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Analysis of Frost Probabilities in Aydın, Türkiye

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ABSTRACT

Frost events are of particular importance for plants. Its occurrence determines growing season. Early or late frost events may cause injuries and damage in plants which have not yet entered dormancy in fall/winter, and for plants in flowering period in winter/spring. Global average temperature increase has been accompanied by changes in extreme temperature events. Observations have shown that there has been a decreasing pattern in frequencies and intensities of frost events. In this sense, it is aimed in this study to analyse probabilities of frost occurrences within the latest 30-year climatic normal period, from the cold period of 1991-1992 to that of 2020-2021, at five locations (Aydın, Kuşadası, Nazilli, Söke ve Sultanhisar) in the province Aydın, western Türkiye. Six frost indices were selected, and three temperature thresholds to define frost were considered when daily minimum temperature (TMIN) being equal to or less than 0.0, -1.2 or -2.3°C.The selected frost indices are first fall frost (FFF), last spring frost (LSF), frost period (FP), number of frost days (NFD), dates of frost occurrences (DFO) and consecutive frost days (CFD). The results revealed that Nazilli and Sultanhisar are characterized by the highest probabilities of frost in terms of frequency, intensity and duration, along with the earliest occurrence of first fall frost and latest occurrences of last spring frost, and with longest duration of frost period. On the other hand, Kuşadası and Söke have opposite characteristics in comparison to Nazilli an Sultanhisar. Aydın lies in between them. The results are expected to provide information to schedule the agricultural activities, and to avoid detrimental impacts of frost events.

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Introduction

Temperature has a control on growth, development and yield of crops (Hatfield and Prueger 2015). Very low (below freezing) temperatures can cause formation of ice crystals within or between cells, causing physical damage and triggering physiological problems (Inouye, 2000), and eventually resulting in yield loss (Luo 2011; Piticar, 2019). Early frosts in fall/winter can cause significant damage, especially in plants that have not yet entered dormancy (Garcia-Martin et al., 2021). Late frosts during flowering period can harm the blossoms, and total crop failures can occur (Chmielewki et al., 2004). As frost can limit plant growth period (Inouye 2000), apart from other definitions (see, e.g, Walther and Linderholm, 2006), the duration between the dates of last and first occurences of frost is defined as climatological growing season (Robeson, 2002; Menzel et al., 2003; Kukal and Irmak, 2018), in which last and first dates of frost are start and end of climatological growing season, respectively.

Global average temperature (land and ocean combined) increased by 0.85°C from 1880 to 2012, and this warming has been accompanied by the changes in extreme temperatures (IPCC, 2013). Both minimum and maximum temperatures increased, but minimum temperature increased faster than maximum temperature over global land areas since 1950 (Vose et al., 2005). As a result of increased minimum temperature, decreases in frequency and intensity of frost events have been observed worldwide, e.g., in USA (Anandhi et al., 2013a; Anandhi et al., 2013b), in Chile (Piticar, 2019), in the Iberian Peninsula (Garcia-Martin et al., 2021), in Argentina (Fernandez-Long et al., 2013), in China (Wang et al., 2021). Increases in minimum temperature and decreases in frost events were also observed In Türkiye (Abbasnia and Toros, 2020).

Given the fact that frequency of frost events has changed, it is aimed in this study to assess probabilities of frost occurrences over the latest 30-year climatic normal period (from 1991 to 2020), with use of various frost indices and considering three temperature thresholds to define frost when daily minimum temperature (TMIN)

being equal to or less than 0.0, -1.2 or -2.3°C. The selected frost indices are first fall frost (FFF), last spring frost (LSF), frost period (FP), number of frost days (NFD), dates of frost occurrences (DFO) and consecutive frost days (CFD). The results are expected to helpful for farmers or agricultural practitioners to schedule the agricultural activities, and to avoid detrimental impacts of frost events.

