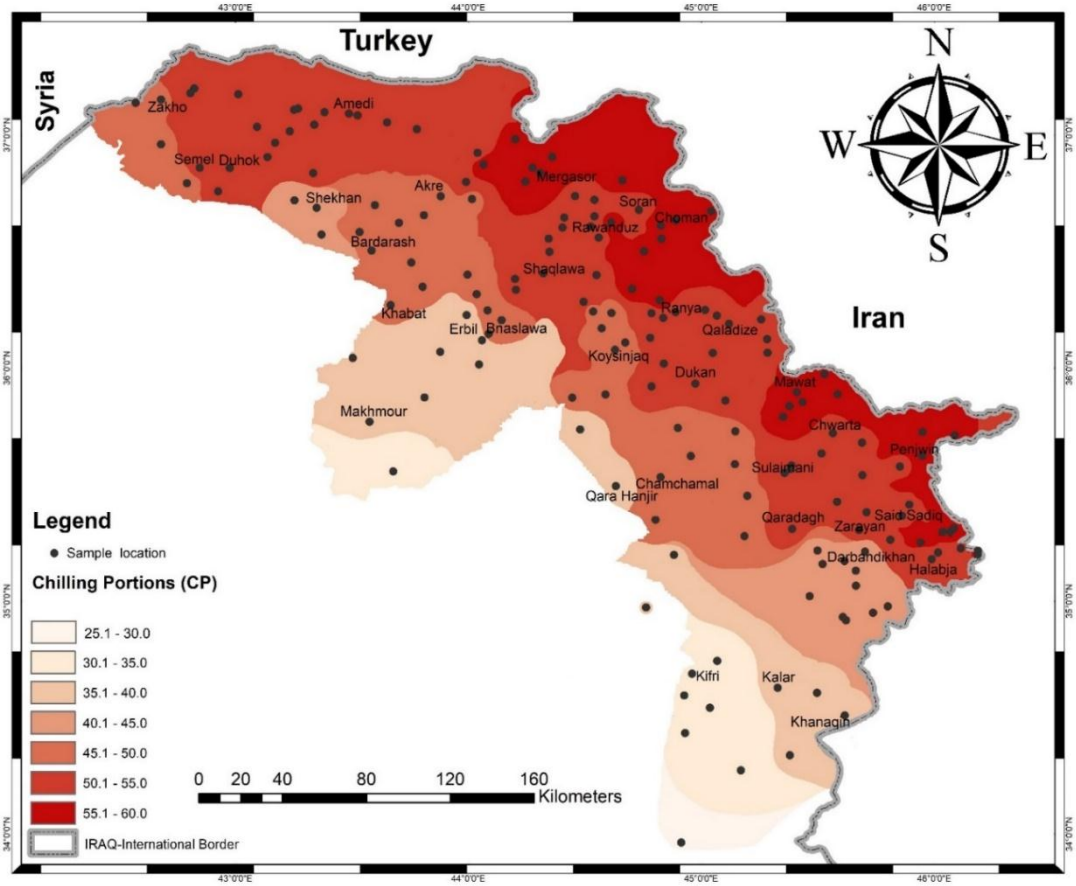

Fig 5. Distribution of studied locations according to chilling portions (1983-2022)

Growing degree hours (GDP)

