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RESEARCH ARTICLE

ASSESSMENT OF FUTURE WINTER CHILL IN EGYPT.

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Abstract

Climate change has affected the rates of chilling and heat accumulation, which are vital for flowering and production, in temperate fruit trees. The aim of this study is to investigate current and projected future changes in winter chill in Egypt. The study was carried out on 20 locations in Egypt distributed into Lower, Middle, and Upper Egypt, in addition to outside valley region. The winter chill units for the months from October to February depending on the 7.2 and 10 °C models has been calculated for each season and the accumulation units each 10 years. The future climate data has been obtained from downscaling ECHAM6 GCM of RCP 4.5 scenario from 2010 up to 2090. Results of this study found that, the winter chill units tend to decrease in the future at all Egyptian locations, and there are an extreme decrement in temperature during (2051-2060) and (2061-2070) periods will effect on Aswan and Gharbia locations respectively and led to increasing the winter chill units during these periods, on other side, there is an extreme increment in temperature at Minya location during (2061-2070) period will led to decrease the winter chill units during this period in it. The highest winter chill units have been found in Matruh location while the lowest one was Kafr El-Sheikh location among the studied locations. The fruit trees will likely need to develop agricultural adaptation measures (e.g. low-chill varieties and dormancy-breaking chemicals) to cope with these projected changes.

Introduction:-

Climate change is likely to affect chilling requirement of temperate fruit crops significantly and therefore, the opportunity to meet this requirement will be reduced as the climate becomes warmer **(Rai *et al.*, 2015)**. Climate warming has affected chilling and heat accumulation rates for fruit trees in recent decades **(Baldocchi and Wong 2008; Luedeling *et al.* 2011a and Liang Guo *et al.* 2013)**. Cool temperatures in the winter are essential for successful cultivation of many tree crops. Temperature affects horticultural crops in many ways, including influencing timing and reliability of plant growth, flowering, fruit growth, ripening, and product quality. There are strong trends of increased mean annual temperature in all production regions. The strongest warming trend has been identified for daily minimum temperatures during the winter months indicating that winter chill might be strongly affected by climate change **(LaDochy *et al.*, 2007 and Farag *et al.* 2010)**. One of the major determinants of good yields in many fruit trees is the availability of winter chill. Trees and shrubs that require winter chill rely on the

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occurrence of cold conditions during the winter, in order to break their dormancy and initiate fructification **(Eike Luedeling *et al.* 2009)**. Dormancy minimizes low temperature injury to flowers by delaying bud break **(Atkinson *et al.* 2013)**. Perennial crops, suitable for growing in these seasonally-restricted temperate regions, have to satisfy their chilling requirements to initiate spring bud break, extension growth and anthesis. Chilling units are most meaningfully described and measured using an hourly time scale. Chill hours below a threshold are one of the most common methods for calculating chill. A base temperature is chosen in some studies at 7.2 ºC and other studies chosen it at 10 ºC. If the temperature is above this base then it is too warm for the plant to accumulate chilling, and if the temperature is below it then the plant is affected by the cold temperatures, and with colder temperatures producing bigger effects. As soon as temperature drops below the base temperature for one hour, one chill unit is accumulated **(Sheard and KwaZulu-Natal, 2002 and Farag *et al.* 2010)**. Fruit orchards might thus be among those agricultural systems in Egypt, and probably in other parts of the world, that are most vulnerable to the environmental stresses invoked by climate change **(Farag *et al.* 2010).** The first and second Egyptian communications reports mentioned that, Egypt is one of the most vulnerable countries to the potential impacts and risks of climate change **(Fahim *et al.*, 2013).** Agriculture in Egypt is expected to be especially vulnerable because of hot climate. Further warming is consequently expected to reduce crop productivity. The objective of the present study is to assessing the future winter chill in Egypt to helping fruit trees growers refine the tools available to them for understanding and reacting to the consequences of climate change.

Materials and Method

Study area:-

The study was carried out on twenty locations distributed in the different geographic regions (Lower, Middle, Upper Egypt, and Outside Valley) as shown in table (1) which demonstrates the locations latitude, longitude, and elevations.

Table 1:- List of studied locations with their latitude, longitude and elevation.

