The Effect of Some Climatic Variables and Frosts Waves on Citrus Crops

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Abstract

This study examined the effect of some climatic variables and their role in growing citrus fruits in northern Saudi Arabia, which showed that low temperatures accompanied by calm winds and high relative humidity as well as creeping air masses are among the most important factors that contribute to the worsening of frost. This study also dealt with hourly frost waves - a case study - based on the study of climatic data of the study area stations for one day of frost waves that occurred in the study area for the year 2008**.**

Keyword: climatic variables, citrus, Critical temperatures, and Frost.

1. Introduction

Frost exposure is a geographical constraint on growing crops, and it can be an environmental constraining factor for crop production in arid and semi-arid climates.(Maracchi et al., 2005; Maracchi et al., 2021). Farmers and investors are exposed to dire economic consequences as a result of the effects of exposure to frost, as frost causes damage to citrus crops of economic value in northern Saudi Arabia. As temperatures rise in early spring, citrus crops gradually begin to bud and flower, and become increasingly sensitive to cold temperatures, increasing their vulnerability to frost damage. Temperatures in an abnormally warm late winter or early spring can also lead to the development of phenology, leading to a false spring in which crops break dormancy and begin their annual growth earlier than normal, increasing the risk of damage from subsequent frost exposure. (Peterson et al., 2014; Reyes et al., 2019; Allstadt et al., 2015). Numerous studies have shed light on the devastating frost events which have caused massive damage in large areas of the world, to citrus crops, or crops in general. (Vitasse et al., 2018; Hufkens et

al., 2012; Kistner et al., 2018; Kotikot et al., 2020; Alhader, 2016; Lhotka et al., 2020; Pfleiderer et al., 2019*).* These studies also indicated that exposure to low and very low temperatures creates environmental pressures on plants and affects their productivity, especially very low temperatures. Northern Saudi Arabia has a desert climate and is affected in winter and spring by the Mediterranean climate, and is not ideally suited to subtropical fruits, such as citrus fruits. Frost damage has become one of the main challenges facing citrus farmers in this region, and the harvest time coincides with the late autumn and early winter seasons, as well as the flowering and budding period in the spring, and this indicates a possible relationship between the spatial distributions of citrus groves and the climatic conditions prevailing in the study area. These areas are exposed to a decrease in temperatures below zero degrees Celsius, which results in frequent frost waves and varies in intensity from one region to another and from year to year according to the climatic conditions prevailing in these areas. (Alhader, 2016). This paper sheds light on the hourly low temperatures in the study area and the factors that exacerbate the frost phenomenon.

2. Study area

The study area constitutes the northern part of the Kingdom of Saudi Arabia and includes the Hail region, the Al-Jouf region, the Tabuk region, and the northern border region (Figure1). Soils in the regions of Hail, Tabuk, and Al-Jouf are among the best agricultural soils, and the most fertile ones for agriculture in general, and for growing citrus fruits in particular.

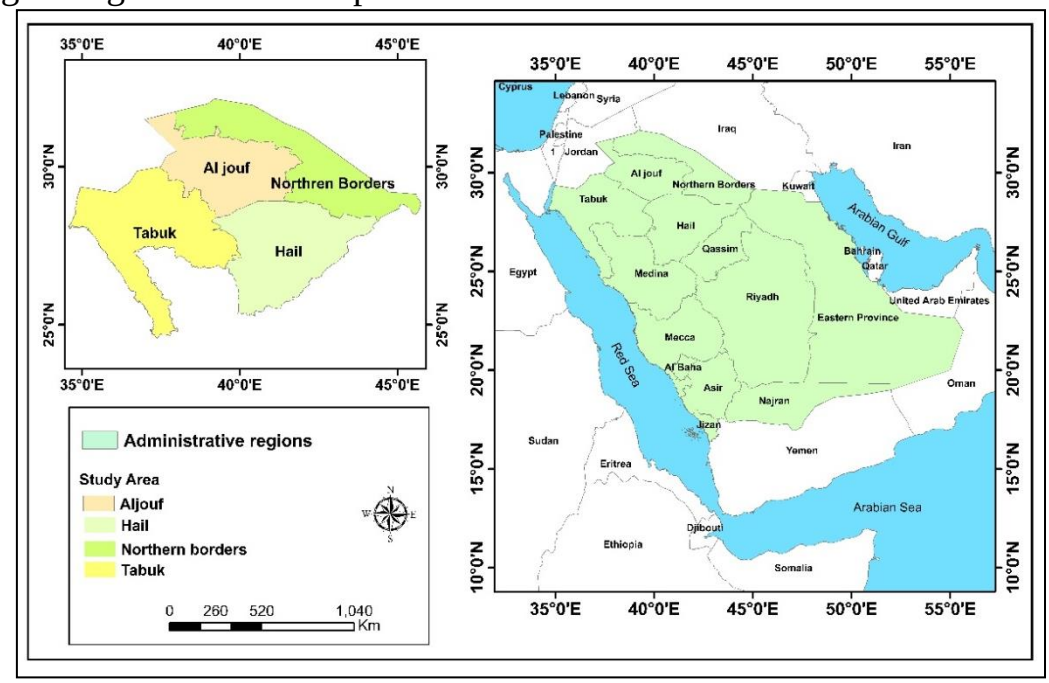

Figure.1 the study area

2. Materials and methods

2-1: Climate data*:* This study analyzed the minimum temperatures and frost recurrence rates in the study area based on the climatic data in the monitoring stations in the study area during the period from November 1985 to April 2018.