Figure 6 illustrates the distribution of accumulation of growing degree hours (GDH) in Kurdistan region into 7 strips ranging from 8564 hrs in Shahreban, Diyala to 1136 GDH in each Choman, Galala, Haji Omaran and Samilan, Erbil, with an average of 3256 GDH. The first strip (1001-2000 GDH) joins 39 locations together which are Ahmad Awa, Anab, Awesar, Betwata, Byara, Dashti Tle, Gapilon, Garmk, Gokhlan, Halabja, Khurmal, Mawat, Penjwin, Sarkapkan, Shanakhse, Sirwan, Siwayil, Tawella, Wlaghlu and Zalm from Sulaymaniyah; Barzan, Ble, Choman, Galala, Goratu, Haji Omaran, Mergasor, Piran, Qasre, Samilan, Shanadar, Sherwan Mazin, Sidakan and Warte from Erbil; and Amedi, Deraluk, Dinarte, Kani Masi and Shiladize from Duhok. The second strip (2001-3000 GDH) joins 59 subdistricts: Arbat, Bakrajo, Barzinja, Bingird, Chwarqurna, Chwarta, Dukan, Esewa, Hajiyawa, Halsho, Hero, Kani Panka, Khalakan, Khidran, Nalparez, Qaladize, Qalbaza, Qaradagh, Ranya, Said Sadiq, Sangasar, Sarchinar, Shanadari, Sitak, Sulaimani, Surdash, Zalan, Zarayan and Zharawa from Sulaymaniyah; Akoyan, Ashti, Balisan, Barzewa, Basirma, Bastora, Diana, Harir, Hiran, Khalifan, Mazne, Pirmam, Rawanduz, Shaqlawa, Soran and Sreshma from Erbil; and Atrush, Bagera, Bamarne, Batifa, Chamanke, Darkar, Duhok, Fayda, Goramark, Mangesh, Qadesh, Sarsing, Semel and Zawita from Duhok. The third strip (3001-4000 GDH), however, covers only 5 locations from Duhok governorate which are Baadre, Batel, Ibrahim Khalil, Khanke and Zakho. Meanwhile, the fourth strip (4001-5000 GDH) includes 55 locations: Ankawa, Bahirka, Bnaslawa, Chnarok, Dara Shakran, Daratoo, Dibaga, Gwer, Kasnazan, Kawr Gosk, Khabat, Koysinjaq, Makhmour, Nazanin, Qushtapa, Segrdkan, Shamamek, Shaways, Siktan, Smaquli and Taq Taq from Erbil; Aghjalar, Bani Khelan, Bawakhoshen, Bazian, Chamchamal, Chnara, Darbandikhan, Delezha, Pebaz, Piramagroon, Qadir Karam, Sangaw, Sewsenan, Shekh Taweel, Takyay Jabari and Takyay Kakamand from Sulaymaniyah; Akre, Bardarash, Bjeel, Daratu, Grdasen, Hizawa, Kallak, Qasrok, Rovia, Shekhan and Zilkan from Duhok; Awa Spi, Bamo, Maidan, Nawjul and Sartak from Diyala; and Qara Hanjir and Shwan from Kirkuk. At time, the fifth strip (5001-6000 GDH) involves 4 locations: Alwan, Khanaqin and Qoratu from Diyala; Kandenawa from Erbil; and Kalar from Sulaymaniyah. Whereas, the sixth strip (6001-7000 GDH) contains 6 locations from Diyala, which are Gulala, Jabara, Kifri, Kullajo, Qara Tapa and Sar Qalla. The last strip which is more than 7000 GDH contains only Shahreban from Diyala.

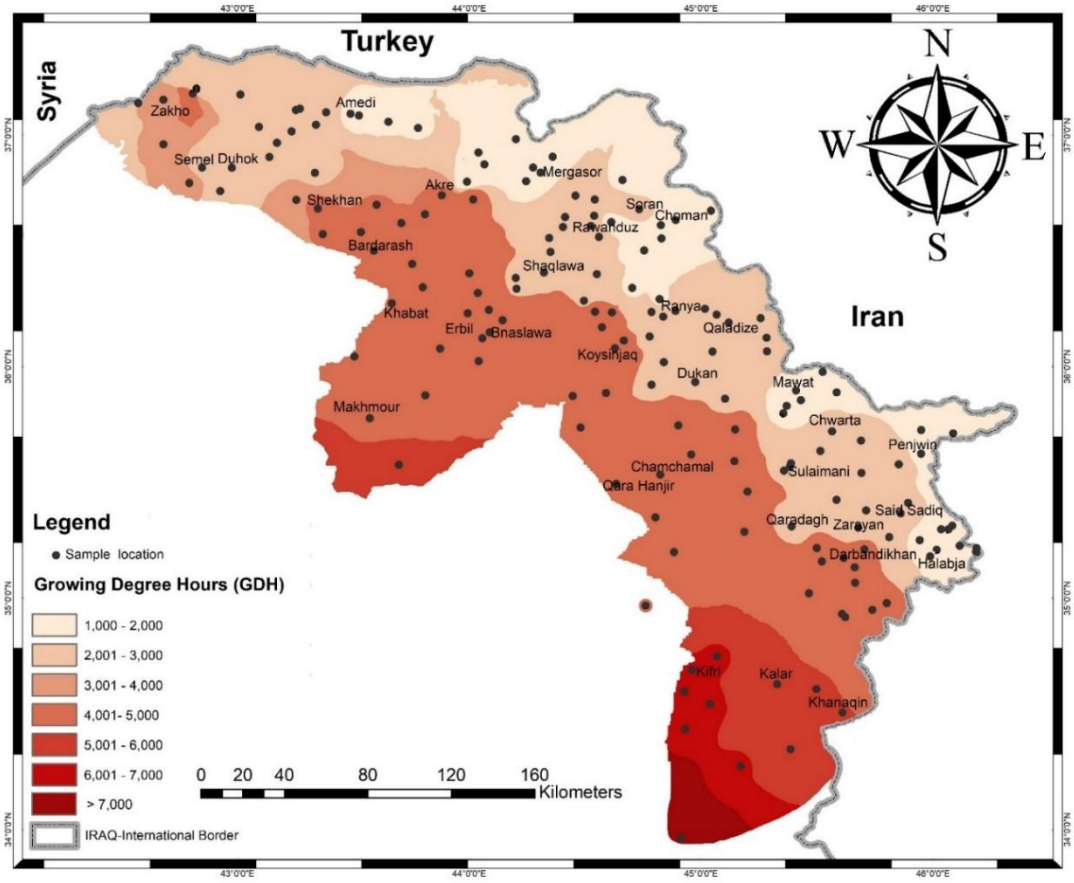

Fig 6. Distribution of studied locations according to growing degree hours (1983-2022)