Regions	Location name	Latitude (deg.)	Longitude (deg.)	Elevation (m)
Lower Egypt	Alexandria	31.20	29.95	7.0
	Beheira	29.87	30.91	6.7
	Kafr El-sheikh	31.12	30.95	20.0
	Ismailia	30.60	32.28	10.0
	Sharqia	30.58	31.50	13.0
	Gharbia	30.82	31.93	14.8
	Dakahlia	31.00	31.27	7.0
	Monufia	30.60	31.02	17.9
Middle Egypt	Giza	30.02	31.13	22.5
	Beni Suef	29.07	31.10	30.4
	Faiyum	29.30	30.85	30.0
	Minya	27.74	30.83	40.0
Upper Egypt	Asyut	27.20	31.17	71.0
	Sohag	26.60	31.78	68.7
	Qena	26.18	32.73	72.6
	Aswan	23.97	32.78	108.3
Outside Valley	Dakhla	25.48	29.00	146.0
	Kharga	25.45	30.53	63.0
	Matruh	31.33	27.22	13.0
	Arish	31.00	33.09	17.1

Climate data:-

The future climate data has been obtained from downscaling global climate model (ECHAM6) of scenario RCP (Representative Concentration Pathways) 4.5 by a horizontal resolution 50 km using regional climate model (RegCM 4). The hourly temperature records from October to February have been exported and processed from 2010 up to 2090 to estimating winter chill for the determined locations.

Chilling Hours Model:-

Chilling units for the months from October to February depending on the 7.2 and 10 °C models will be used in this study to assessment the winter chill in the future. The Chilling Hours Model (sometimes referred to as Weinberger model **(Bennett, 1949 and Weinberger, 1950**), as originally proposed, simply calculates the number of hours, when the temperature (T) is below 7.2 or 10 °C as shown in equations (1and 2) respectively.

- **Model: T7.2**

$$CH_t = \sum_{i=1}^{t} T_{7.2} \qquad with\, T_{7.2} = \begin{cases} 0 < T < 7.2\,°C & : 1 \\ else & : 0 \end{cases} \qquad (1)$$

- **Model: T10**

$$CH_t = \sum_{i=1}^{t} T_{10} \qquad with\, T_{10} = \begin{cases} 0 < T < 10\,°C & : 1 \\ else & : 0 \end{cases} \qquad (2)$$

Results:-

The winter chill units based on 7.2 and 10 °C models have assessed for the months from October to February during the period (2010/11 – 2089/90)[1] in the determined locations and accumulate the resulted units every 10 years to study the change with time in each region.

Lower Egypt locations:-

Tables (2 and 3) show the accumulated winter chill units of the Lower Egypt locations depending on the 7.2 and 10 °C models respectively, and it has been observed that, at 7.2 °C model the highest number of winter chill units observed in the first 10 years (2011 – 2020) but the lowest number observed in the period from 2071 up to 2080, while at 10 °C model the highest number of chilling units observed in the period (2011 – 2020) except in Gharbia location where its highest number of winter chill units observed in the period (2061 -2070) while the lowest number in this model observed in the last three periods (2061 – 2090).

The curve of the accumulation winter chill units during the periods from 2011 up to 2090 based on 7.2 and 10°C models for Lower Egypt locations is shown in figures (1and 2) and it indicated that the chilling units tend to decrease in the future at all Lower Egypt locations in both models, and there is an extreme increment in Gharbia Governorate during the period of (2061-2070). Also it has been observed that, Kafr El Sheikh Governorate is the lowest one in chilling units while Ismailia location is the highest one.

Table 2:- The accumulated winter chill each 10 years of the Lower Egypt locations depending on the 7.2 °C.

[2]**Model based on Temp. < 7.2 C**								
Date	**Alexandria**	**Behera**	**Kafr El Sheikh**	**Ismailia**	**Sharqia**	**Gharbia**	**Dakahlia**	**Monufia**
2011 – 2020	588	962	172	1232	750	794	744	908
2021 – 2030	528	858	140	1140	588	700	680	798
2031 – 2040	232	496	72	652	348	368	364	440
2041 – 2050	186	486	48	964	378	442	366	472
2051 – 2060	228	476	58	764	342	518	334	442
2061 – 2070	92	260	40	348	184	766	196	236
2071 – 2080	62	242	12	322	150	170	88	234
2081 - 2090	124	324	38	524	258	282	204	316

[1] The seasons will be represented in this paper by the end year of the season, for example, season (2010/11) will be called as 2011, and so on.