Materials and Methods

The study area, Aydın, is located in western Türkiye. The neighboring provinces are İzmir in the North, Manisa in the Northeast, Denizli in the east and Muğla in the South. Aegean Sea lies in the West. It is located between the latitudes 37° 44' to 38° 08' N and longitudes 27° 23' to 28° 52' E (Anonymous, 2013). Typical mediterranean climate is dominant, with hot and dry summers and mild and rainy winters.

Daily minimum (TMIN) temperatures recorded during the period from 1991 to 2021 at 5 weather stations operated by State Meteorological Agency of Türkiye were used. The stations are listed in Table 1, and shown on a map in Figure 1. TMIN data was subjected to a careful quality control procedure to detect missing data. Missing data were less than 0.15% at any station. Missing data were filled by using data of neighboring stations with simple linear regression (Hu et al., 2012). Annual mean series of TMIN were examined for homogeneity using the double mass curve method and no apparent breakpoint was detected (Hu et al., 2012).

In this study, three frost related thresholds were defined, in which TMIN is less than or equal to 0.0,-1.2 and -2.3°C. The definitons adopted were based on World Metetorological Organization (WMO) definitions (Rahimi et al., 2007), mild frost (-1.2°C <TMIN≤0.0°C), moderate frost (-2.3°C <TMIN≤-1.2°C), and severe frost (TMIN≤-2.3°C) (Rahimi et al., 2007). The selected frost indices are first fall/winter frost (FFF), last winter/spring frost (LSF), frost period (FP), number of frost days (NFD), date of frost occurrence (DFO), and consecutive frost days (CFD). FFF is the date when TMIN is less than or equal to the threshold for the first time in fall or winter. LSF is the last date in winter or fall when TMIN is less than or equal to the threshold. FP is the duration from FFF to LSF for any threshold. NFD is the number of days when TMIN less than or equal to the threshold. DFO refers to dates when TMIN less than or equal to the threshold. CFD is the number of days when TMIN less than or equal to the threshold successively. They are determined for three thresholds at each station and each cold season during the latest normal period (from 1991-1992 to 2020-2021). The 10%, 30%, 50%, 70% and 90% probabilities corresponding to each threshold were computed using Weibull method (Didari et al., 2012):

$$P=\frac{m}{n+1}$$

Where;

P: the probability
m: data rank
n: number of data.

Table 1. The list of the stations and their geographical coordinates.

Station No	Station Name	Latitude	Longitude
17234	Aydın	37° 50′ 24.7′′	27° 50′ 16.4′′
17232	Kuşadası	37° 51′ 34.9′′	27° 15′ 54.7′′
17860	Nazilli	37° 54′ 48.6′′	28° 20′ 37.3′′
17881	Söke	37° 42′ 17.6′′	27° 22′ 57.7′′
17850	Sultanhisar	37° 53′ 03.5′′	28° 09′ 01.4′′