2-1: Field study: During, the problems faced by farmers and the effect of frost on citrus cultivation were learned.

3. The Influences of Certain Climate Variables in Citrus Crops

3.1. Effect Low Temperature : The temperature drop affects the onset of budding and flowering of the citrus crop, especially in late winter and early spring.

Pollination negatively affects the beginning of budding, and the early growth of buds causes them to be exposed to frost. (Kumar et al., 2007). By studying the minimum temperatures in the study area during the period from 1985-2018, table 1, The lowest temperatures were observed at high levels, which resulted in frost waves that led to great economic losses in citrus crops in the study area. In the Hail region that was hit by a frost wave in 1989, this is one of the worst frost's waves, as it extended from December to February when the minimum temperature reached -9.5 °C, and the average temperature for January of the same year was -3.1 °C, and the average for the month of February was -1.5 °C, and the average minimum temperature for December -1 °C (Almarai Company, 1989). The Hail region was also subjected to a drop in minimum temperatures in 2008, reaching -7.5 °C. In the northern border region, the Turaif station in the far north recorded about -7 °C during 2015, and it recorded -6.3 °C during 2016 °C, and in 2017 the minimum temperature was approximately -6.2 °C. In the Arar station, the lowest temperature was recorded in 1997, at -5.8 °C. In 2008, it was recorded at -4 °C. In the Al-Jouf region, the lowest temperature reached its lowest level during the study period in 1989 by - 6.5 °C, and in 2017 it recorded -6 °C, and also in 2008, it reached approximately -5.4 °C. In the Tabuk region, the lowest minimum temperature levels were recorded in 2008, at -5.3 °C, and were affected by the 1989 frost waves, with which the minimum temperature reached -5.2 °C. The reason for the low temperature during 1989 and 2008 is due to the multiple depressions of polar origin that affected the study area.

Table.1 Monthly rate of the lowest temperature °C in the study area for the period from 1985-2018

	Jan	Feb	Mar	April	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Hail	4.2	5.6	9.7	15.3	20.7	23.6	25.4	25.9	23.1	18.5	11.8	6.5
Al-Jouf	2.4	3.7	7.6	12.9	17.9	21	22.9	23.8	21.1	16.5	9.6	5
Northern borders	2.4	3.8	7.9	13.5	19	22.4	24.8	25	21.9	17	9.8	4.4
Tabuk	2.8	3.8	7.1	12	16.1	18.8	20.9	21.3	19	15.1	9.6	4.7

3-2: Critical temperatures for citrus fruits: Frost and low temperatures cause great damage to citrus trees; This is because citrus trees are generally sensitive to low temperatures and frost, and not all citrus varieties have frost sensitivity, as the critical temperatures vary from one crop to another. (Yelenosky,1991). Low temperatures damage citrus fruits by causing ice crystals to form in their cells, and the damaged vegetation turns dark brown or black. Citrus fruits, especially ripe, can also form ice crystals, causing the juice sacs inside the fruit to rupture, and the fruits to dry out. (Pamela, 2003). Among the types of citrus fruits that are easily affected by low temperatures are lemons, while sweet oranges and grapefruit are more tolerant to lower temperatures to some extent, and tangerines are the most tolerant of these types. Table 2. The percentage of damage to citruses also varies according to the period of time the crop is exposed to, so the longer the frost period, the more damage.

Table.2 Critical temperatures for citrus fruits

Fruit	Critical temperature*. (ºC)
lemon buds and blossoms	–2.8
Lemons button	–1.4 to –0.8
Lemons green	–2.8 to –1.4
lemons tree-ripe	–3.3 to –0.8
oranges, green	–1.9 to –1.4
oranges, grapefruits, and mandarins, half-ripe	–2.8 to –1.7
oranges, grapefruits, and mandarins, tree-ripe	–3.9 to –1.7

Note: *Critical temperature is affected by relative humidity and duration. Fruits can withstand the lower temperature ranges in drier air and shorter durations of cold. (Pamela, 2003).

3-3: Effect Relative humidity

The relative humidity is an important factor along with the lowest temperatures in frost. And the relative humidity helps to determine the type of frost (black or killing). The presence of water vapor is important for maintaining the Earth's temperature; Because it

absorbs the heat radiated by the earth and reduces its infiltration into the upper layers Table 3, shows the relative humidity levels in the study area, on which the rise appears from November to March, during which time frost waves occur.