[2] Orange and blue colored cells indicate to Highest and lowest accumulation chilling each 10 years in the studied region.

Table 3:- The accumulated winter chill units each 10 years of the Lower Egypt locations depending on the 10 °C

Model based on Temp. < 10 C								
Date	**Alexandria**	**Behera**	**Kafr El Sheikh**	**Ismailia**	**Sharqia**	**Gharbia**	**Dakahlia**	**Monufia**
2011 - 2020	3348	3784	1424	4486	3296	3668	3358	3850
2021 - 2030	2994	3636	1360	4300	3038	3384	3134	3560
2031 - 2040	1884	2566	734	3210	2030	2250	2160	2458
2041 - 2050	2290	2984	846	3884	2520	2846	2580	2980
2051 - 2060	1776	2420	672	3066	1920	2366	1992	2366
2061 - 2070	1054	1692	446	2186	1424	3712	1402	1668
2071 - 2080	1114	1778	368	2296	1396	1550	636	1746
2081 - 2090	1094	1664	382	2222	1368	1532	738	1648

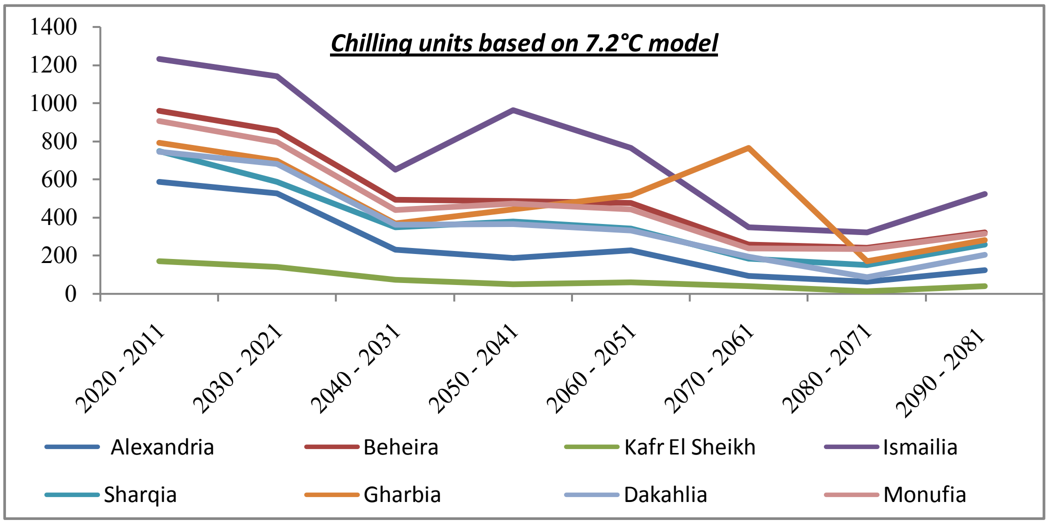

Figure 1:- The accumulated winter chill units during the periods from 2011 up to 2090 based on 7.2 °C models for Lower Egypt locations.