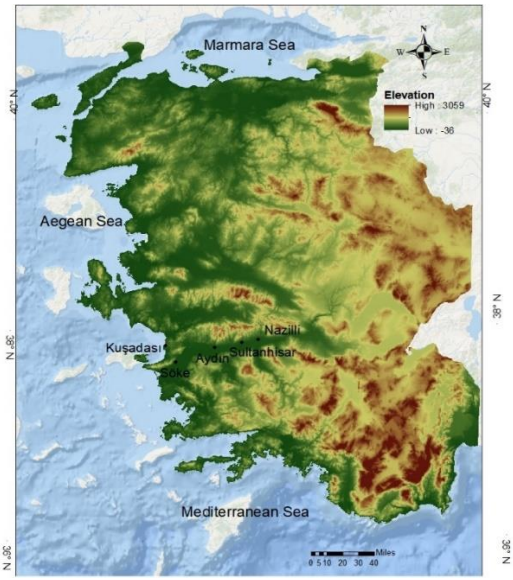

Figure 1. Locations of the stations

Results and Discussion

Figure 2 presents the dates and probabilities associated with FFF, in which any date indicates the probability of TMIN being less than or equal to the threshold for the first time in fall or winter on or before that date. As an example, for Aydın, the threshold 0.0°C and 10% probability, the corresponding date is Julian day 329 (November 25). It means that there is 10% probability that TMIN being less than or equal to 0.0°C occurs for the first time on or before Julian day 329 (November 25). Figure 2 firstly manifests that there is a spatial trend on the occurrence date of FFF, from inland to the coastline. FFF occurs earlier in inland stations than the stations more close to Aegean Sea. The earliest FFFs occur at the farthermost station from the coastline, namely Nazilli. The latest FFFs occur at either Kuşadası or Söke, which are the nearest stations to the Aegean Sea. This spatial pattern can be shown, for the sake of simplicity, using the the dates of occurrence at 50% probability as follows. At the farthest station from the sea (namely, Nazilli), FFF occurs on or before Julian days 342 (December 8), 349 (December 15) and 356 (December 22) for the thresholds 0.0,-1.2 and -2.3°C, respectively. The corresponding dates at the second and third farthest stations from the sea (namely, Sultanhisar and Aydın, respectively) are Julian days 344 (December 10), 359 (December 25) and 1 (January 1), and Julian days 357 (December 23), 365 (December 31) and 9 (January 9), respectively. It follows that climatic growing season, if based on frost occurrence, ends earlier at inlad stations. Fruit trees grown at the inland stations experience frosts earlier than those at the coastal stations.

The dates associated with LSF are shown in Figure 3, in which for a given threshold and probability, any date in the Figure represents the last occurence of TMIN being less

than or equal to the threshold on or after that date. As a specific example, at the station Aydın with the threshold of-1.2°C and probability of 70%, the date is Julian day 25 (January 25). It represents that the probability of last occurrence of TMIN (≤-1.2°C) on or after Julian day 25 (January 25) is 70%. Figure 3 indicates that LSF might occur before January. There is 10% probablity that LSF occurs before the end of December at Kuşadası and Söke. Even, there is 10% probability that LSF might occur after fourth quarter of March, e.g, in Aydın after Julian day 84 (March 25) for the threshold 0.0°C, even after Julian day 99 (April 9) in Sultanhisar for 0.0°C. At 50% probability, LSF takes place mostly during February, which means that frost period ends during February at 50% probability.