Table. 3 The average relative humidity in the study area for the period from 1985-2018. %

	Jan	Feb	Mar	April	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Hail	46	37	30	25	18	12	12	13	14	21	38	46
Al-Jouf	52	43	33	26	20	16	17	17	19	27	42	51
Northern borders	52	42	33	25	19	16	14	15	17	26	41	51
Tabuk	48	39	31	23	20	18	19	20	23	30	40	47

3-4: Effect Location of Growing Area

Cold air settles in the valleys; Because it is heavier than warm air, frost conditions are more vulnerable in these areas, and valleys or low-lying areas obstruct the region's strong winds, which increases the possibility of frost. So, the best way to prevent frost or reduce the associated risks - if possible - is to avoid valley floors, narrow ponds, or depressions that may create pockets of frost. While foothills, hills, or areas near large water bodies are favorable conditions that reduce the risk of frost. So, the local geography plays a big role in determining whether or not there is an increase in frost.

3-5: A period of time

A short frost of fewer than two hours may not cause much damage if the frosts are light, on citrus crops; As these crops are adapted to short periods of frost, they can withstand short periods and recover their vigor when temperatures rise and feel warm. The damage caused by frost is variable in the study area from one region to another, and whether the frost is light or harsh, the higher the negative temperature (more than two hours) the greater the time of the damage.

3-6: Effect Wind speed and Direction

The study area is affected by different wind systems; The northern winds prevail, and the westerly and northwestern winds, which accompany the depressions, are accompanied by cold polar air masses. If there is no wind, the air will remain steady, and the cold air will settle on the ground creating frost, but if there are slow and gentle winds, the cooler air will be pushed, and it will not have a chance to settle on the ground, which makes the formation of frost a little difficult. And the most damaging types of winds are very cold, and temperatures below freezing, and it is noticeable that most frosts occur during the calm and still winds. Table 4.

Table.4 Average wind speed in the study area for the period from 1985-2018. m /s

	Jan	Feb	Mar	April	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Hail	3.7	3.9	4	3.9	3.9	4	4.2	3.7	3.4	3.7	3.8	3.7
Al-Jouf	2.6	2.8	2.9	3	2.8	2.8	3	2.6	3.2	2.6	2.7	2.5
Northern borders	3.5	3.8	4	4.1	4	4	4.2	3.5	3.2	3.5	3.3	3.3
Tabuk	2.6	2.8	3	3	2.9	2.8	2.6	2.5	2.4	2.5	2.7	2.6

3-7: Air masses

Through the study of the weather conditions that the study area was exposed to, it can be said: The study area is affected by the cold and dry air masses crawling from the southern edges of the Siberian High, and the air depression centered in central Europe affects the study area and may cause the cold air masses to rush The study area had to lower the temperatures over the entire study area to below zero degrees Celsius, which caused many frost waves, which inflicted a lot of damage on the citrus crops in the study area.

4- Result

The study area is exposed to low temperatures during late autumn until spring, and the amount of temperature drops varies from year to year. Some years in the study area were marked by severe frost waves, and temperatures decreased to great levels. This is due to the influence of northern Saudi Arabia by the air depression coming from northern and central Europe, and the extension of the Siberian high to the eastern Mediterranean region, which leads to the eruption of cold and dry air masses, which results in lower air temperatures. This period was characterized by very low temperatures, which caused severe frost waves over the study area. The following is a breakdown of the weather conditions for each day as follows:

4-1: Weather study on 17-15 / 01/2008 in the region of Hail

Through the study of the hourly climatic conditions on 1/15/2008, which are shown in Table 5 and Figure 2, we note that the highest temperature for this day was recorded at midday at 12 pm, then after that, the minimum temperature began to gradually decrease, and it reached at four in the morning, it has a minimum low of -8 °C, and relative humidity of 86%, accompanied by calm and still winds, with a clear sky. The direction of the prevailing winds during this day also indicates that they varied between northeasterly and easterly northeast. The frost hours for this day reached 17 hours of frost, which varied between white frost at a rate of 5 hours, followed by black frost at a rate of 3 hours, while fatal frost formed 9 consecutive hours. Whereas on 1/16/2008, and Table 5 shows, that 4 pm recorded a temperature of 8 °C, then after that, the minimum temperature began to gradually decrease, and at 7 am it reached its lowest minimum of -9

°C, the relative humidity reached 70%. Also, calm prevails most of the day, and the directions of the northeastern winds formed most of the wind directions for the day. The number of hours of frost during this day reached 15 hours, and white frost formed four hours of frost, while the number of hours of black frost reached only one hour, and the deadly frost formed ten hours. Through the hourly weather study on 1/17/2008, Table 5 shows that 4 pm recorded a temperature of 11°C, then after that, the minimum temperature began to gradually decrease, and it reached at seven in the morning the lowest minimum at a rate of -8 °C, the relative humidity reached 68%. The directions of the eastern and southern winds also formed most of the wind directions for today. The number of hours of frost during that day was 10 hours, which ranged between an hour of black frost, and nine hours of deadly frost.