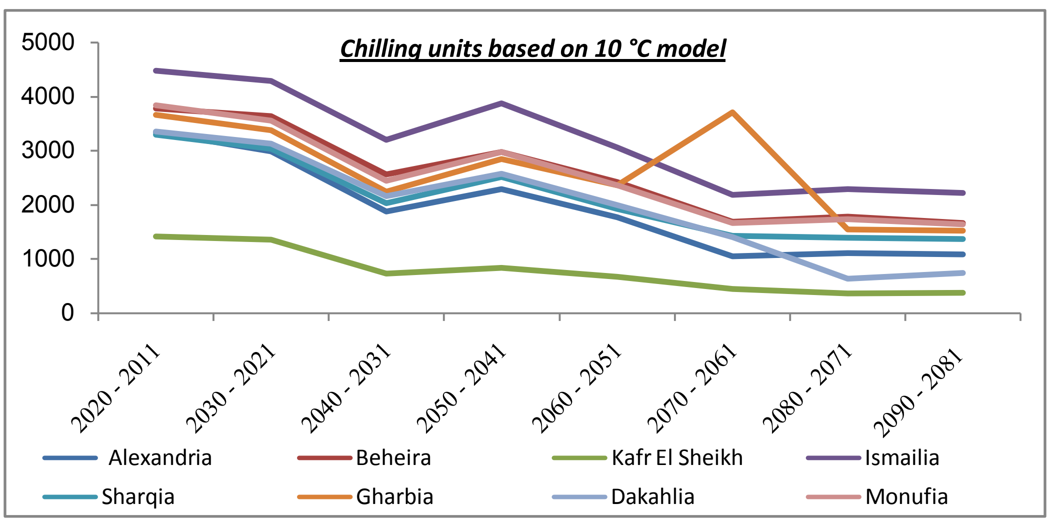

Figure 2:- The accumulated winter chill units during the periods from 2011 up to 2090 based on 10 °C models for Lower Egypt locations.

Middle Egypt locations:-

Tables (4 and 5) show the accumulated winter chill units each 10 years of the Middle Egypt locations depending on the 7.2 and 10 °C models respectively and it has been found that, the highest number of winter chill units at both 7.2 and 10 °C models observed in the first 10 years (2011 – 2020) while the lowest number observed in the period of (2061 – 2070) in the studied locations except in Giza and Beni Suef at 7.2°C model where its lowest accumulated winter chill units observed during (2071-2080) period.

Table 4:- The accumulated winter chill units each 10 years of the Middle Egypt locations depending on the 7.2°C

Model based on Temp. < 7.2 C				
Date	**Minya**	**Giza**	**Beni Suef**	**Faiyum**
2011 - 2020	1798	580	2142	1396
2021 - 2030	1490	488	1808	1210
2031 - 2040	696	220	1012	612
2041 - 2050	950	270	1344	820
2051 - 2060	590	230	1000	628
2061 - 2070	6	120	626	320
2071 - 2080	354	58	608	328
2081 - 2090	448	160	684	434

Table 5:- The accumulated winter chill units each 10 years of the Middle Egypt locations depending on the 10°C

Model based on Temp. < 10 C				
Date	**Minya**	**Giza**	**Beni Suef**	**Faiyum**
2011 - 2020	5222	3850	3154	5772
2021 - 2030	4586	3560	2744	5116
2031 - 2040	3174	2458	1776	3842
2041 - 2050	3820	2980	2306	4514
2051 - 2060	2782	2366	1720	3626
2061 - 2070	166	1668	1128	2910
2071 - 2080	2524	1746	1214	3074
2081 - 2090	2380	1648	1160	2922

The curve of the accumulated winter chill units during the periods from 2011 up to 2090 based on 7.2 and 10°C models for Middle Egypt locations is shown in figures (3 and 4) and it's indicted that, the winter chill units tend to decrease in the future at all Middle Egypt locations, and there is an extreme decrement in accumulated winter chill units observed at Minya location during the period of (2061-2070).

In both models, Giza location was the lowest one in the accumulation winter chill units at study period except Minya location extreme of the period (2061-2070), while the highest accumulation winter chill units is observed in Beni Suef location.

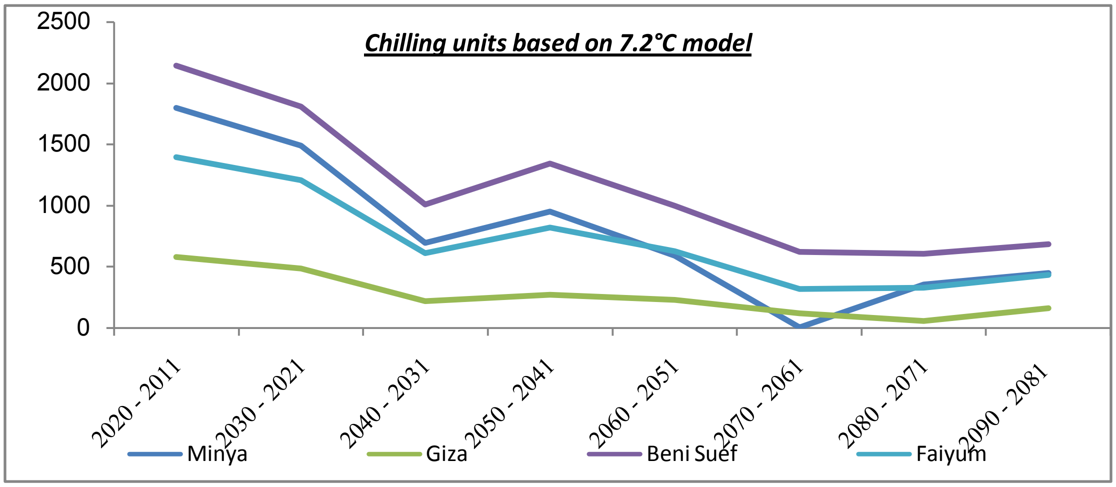

Figure 3:- The accumulated winter chill units during the periods from 2011 up to 2090 based on 7.2 °C models for Middle Egypt locations.