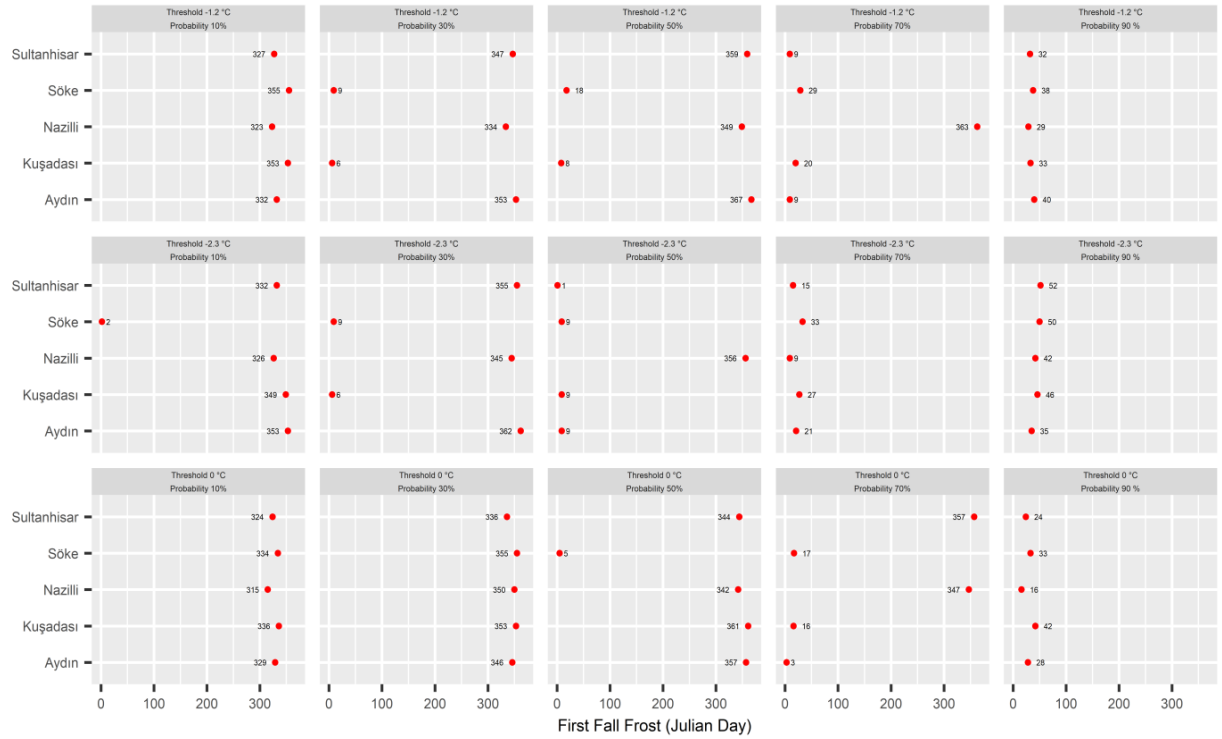

Figure 2. The dates of occurrences of first fall frost (FFF) with various probabilities, when TMIN being equal to or lower than threshold, on or before that date

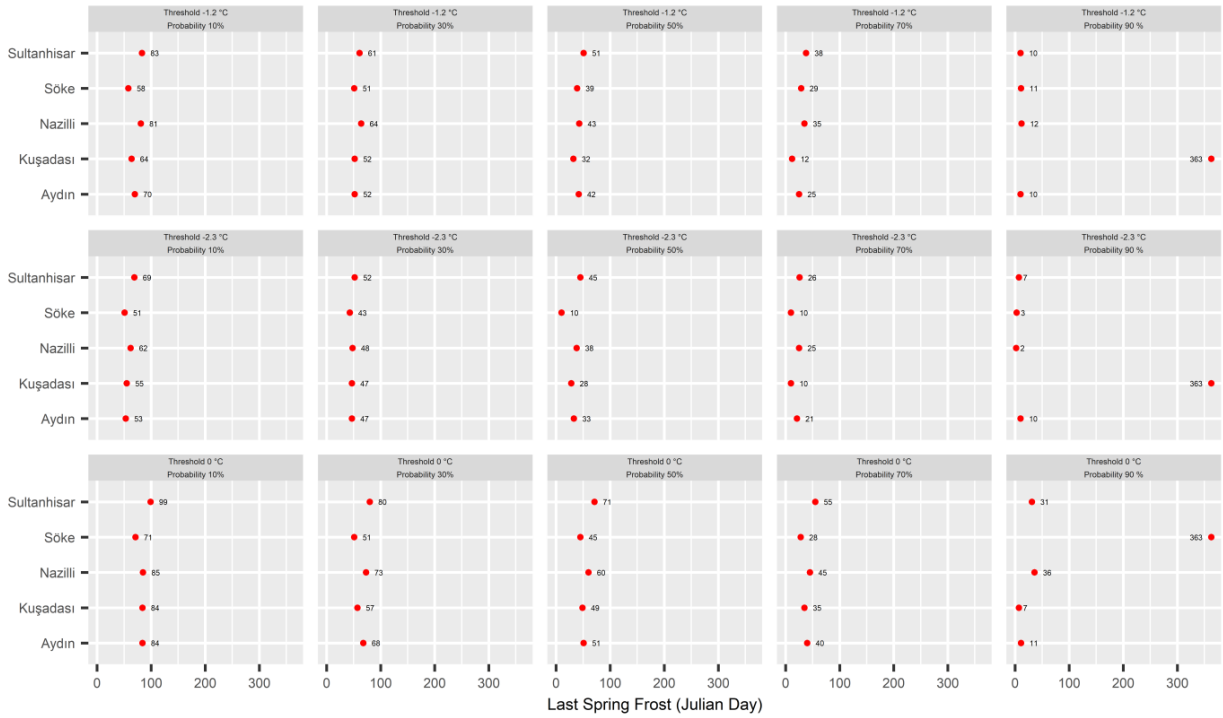

Figure 3. The dates of occurrences of last spring frost (LSF) with various probabilities, when TMIN being equal to or lower than threshold, on or after that date