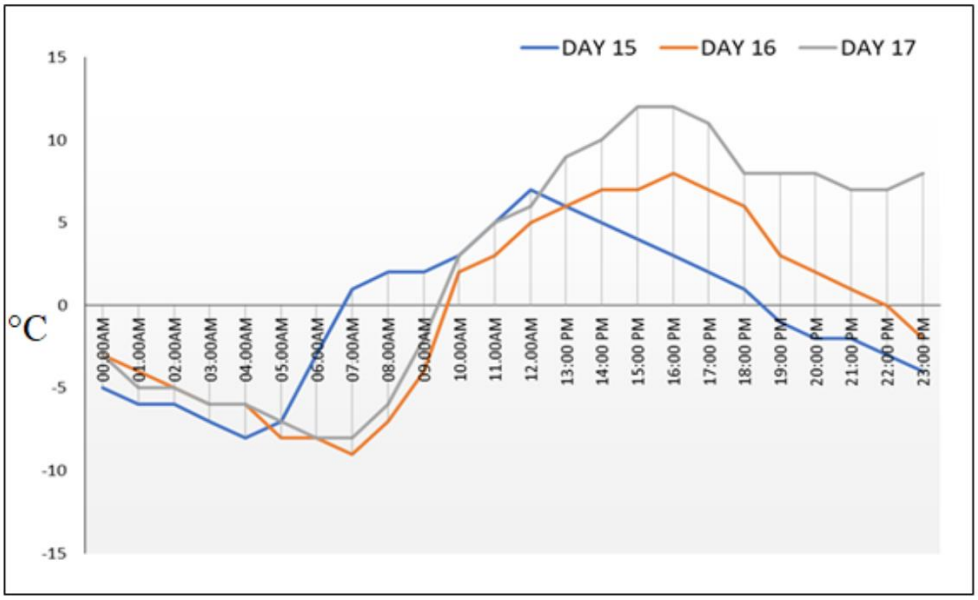

Figure.2 The lowest temperature in the Hail region on 15-17 January 2008.

Table. 5 Climatic conditions in the Hail region on 15-17 January 2008.

Time	Temperature C °			Dew Point C °			Humidity %			wind directions			Wind Speed Km/h		
	15	16	17	15	16	17	15	16	17	15	16	17	15	16	17
00:00 AM	-5	-3	-3	-11	-6	-11	63	80	55	CALM	NE	CALM	0	7	0

1:00 AM	-6	-4	-5	-11	-6	-11	68	86	63	CALM	CALM	CALM	0	0	0
2:00 AM	-6	-5	-5	-11	-8	-11	68	80	63	S	CALM	S	4	0	7
3:00 AM	-7	-6	-6	-10	-8	-12	80	86	63	SSW	CALM	S	4	0	7
4:00 AM	-8	-6	-6	-10	-8	-12	86	86	63	CALM	CALM	S	0	0	11
5:00 AM	-7	-8	-7	-10	-10	-11	80	86	74	CALM	SE	SSE	0	4	11
6:00 AM	-3	-8	-8	-10	-12	-11	59	73	68	CALM	S	S	0	11	7
7:00 AM	1	-9	-8	-7	-18	-13	56	70	68	CALM	CALM	S	0	0	11
8:00 AM	2	-7	-6	-7	-12	-12	52	68	63	ENE	SSE	S	11	11	7
9:00 AM	2	-4	-2	-7	-11	-10	52	59	55	ENE	S	CALM	11	11	0
10:00 AM	3	2	3	-7	-13	-12	48	33	33	EN	E	SW	11	11	7
11:00 AM	5	3	5	-9	-8	-12	36	45	29	EN	ENE	S	4	4	7
12:00 PM	7	5	6	-10	-6	-9	29	45	34	NNE	E	S	11	4	11
13:00 PM	6	6	9	-15	-10	-8	21	31	30	N	CALM	CALM	15	0	0
14:00 PM	5	7	10	-13	-13	-8	26	23	28	NNE	WNW	SSE	15	4	7
15:00 PM	4	7	12	-12	-13	-10	31	23	21	NNE	CALM	ENE	15	0	11
16:00 PM	3	8	12	-11	-13	-11	36	22	19	NNE	ENE	E	15	11	15
17:00 PM	2	7	11	-12	-13	-9	35	23	24	NNE	E	ESE	15	11	11
18:00 PM	1	6	8	-11	-11	-7	41	29	34	ENE	ENE	E	11	19	15
19:00 PM	-1	3	8	-11	-9	-7	47	41	34	ENE	ENE	E	4	15	15

20:00 PM	-2	2	8	-7	-9	-6	69	44	37	ENE	ENE	E	4	15	19
21:00 PM	-2	1	7	-10	-10	-2	55	44	53	NE	E	ESE	4	7	15
22:00 PM	-3	0	7	-10	-10	-4	59	47	46	ENE	CALM	SSE	4	0	15
23:00 PM	-4	-2	8	-10	-10	-9	64	55	29	NNE	CALM	S	4	0	7