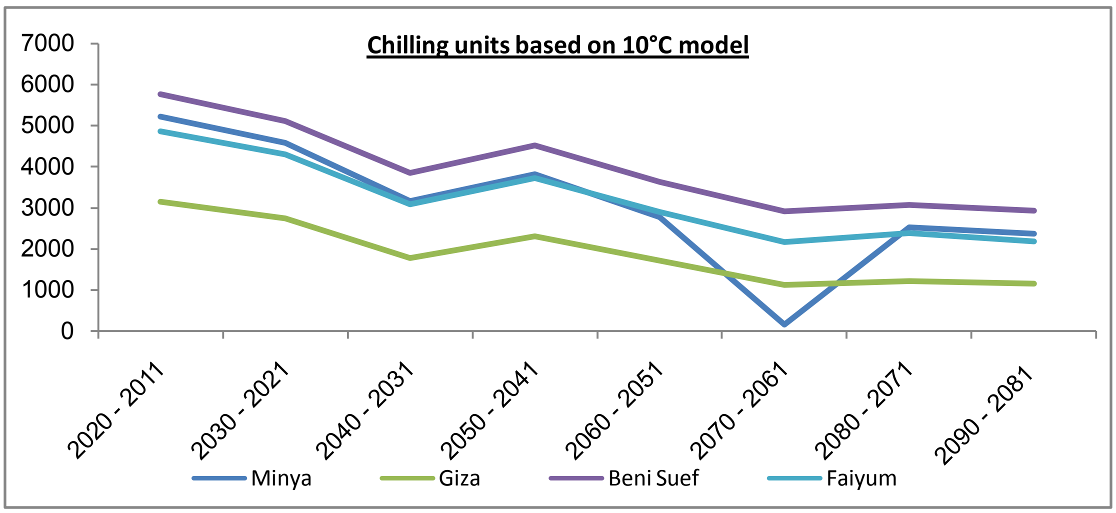

Figure 4:- The accumulated winter chill units during the periods from 2011 up to 2090 based on 10 °C models for Middle Egypt locations.

Upper Egypt locations:-

Tables (6 and 7) show the accumulated winter chill units each 10 years of the Upper Egypt locations according to the 7.2 and 10 °C models respectively and it has been found that, the highest number of winter chill units in both models has been observed in the first 10 years (2011 – 2020) in all studied locations except in Aswan of 10 °C model where its highest accumulated winter chill count has been observed during (2051-2060) period, while the lowest number observed in the last three periods (2061 – 2090) to be during (2061-2070) in Qena of both models, during (2071-2080) in Sohag of 7.2 °C model, and during (2081-2090) in Asyut and Aswan of both models and Sohag of 10 °C model.

Table 6:- The accumulated winter chill units each 10 years of the Upper Egypt locations depending on the 7.2°C

Model based on Temp. < 7.2 C				
Date	**Asyut**	**Sohag**	**Qena**	**Aswan**
2011 - 2020	2370	1576	2900	720
2021 - 2030	1854	1336	2214	352
2031 - 2040	914	534	1292	226
2041 - 2050	1284	756	1626	350
2051 - 2060	948	556	1268	604
2061 - 2070	670	486	938	166

2071 - 2080	556	338	962	132
2081 - 2090	552	392	984	112

Table 7:- The accumulated winter chill units each 10 years of the Upper Egypt locations depending on the 10 °C.