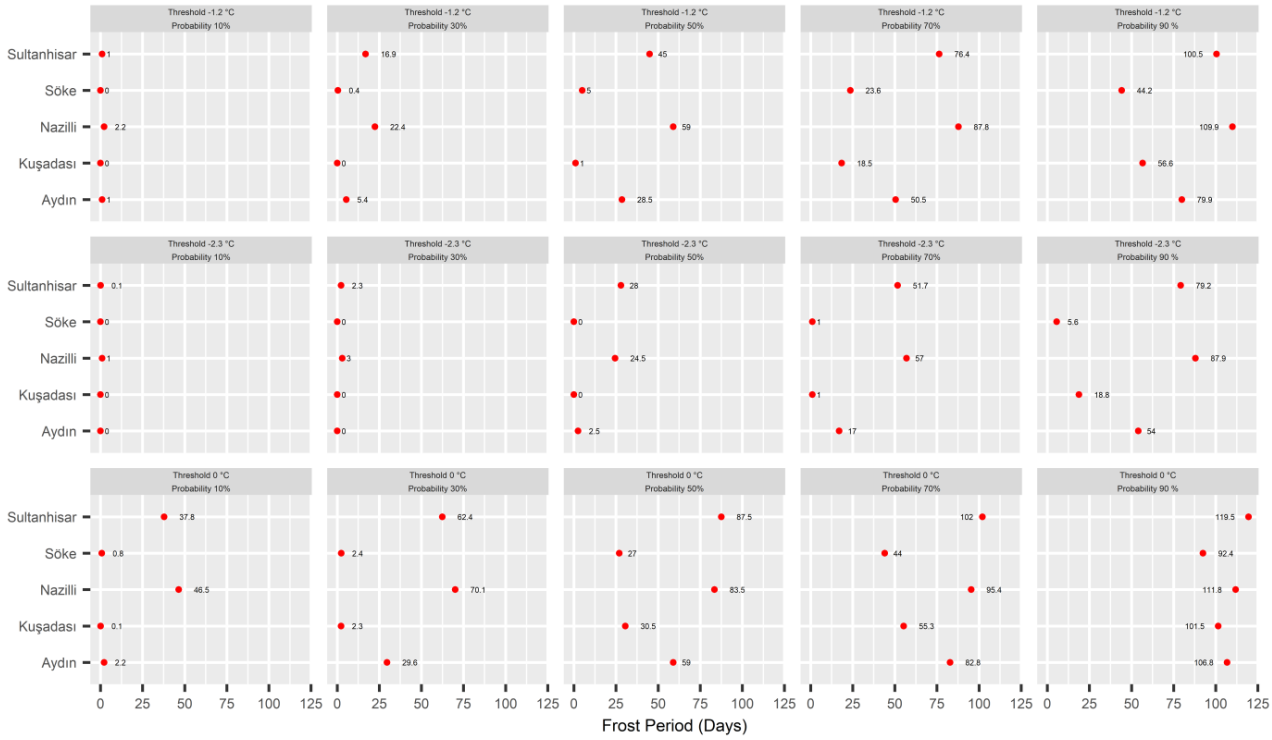

Figure 4. Periods of frost in days less than or equal to the indicated figure, with various probabilities and thresholds.