Source: Researchers' work based on wunderground

4-2: Weather study on 15 - 17/ 1 /2008 in Al-Jouf region

Through the study of the hourly climatic conditions on 1/15/2008, Table No. 6 and Fig. 3 show that 2 pm recorded a temperature of 8 ˚C, then after that, the minimum temperature began to gradually decrease, and it reached five in the morning Its lowest minimum was -5 ˚C, and the relative humidity reached 74%, accompanied by clear skies, and winds of 7 km/hr. It also notes the direction of the prevailing winds during this day, which varied between hours of calm and silence, and the westerly, southwestern, and northerly winds and the northwestern winds. The number of hours of frost during this day reached 17 hours, and white frost formed three hours, while the number of hours of black frost reached 4 hours, and the deadly frost formed 6 hours. And through the study of the hourly weather situation in the Al-Jouf region on 1/16/2008, table 6, shows that 4 pm recorded a temperature of 8 °C, then after that, the minimum temperature began to gradually decrease, and it reached seven o'clock in the morning, the lowest low of -4 °C, with the relative humidity reached 69%. Wind directions varied most of the day. The number of hours of frost during this day reached 14 hours, of which white frost formed seven hours, while the number of hours of black frost reached three hours, and fatal frost formed four hours. Through the study of the hourly weather on 1/17/2008, Table 6, shows that 4 pm recorded a temperature of 10 °C, then after that, the minimum temperature began to gradually decrease, and it reached at eight in the morning its lowest minimum by -5 °C, the relative humidity reached 51%. Wind directions varied most of the day. The number of hours of frost during this day reached 11 hours, and white frost formed only one hour, while the number of hours of black frost reached four hours, and the deadly frost formed six hours.

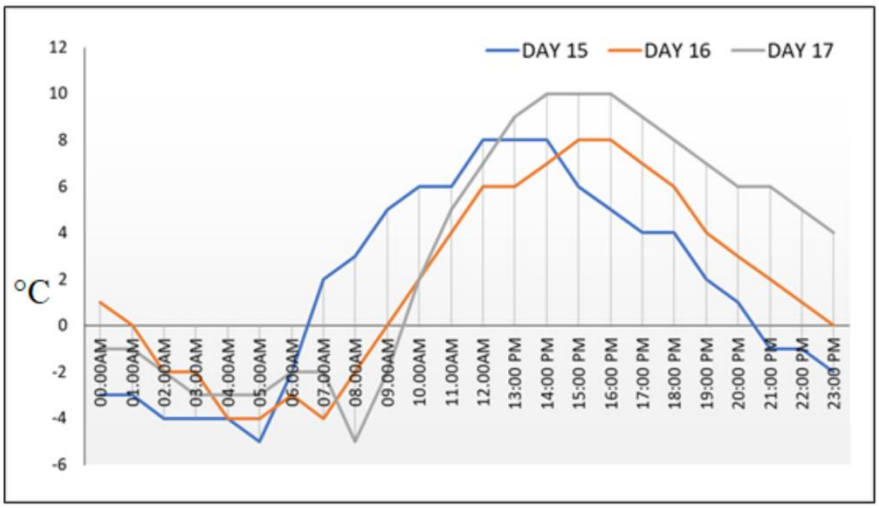

Figure 3: The minimum temperature in the Al-Jouf region on 15-17 January 2008.

Table. 6 Climatic conditions in the Al-Jouf region on 15-17 January 2008

Time	Temperature C °			Dew Point C °			Humidity %			wind directions			Wind Speed Km/h		
	15	16	17	15	16	17	15	16	17	15	16	17	15	16	17
00:00 AM	-3	1	-1	-9	-9	-10	64	48	51	WNW	SE	ESE	7	6	9
1:00 AM	-3	0	-1	-10	-8	-10	59	55	51	WSW	SSE	SE	7	7	11
2:00 AM	-4	-2	-2	-9	-8	-11	69	64	51	WSW	SSW	SE	7	9	9
3:00 AM	-4	-2	-3	-8	-8	-11	74	64	55	WSW	S	SE	7	6	11
4:00 AM	-4	-4	-3	-8	-9	-11	74	69	55	WSW	W	ESE	7	6	7
5:00 AM	-5	-4	-3	-9	-9	-11	74	69	55	WSW	W	ESE	7	6	6
6:00 AM	-2	-3	-2	-8	-8	-12	64	69	47	CALM	CALM	E	0	0	9
7:00 AM	2	-4	-2	-11	-9	-12	38	69	47	CALM	E	ESE	0	4	11
8:00 AM	3	-2	-5	-11	-10	-12	36	55	51	CALM	CALM	ENE	0	0	11
9:00 AM	5	0	-2	-12	-11	-11	29	44	51	CALM	CALM	NE	0	0	6
10:00 AM	6	2	2	-12	-10	-14	27	41	30	N	CALM	NE	7	0	19
11:00 AM	6	4	5	-12	-11	-15	27	33	23	CALM	CALM	SE	0	0	22
12:00 PM	8	6	7	-12	-13	-15	23	25	20	CALM	CALM	ESE	0	0	19
13:00 PM	8	6	9	-13	-14	-16	22	23	16	WNW	SE	ESE	11	6	15
14:00 PM	8	7	10	-14	-15	-16	20	20	15	N	SE	SE	9	6	19
15:00 PM	6	8	10	-14	-15	-17	23	18	14	N	S	ESE	6	11	22
16:00 PM	5	8	10	-13	-15	-17	26	18	14	CALM	SE	E	0	11	19
17:00 PM	4	7	9	-13	-15	-17	28	20	15	CALM	SE	E	0	11	11
18:00	4	6	8	-	-	-	28	21	16	E	SE	E	6	7	11