Model based on Temp. < 10 C				
Date	**Asyut**	**Sohag**	**Qena**	**Aswan**
2011 - 2020	5840	4530	6096	2406
2021 - 2030	5088	3966	5094	1590
2031 - 2040	3696	2620	4044	1200
2041 - 2050	4338	3200	4438	1674
2051 - 2060	3442	2430	3698	2878
2061 - 2070	3132	2182	3366	1048
2071 - 2080	3004	2144	3454	896
2081 - 2090	2724	1978	3380	840

The curve of the accumulated winter chill units during the periods from 2011 up to 2090 based on 7.2 and 10°C models for Upper Egypt locations is shown in figures (5 and 6) and it's indicted that, the chilling units tend to decrease in the future at all Upper Egypt locations, and the highest accumulated winter chill count has been observed in Qena location, while the lowest count has been observed in Aswan location during the study period except in (2051-2060) period where there is an extreme increment in Aswan winter chill count during this period and lowest count in it recorded in Sohag location.

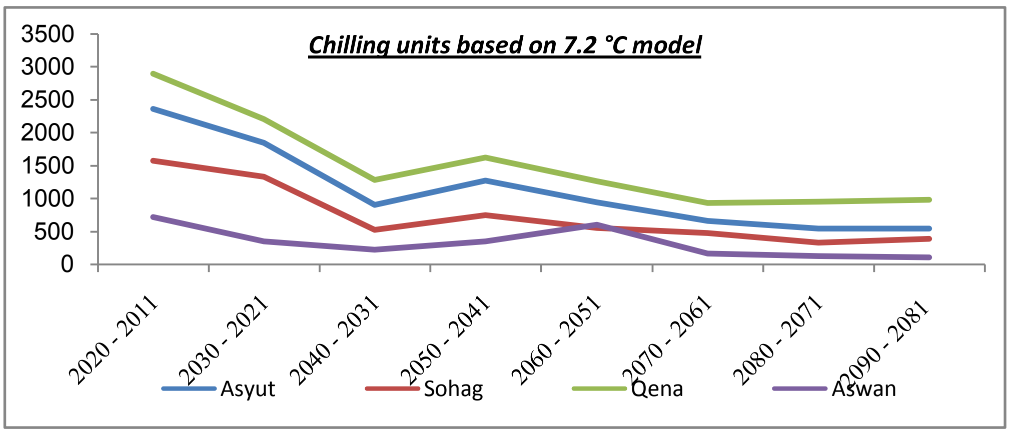

Figure 5:- The accumulated winter chill units during the periods from 2011 up to 2090 based on 7.2 °C models for Upper Egypt locations.

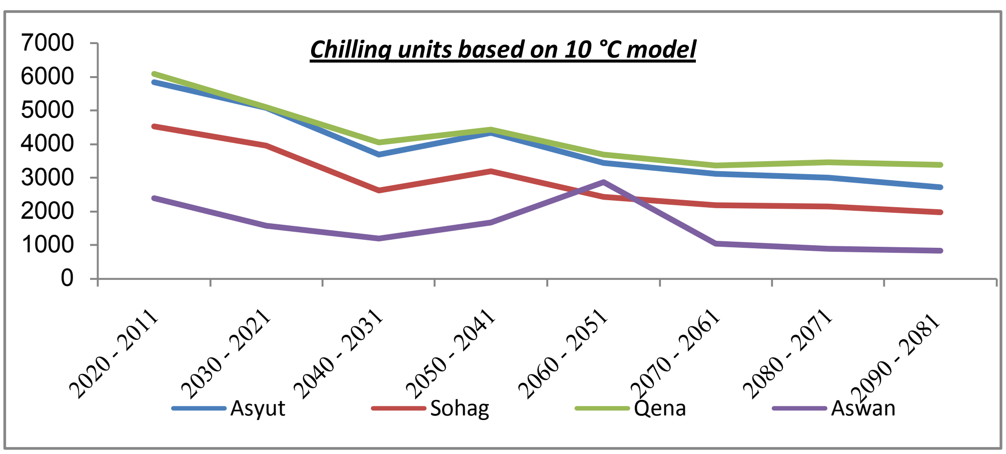

Figure 6:- The accumulated chill units during the periods from 2011 up to 2090 based on 10 °C models for Upper Egypt locations.

Outside Valley locations:-

The Outside Valley locations accumulated winter chill unit each 10 years based on the 7.2 and 10 °C models is shown in tables (8 and 9) and it has been found that, the period (2011-2020) has the highest number of accumulation winter chill units in both models while the lowest number is observed in the last 30 years of study period (2061 – 2090) where it was during (2061-2070) in Matruh of 7.2 °C model and Kharga location of 10 °C model, during (2071-2080) in Arish location of 7.2 °C, and during (2081-2090) in the reaming locations of outside valley region (Dakhla and Kharga of 7.2 °C model and all studied locations of 10 °C model except Kharga).