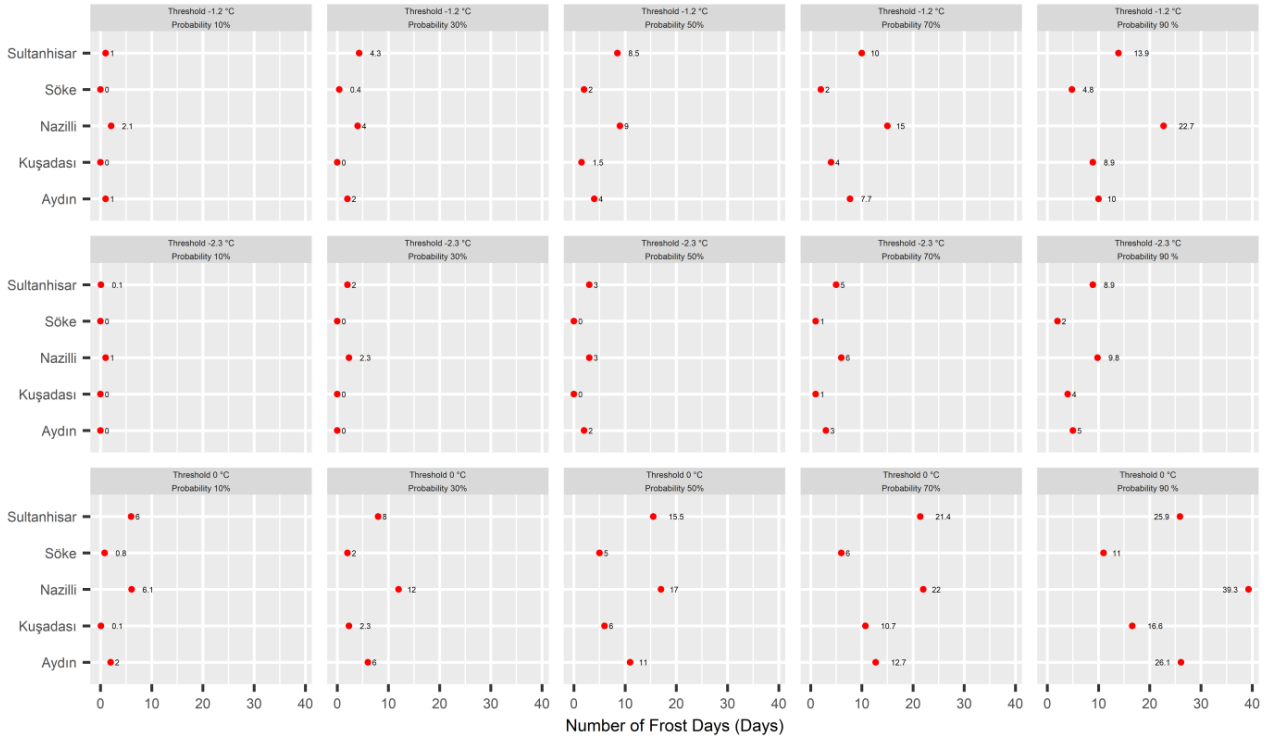

Figure 5. Number of frost days less than or equal to the indicated figure, with various probabilities and thresholds.