PM				13	15	17									
19:00 PM	2	4	7	-10	-15	-17	41	24	17	SE	SE	E	6	7	11
20:00 PM	1	3	6	-9	-14	-17	48	28	18	E	ESE	E	4	6	15
21:00 PM	-1	2	6	-9	-13	-17	55	33	18	SSW	ESE	E	7	6	11
22:00 PM	-1	1	5	-8	-12	-16	60	38	21	WSW	ESE	E	7	9	11
23:00 PM	-2	0	4	-9	-10	-15	59	47	24	WSW	SE	E	7	7	15

Source: Researchers' work based on wunderground

4-3: Weather study on 15-17/ 1 /2008 in the northern border region

Table7 and Fig. 4, show the hourly weather conditions on January 15, 2008. As it recorded at 2 pm a temperature of 5 °C, then after that the minimum temperature began to gradually decrease, and at five in the morning it reached its lowest low of -7 °C, and with it, the relative humidity reached 93%, accompanied by calm and calm of the winds, with a clear sky. The direction of the prevailing winds during this day also indicates that it varied between northerly winds, northeasterly, northwestern, and northwestern winds. The number of hours of frost during this day reached 18 hours, of which white frost formed four hours, while the number of hours of black frost reached three hours, and the deadly frost formed 11 hours. And through the hourly weather study on 1/16/2008, it is clear from Table 7 that 5 pm recorded a temperature of 7 °C, then after that, the minimum temperature began to gradually decrease, and the temperature decreased significantly after midnight. As it peaked at 7 o'clock in the morning at -8 °C, and the relative humidity was recorded at 86%, and the surface pressure values for this day ranged between 927.45 - 931.98 hectopascal. Wind directions varied most of the day. The number of hours of frost during this day was 14 hours, of which white frost formed three hours of frost, while the number of hours of black frost was only two hours, and the deadly frost formed nine hours. And through the hourly weather study on 1/17/2008, Table 7 shows that 4 pm recorded a temperature of 8 °C, then after that, the minimum temperature began to gradually decrease, and it reached at six in the morning its lowest minimum by -8 °C, and the relative humidity reached 79%. The eastern winds prevail most of the day. The number of hours of frost during this day reached 16 hours, of which white frost formed three hours of frost, while the number of hours of black frost reached three hours of frost, and the deadly frost formed 10 hours of frost.

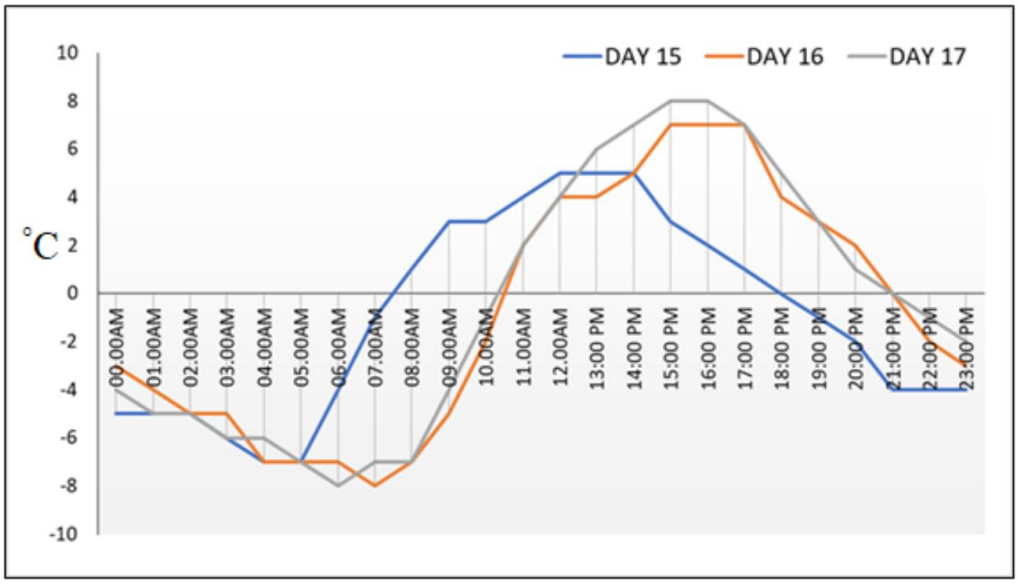

Figure. 4 The minimum temperature in the northern border region on 15-17 January 2008.

Table.7 The climatic conditions in the northern border region on 15-17 January 2008.