Figures (7 and 8) show the curve of the accumulated winter chill units during the periods from 2011 up to 2090 based on 7.2 and 10°C models for Outside Valley locations and it has been indicted that, the winter chill units tend to decrease in the future at all Outside Valley locations, and Kharga is the lowest one in the accumulated winter chill units in both models while the highest one is Matruh location during study period.

Table 8:- The accumulated winter chill units each 10 years of the Outside Valley locations depending on the 7.2°C

Model based on Temp. < 7.2 C				
Date	**Dakhla**	**Kharga**	**Matruh**	**Arish**
2011 - 2020	3258	2302	4004	2418
2021 - 2030	2850	1958	3540	2020
2031 - 2040	1524	940	2598	1200
2041 - 2050	2012	1410	2498	1796
2051 - 2060	1562	922	2600	1318
2061 - 2070	1188	722	1374	848
2071 - 2080	1216	616	1492	714
2081 - 2090	1046	602	1546	870

Table 9:- The accumulated winter chill units each 10 years of the Outside Valley locations depending on the 10°C

Model based on Temp. < 10 C				
Date	**Dakhla**	**Kharga**	**Matruh**	**Arish**
2011 - 2020	6634	5594	7716	6470
2021 - 2030	6044	4976	7136	5908
2031 - 2040	4580	3544	6116	4712
2041 - 2050	5132	4262	6136	5432
2051 - 2060	4244	3218	6000	4588
2061 - 2070	4184	2892	5102	3926
2071 - 2080	4234	2900	4860	3912
2081 - 2090	3764	2904	4766	3496

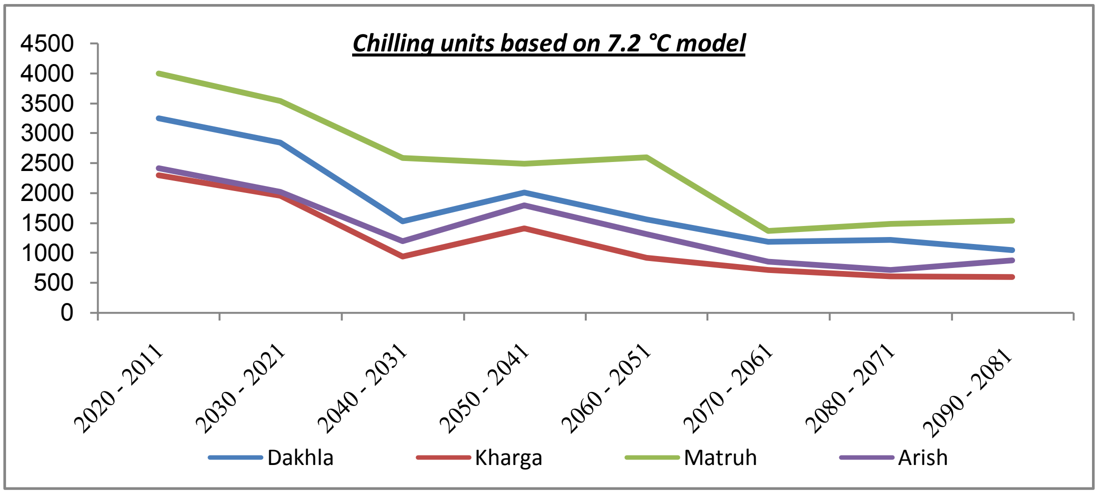

Figure 7:- The accumulated winter chill units during the periods from 2011 up to 2090 based on 7.2 °C models for the Outside Valley locations.