Correlation coefficients among studied parameters

Correlation coefficients of location parameters; average annual temperature (AAT), altitude (ALT) and latitude (LAT) with chilling parameters; CH, CU, CP and GDH (Figure 7) show that there is a perfect positive correlation (R=0.958**) between AAT and GDH, meaning that as much as AAT is higher, as much as GDH is more, in contrast, each CH, CU and CP are negatively correlated with AAT, among these, the strongest negative correlation (R=-0.926**) is between CP and AAT, followed by a strong negative correlation (R=-0.887*) between CH and AAT, however, there is a weak negative correlation (R=-0.34) between CU and AAT. The correlations emphasize that among the studied chilling models, CU (Chilling Units, Utah model) is less responsive to the higher temperatures exceeding plant growth requirements either during growing season or dormancy. In other words, for most warm regions, chilling units (CU) model is better to be used. In contrast, chilling portions model is better for regions with low AAT.

As for the effect of ALT on chilling and growing degree hours, it is clear that the strongest positive correlation (R=0.693*) was observed between CP and ALT, followed by another positive strong correlation (R=0.676*) between CH and ALT, these findings were also observed by Alburquerque *et al.* (3). However, the correlation between CU and ALT was

positively weak (R=0.349). However, a negative strong correlation (R=-0.683*) was noticed between GDH and ALT. These observations, again, emphasize that the better model for considering the calculation and determination of chilling and growing degrees in Kurdistan region, is CU model.

Regarding the correlations between each chilling models and latitudes (LAT), the strongest positive correlation (R=0.615*) was seen between CU and LAT, followed by another strong positive correlation (R=0.576*) between CH and LAT, however, the correlation between CP and LAT was positively weak (R=0.493). On the other hand, the strongest negative correlation (R=-0.514*) was seen between GDH and LAT.

The overall observations make clear that each CU and CP are better than considering the CH model in Kurdistan region, since CH model cannot separate the active chilling hours, and calculates all minima temperatures including the very low temperatures that may considered to have chilling injury effects on fruit trees during winter dormancy, while each CU and CP models, are capable of ignoring the very low temperatures that close to injuring low temperatures.

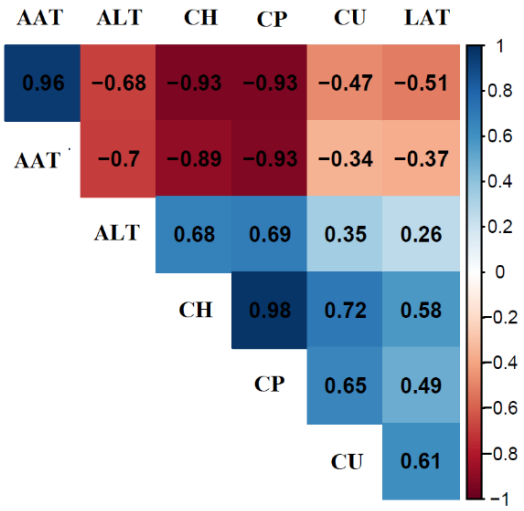

Fig 7. Correlation matrices among chilling models and location parameters

Discussion

This is the first attempt to estimate chilling and heat requirements for deciduous fruit tree cultivation in Kurdistan region of Iraq. If previous efforts relied on out-of-date methods, the need for this new update can be justified at least by the cause of climate changes and global warming phenomena (6, 23, 24, and 35), which have negative effects on all the planet phenomena including chilling aspects and changes in the distribution of each spot of earth from an environmental standpoint (1).