Time	Temperature C °			Dew Point C °			Humidity %			wind directions			Wind Speed Km/h		
	15	16	17	15	16	17	15	16	17	15	16	17	15	16	17
00:00 AM	-5	-3	-4	-7	-7	-8	86	74	74	N	E	SE	6	7	11
1:00 AM	-5	-4	-5	-8	-8	-8	80	74	80	CALM	E	ESE	0	7	11
2:00 AM	-5	-5	-5	-8	-8	-9	80	80	74	CALM	E	E	0	7	7
3:00 AM	-6	-5	-6	-9	-9	-10	80	80	74	CALM	ESE	E	0	7	7
4:00 AM	-7	-7	-6	-9	-9	-10	86	86	74	NNE	SE	E	6	7	11
5:00 AM	-7	-7	-7	-8	-9	-11	93	86	74	CALM	SE	ESE	0	7	11
6:00 AM	-4	-7	-8	-7	-10	-11	80	80	79	CALM	ESE	ESE	0	4	11
7:00 AM	-1	-8	-7	-6	-10	-10	69	86	80	CALM	ESE	ESE	0	7	11
8:00 AM	1	-7	-7	-7	-9	-10	56	86	80	CALM	SSE	E	0	7	11
9:00 AM	3	-5	-4	-8	-9	-9	45	80	69	W	E	ESE	6	7	15
10:00 AM	3	-2	-1	-9	-10	-10	41	55	54	WSW	SE	ESE	4	11	26
11:00 AM	4	2	2	-3	-12	-11	61	35	38	NNW	SSE	ESE	4	19	26
12:00 PM	5	4	4	-10	-11	-11	33	33	33	NNW	SSE	ESE	4	15	26
13:00 PM	5	4	6	-10	-11	-12	33	33	27	NW	SSE	SE	4	15	19
14:00 PM	5	5	7	-10	-12	-14	33	29	21	N	SSE	SE	4	15	19
15:00 PM	3	7	8	-10	-12	-13	38	25	22	NW	SSE	E	4	15	15
16:00 PM	2	7	8	-8	-12	-14	48	25	20	NW	S	E	6	15	15
17:00 PM	1	7	7	-8	-11	-16	52	27	18	NNE	S	E	7	11	19
18:00 PM	0	4	5	-8	-11	-15	55	33	23	NNW	S	E	4	7	19
19:00 PM	-1	3	3	-7	-10	-13	64	38	30	NNE	S	E	4	7	19
20:00 PM	-2	2	1	-8	-10	-13	64	41	35	NE	S	E	6	7	19

21:00 PM	-4	0	0	-7	-10	-13	80	47	38	N	SSE	E	7	4	19
22:00 PM	-4	-2	-1	-7	-8	-12	80	64	44	N	ESE	E	6	7	19
23:00 PM	-4	-3	-2	-7	-8	-13	80	69	43	NNE	SE	E	6	11	19

Source: Researchers' work based on wunderground

4-4: Weather study on 01-15 / 17/2008 in Tabuk region

Table 8, and Figure 5, show the hourly climatic conditions on 1/15/2008 AD, and it appears that 3 pm recorded a temperature of 10 °C, then after that, the minimum temperature began to gradually decrease, and it reached five in the morning Its lowest minimum, at -3 °C, reached 55% with relative humidity. The direction of the prevailing winds during this day also indicates that it varied between easterly winds and northeasterly winds. The number of hours of frost during this day was 12 hours, of which white frost formed three hours of frost, while the number of hours of black frost reached 8 hours, and the deadly frost formed only one hour. And through the hourly weather study on 1/16/2008, Table 8, shows that 6 pm recorded a temperature of 12 °C, then after that, the minimum temperature began to gradually decrease, and at eight in the morning it reached its lowest low by - 4 °C, and the relative humidity reached 46%. Wind directions varied most of the day. The number of hours of frost during this day reached 11 hours, and white frost formed four hours of frost, while the number of hours of black frost reached four hours, and fatal frost formed three hours. As Table 8, shows, the hourly weather study on 1/17/2008, and it is clear that 4 pm recorded a temperature of 14 °C, then after that, the minimum temperature began to gradually decrease, and it reached at seven in the morning its lowest low by - 4 °C, and the relative humidity reached 43%. Wind directions varied most of the day. The number of hours of frost during this day reached 10 hours, and white frost formed four hours of frost, while the number of hours of black frost also reached four hours, and the deadly frost formed only two hours.

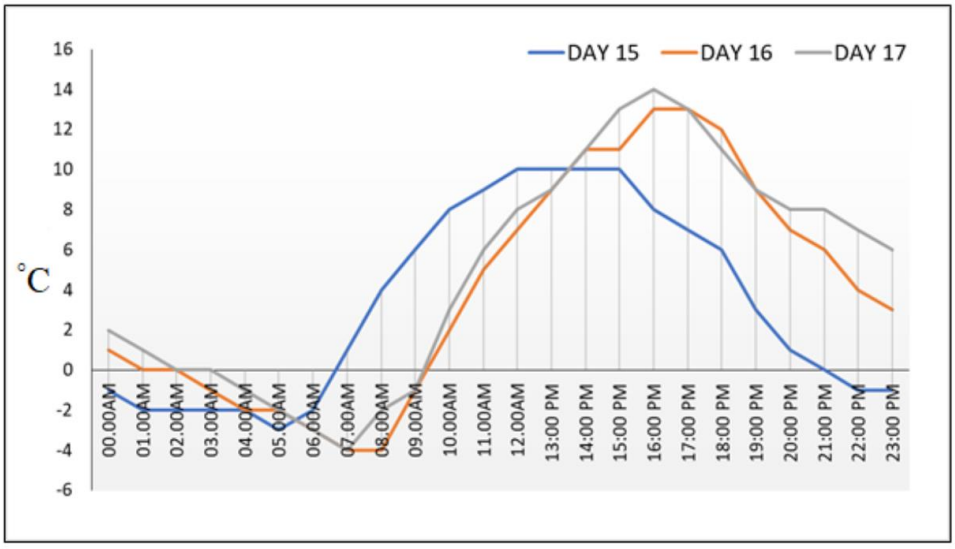

Figure.5 The lowest temperature in the Tabuk region on 15-17 January 2008

Table.7 The climatic conditions in the Tabuk region on 15-17 January 2008.