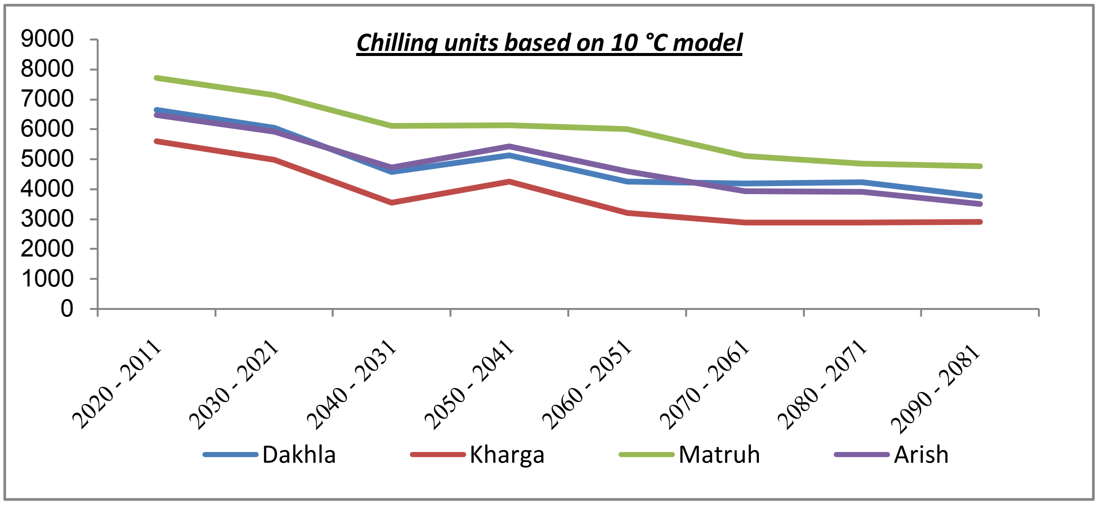

Figure 8:- The accumulated winter chill units during the periods from 2011 up to 2090 based on 10 °C models for the Outside Valley locations.

Discussions:-

Winter chill is essential for most of the plants that fall dormant in the winter in order to avoid frost damage and do not resume growth until a certain amount of winter chill has accumulated for fulfilling their chilling requirement. In general, the result of this study indicates to declining the winter chill hours in the future, a result which in accordance with different studies , such as, **Farag, *et al*, 2010** which study the chilling hours during the winter season by three different GCMs and found that winter chill could decrease in Egypt substantially under warming scenarios over time. Averaging over all three General Circulation Models annual winter chill loss by 2050 compared to 1970 would amount to moderate 17.7 % and 22.6 %. Similar results obtained by **Eike, *et al.*,2009** which recorded that the Chilling Hours Model is most sensitive to rising temperatures and chilling model predicted substantial decreases in winter chill at all sites in California's , but the extent of these decreases varied depending on the model used. Across all sites between 1950 and 2050, mean chilling was predicted to decrease by 33%. In the same line **Darbyshire *et al.* 2011** found that historic declines in winter chill have been detected in many warm fruit growing regions, and this trend will likely be exacerbated by future temperature increases. **Liang Guo *et al* 2013** recorded that over the past 50 years, heat accumulation during tree dormancy increased significantly, while chill accumulation remained relatively stable. Heat accumulation was the main driver of bloom timing, with effects of variation in chill accumulation negligible in Beijing's cold-winter climate. It does not seem likely that reductions in chill will have a major effect on the studied species in Beijing in the near future. Such problems are much more likely for trees grown in locations that are substantially warmer than their native habitats, such as temperate species in the subtropics and tropics. **Liang Guo *et al* 2013,** also recorded that Declining winter chill was also reported in Australia (**Hennessy and Clayton-Greene 1995; Darbyshire *et al.* 2011, 2013b**), Egypt (**Farag *et al.* 2010**), Southern Brazil (**Wrege *et al.* 2010**), the United Kingdom (**Sunley *et al.* 2006**), the Western Cape region of South Africa (**Midgley and Lötze 2011**), and France (**Yann Vitasse, *et al.* 2011)**

Conclusion:-

Studying the future winter chill in Egypt using ECHAM6 model under moderate future scenario RCP 4.5 conclude that, the winter chill units tend to decrease in the future at all Egyptian locations, and there are an extreme decrement in temperature at Gharbia location during (2061-2070) period and at Aswan during (2051-2060) period will led to increasing the winter chill units in these locations, and an extreme increment in temperature at Minya during (2061-2070) period will led to decreasing the winter chill units during this period.

The highest Egyptian location in winter chill units was Matruh while the lowest one was Kafr El-Sheikh among the studied locations. The fruit trees will likely need to develop agricultural adaptation measures (e.g. low-chill varieties and dormancy-breaking chemicals) to cope with these projected changes. Finally, our analysis may be extended to include the impacts of winter temperature increases on fruit species.

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