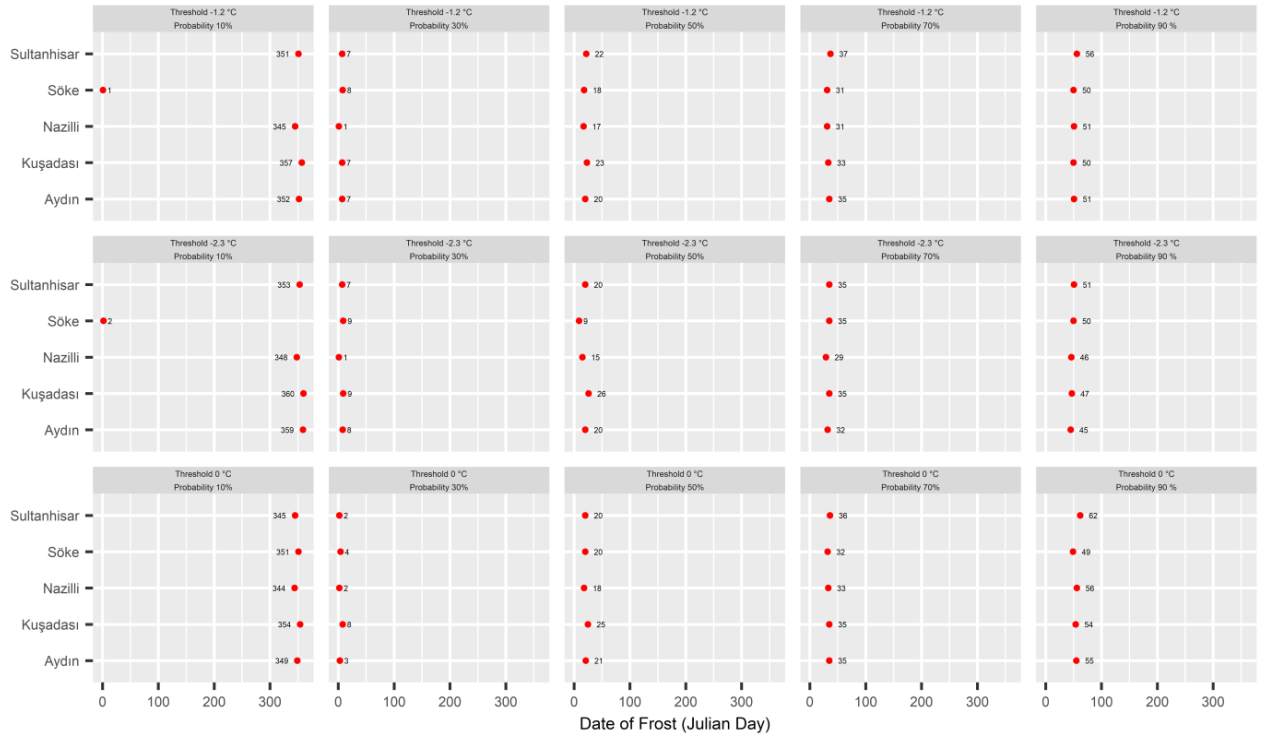

Figure 6. Dates of frost associated with various probabilities, based on the occurrences of TMIN being less than or equal to the threshold.