Time	Temperature C °			Dew Point C °			Humidity %			wind directions			Wind Speed Km/h		
	15	16	17	15	16	17	15	16	17	15	16	17	15	16	17
00:00 AM	-1	1	2	-12	-13	-17	44	35	24	E	SSE	SSE	9	19	9
1:00 AM	-2	0	1	-12	-15	-18	47	32	23	E	SSE	ESE	11	17	13
2:00 AM	-2	0	0	-12	-15	-18	47	32	25	E	SE	ENE	13	13	9
3:00 AM	-2	-1	0	-12	-15	-18	47	34	25	E	E	NE	13	13	11
4:00 AM	-2	-2	-1	-11	-15	-15	51	37	34	ENE	E	NE	15	17	9
5:00 AM	-3	-2	-2	-11	-15	-15	55	37	37	E	E	CALM	19	17	0
6:00 AM	-2	-3	-3	-11	-15	-15	51	40	43	E	E	CALM	15	15	0
7:00 AM	1	-4	-4	-11	-14	-15	41	46	43	E	NE	CALM	13	11	0
8:00 AM	4	-4	-2	-11	-14	-6	33	46	74	ESE	ENE	CALM	19	6	0
9:00 AM	6	-1	-1	-13	-13	-4	25	40	80	E	E	CALM	19	15	0
10:00 AM	8	2	3	-13	-13	-3	22	33	65	E	ENE	CALM	9	11	0
11:00 AM	9	5	6	-8	-13	-4	30	26	49	ESE	E	E	15	15	11
12:00 PM	10	7	8	-8	-14	-3	28	21	46	NNE	E	ENE	11	19	9
13:00 PM	10	9	9	-8	-10	-3	28	25	43	NW	ESE	E	4	15	7
14:00 PM	10	11	11	-8	-10	-4	28	22	35	NNE	SE	N	6	19	11
15:00 PM	10	11	13	-8	-10	-5	28	22	28	SSE	ENE	N	6	11	6
16:00 PM	8	13	14	-8	-10	-5	32	20	27	NNE	E	NNE	4	15	13
17:00 PM	7	13	13	-7	-10	-5	37	20	28	NNE	SSE	NW	7	19	9
18:00 PM	6	12	11	-6	-10	-4	42	19	35	NE	NNE	NW	11	11	15
19:00 PM	3	9	9	-7	-9	-5	4	2	3	N	NE	WNW	7	7	1

							8	7	7						3
20:00 PM	1	7	8	-10	-8	-5	44	34	40	SSE	ENE	CALM	11	15	0
21:00 PM	0	6	8	-10	-8	-5	47	36	40	E	ENE	ENE	9	11	13
22:00 PM	-1	4	7	-11	-10	-5	47	36	43	E	E	ENE	11	11	6
23:00 PM	-1	3	6	-12	-15	-4	44	26	49	E	SSE	ENE	9	13	6

Source: Researchers' work based on wunderground

5- Discussion

The phenomenon of frost is one of the serious problems that hinder the cultivation of citrus and olive crops in the north of the Kingdom of Saudi Arabia and limits their productivity; As frost waves wipe out vast agricultural areas suddenly and quickly, leading to severe economic and social disasters for private owners and investors. Under conditions of general climate change, there will be a negative impact on agriculture, through variation by season and region. There is a risk of production losses, since they are long-lived trees, adapting to climate change through varieties is also a challenge. However, climate models and geographic information systems can help match citrus trees to potential future climate scenarios and open up opportunities for production in new areas or the development of protection methods in existing areas. Finally, knowledge gaps related to tropical fruit trees and climate change must be urgently addressed to build agricultural systems that are resilient to climate change. Thus, climate change is likely to affect the growth and development of many fruit crops in arid and semi-arid regions. To mitigate the damage caused, information on specific climatic conditions and interactions must be established, and farmers' capabilities developed to predict frost waves before they fall.

6- Recommendations

(a) Removal of vegetation and weeds from citrus groves; The earth absorbs a large amount of sunlight during the day, and then allows it to emanate in the evening, with the aim of creating a warm zone inside the orchards, which reduces the occurrence of frost, or reduces its damaging effects.

(b) Since much of the study area is open and often has a flat surface, it is preferable to use plant hedges such as some types of olives; This is to reduce the flow of cold air into the orchards.

(c) If citrus trees sustain frost damage, do not prune away dead wood or remove the trees in early spring. Wait several months in order to assess the full extent of the damage and to allow the trees to recover during warm weather. As new foliage begins to grow in the spring and early summer, frost-killed twigs and branches will become readily apparent and can be pruned out without removing viable portions of

the tree. Postpone heavy pruning until the following year, so that the trees are able to regain their full canopy.

(d) The mixing of the air layer near the soil surface with the layers a few meters above the soil can reduce the risk of frost. Air mixing fans can be used, and they are distributed in the form of points inside orchards, and this helps the possibility of using clean energy, such as solar energy, which is less expensive.

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