So as this work to be validated anyhow, different chilling estimation models, from the oldest (chilling hours) to the newest (chilling portions) have been used. Observations on the forty years' data emphasized that although the annual average temperature of the region increased in the second 20 years (2003-2022) compared to the first 20 years (1983-2002) by 0.85 °C, this is in agreement with the findings of Abdaki *et al.* (1) who found that average annual temperature increased 0.67 C between 1979 and 2006. Baldocchi and Wong (6) also reported that minimum temperatures rise 0.25 °C per decade. Fortunately, compared to these rises in temperature, the chilling parameters had not experienced such a decrease, for example, chilling hours decreased 8.1 hours, chilling units increased 7.4 units, however chilling portions decreased only 0.0071 portion (data not shown), these findings reveal that the chilling hour model is less practical for estimation chilling parameters since it

affected negatively by temperature fluctuations without being avoidable for neglecting high temperatures as observed in recent models (3). The variation in the amount of decrease among the aforementioned parameters are in coincidence with the results obtained by Alburquerque *et al.* (3) who reported that differences in the nature of the environmental condition among locations plays a key role in the amount of the changes. Furthermore, topography and coordinates are effective as it was seen from the correlation coefficients among the parameters (Figure 7).

According to the findings of this work, Kurdistan region-Iraq is divided into 7 zones in accordance with chilling hours, 6 zones of chilling units, 7 zones of chilling portions, and 7 zones of growing degree hours, each of which with a group of locations with occurring differences in the zones as it is also evidenced by the results of Alwan *et al.* (4) on the basis of adequacy and priority for cultivation of different fruit tree orchards.

As shown in the figures (3, 4, and 5) which show the distribution of Kurdistan region-Iraq according to three different models of chilling accumulation estimations; chilling hours, chilling units and chilling portions, there are differences in the coverage of each zone in the involvement of the locations under study, this observation means that the models are affected not only by temperature regimes (5) (Figure 2), but also by other factors, among these, the most important factors are altitude and latitude (Figure 7). Availability of the results of different models including recent models may present facilities in front of fruit growers in decision-making when they plan to establish their orchards with new varieties. From the standpoint of chilling hours, it is clear from Figure 3 that the two largest zones are (900-1000 CH) with the coverage of 50 locations: 34 from Sulaymaniyah, and 16 from Erbil; and (1001-1100 CH) with 48 subdistricts: 19 from Duhok, 15 from Sulaymaniyah, and 14 from Erbil. However, depending on chilling units, the two widest zones are (901-1000 CU) with a coverage of 73 locations: 37 from Erbil, 23 from Sulaymaniyah, and 13 from Duhok, and (801-900 CU) with an involvement of 43 subdistricts: 27 from Sulaymaniyah, 9 from Erbil, and the remainder from Diyala and Duhok. Whereas, according to chilling portions, the largest class is (50.1-55.0 CP) with 71 subdistricts: 34 from Sulaymaniyah, 20 from Duhok, and 17 from Erbil, followed by the zone (55.1-60 CP) which includes 28 subdistricts: 15 from Sulaymaniyah, and 13 from Erbil. These observations reveal that none of these models are similar in estimating chilling accumulation in a given location which is varied from year to year and place to place (29). Other factors influencing chilling aspects include topography, downhill direction, water surfaces (33) and precipitation levels (5 and 7). Hence, this work is a humble effort for being exploited directly by the Kurdish farmer in the establishment of their new proposed orchard projects without hesitation.

Growing degree hours (GDH) is another important aspect in a given location to play its role in the distribution of locations into different zones (Figure 6) which has effects on the length of growing season, blooming

time, blooming intensity, fruit formation, fruit ripening, and hence crop yields (21). From the results of this study, it is clear that GDH has a wide variation among studied locations ranging from 1136 (Choman, Galala, Haji Omaran and Samilan) in Erbil to 8564 (Shahreban) from Diyala, with an average of 3256 hrs. These variations also have a substantial role in distributing the locations into different zones of fruit production in the region as was also found by (13 and 14).

Conclusion

Chilling hours (CH) ranged from 335 hrs (Shahreban, Diyala) to 1083 hrs (Amedi, Deraluk, Dinarte, Kani Masi, and Shiladize) from Duhok, and (Barzan) from Erbil, with an average of 886 hrs. The chilling units (CU, Utah Model) ranged from 507 CU (Shahreban) to 1135 CU (Hizawa, Duhok), with an average of 927 hrs. However, the chilling portions (CP) ranged from 30.0 (Shahreban) in Diyala to 58.3 (Ahmad Awa, Khurmal, Penjwin, Sirwan, and Zalm) in Salaymaniyah, with an average of 49.5 CP. Growing degree hours (GDH) ranged from 1136 (Choman, Galala, Haji Omaran and Samilan) in Erbil to 8564 (Shahreban), with an average of 3256 hrs. All models were strongly correlated with location parameters, the highest strong correlations were found between each CP and GDH with AAT. The observations emphasize that both CU and CP models are more accurate than CH model for estimation of chilling and growing degree hours (units) in Kurdistan region-Iraq.

Conflict of Interest

The author have no conflict of interest.

Acknowledgement

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