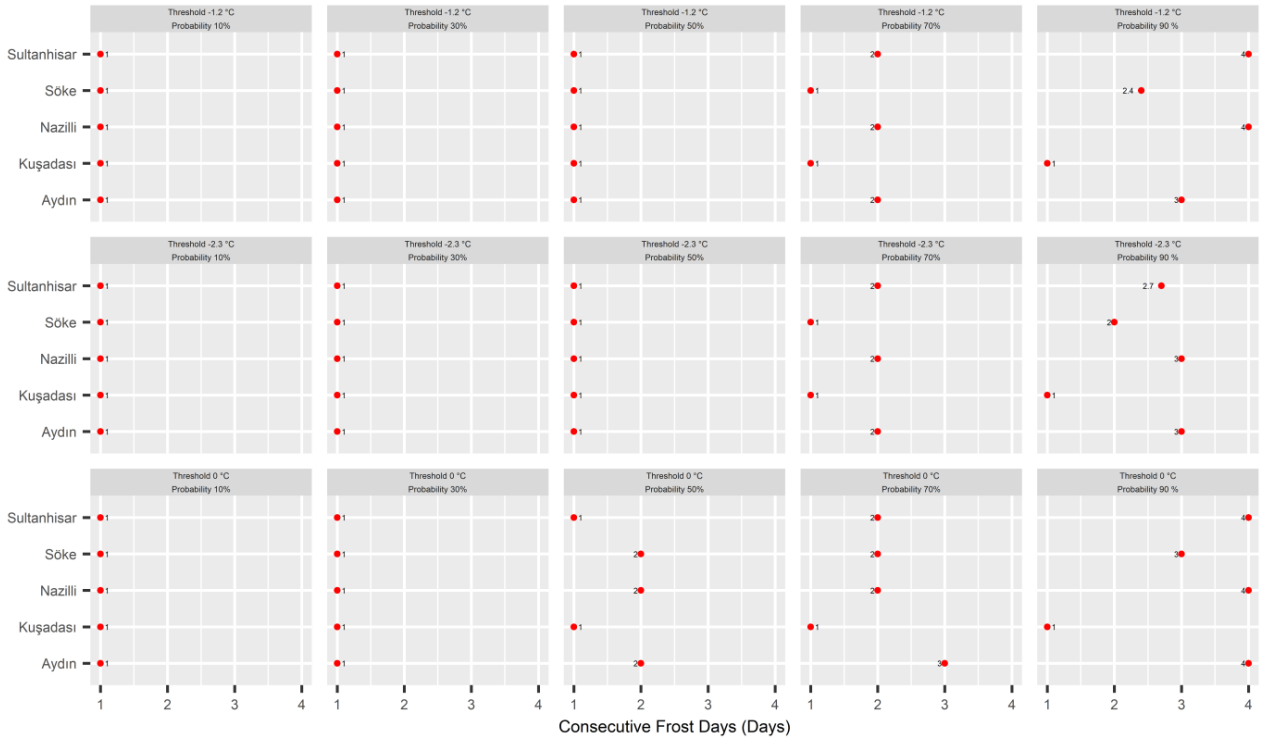

Figure 7. Number of consecutive frost days less than or equal to the indicated figure, with various probabilities and thresholds.

Figure 4 presents duration of frost periods with various probabilites, calculated based on FFF and LSF given in Figures 2 and 3. Frost period is the duration from FFF to LSF. The rest of the year is frost-free period (FFP), from LSF to FFF. Any figure with the corresponding threshold and probability in the Figure represents that FP lasts those days or less. As an example, at Aydın with the probability 70% and the threshold -2.3°C, the period is 17 days. It means that FP lasts 17 days or less with 70% probability, from FFF to LSF when TMIN≤-2.3°C. The shortest FPs for all thresholds are generally observed at Kuşadası or Söke. FP lasts 2 days or less at 30% probability at these stations for any threshold. On the other hand, the longest FPs for all thresholds generaly occur at Sultanhisar or Nazilli.

The probabilities of number of frost days (NFD) are given in Figure 5. Any NFD value in this Figure indicates that TMIN falls below or equals to the threshold that days or less at that probability. For example, for the station Nazilli, the threshold -1.2°C and the probability 70%, NFD is 15 days. It means that TMIN falls below or equals to -1.2°C at15 days or less at the probability of 70%. As the threshold temperature decreases, for any given probability, NFD also decreases. It follows that more severe frosts take place less likely, in comparison to milder frosts. For example, at Aydın and at 50% probability, while TMIN is equal to or less than 0.0°C for 11 days, it is equal to or less than -1.2 and -2.2°C for 4 and 2 days, respectively. Lowest frequencies of frost events belong to Kuşadası and Söke. These sites do not experience any frost with any strength at no more than 6 days. On the other hand, Nazilli experiences the highest number of NFD for all threholds

Figure 6 reveals the probabilities associated with frost dates. Any given date in the Figure is the date when TMIN is less than or equal to the threshold before the indicated date at the correspoding probability. Julian day 2 (January 2) is read from Figure 6 for Söke with the threshold -2.3°C and probability 10%, meaning that TMIN is equal to or less than -2.3 C with a probability of 10% on or before January 2. As the threshold decreases from 0.0 through -2.3°C, the date of occurrence takes place later for lower probablities than 50%, and earlier for higher probabilities than 50%. This is a direct consequence of temparature avolution during a year. As approaching mid-winter, temperatures get colder and the probability of occurrences of lower temperature increases. Then, after mid-winter, toward spring, as temperatures increases, the probabilty of occurrences of low temperatures decreases. Spescifically, at Aydın, at early winter, while 10% of all TMIN≤0.0 takes place on or before Julian day 349 (December 15), the corresponding dates are 3 days later (December 18) for TMIN≤-1.2°C and 10 days later (December 25) for TMIN≤-2.3°C. Similarly, at Aydın, at late winter or early spring, while 90% of all TMIN≤0.0 occur on and before Julian day 55 (February 24), the corresponding dates are 6 days earlier for TMIN≤-1.2°C, and 10 days earlier for TMIN≤-2.3°C.

The probabilities asscoiated with consecutive frost days (CFD) are shown in Figure 7. The days in the Figure indicates that TMIN is less than or equal to the threshold consecutively for indicated days or less. As an example, in Aydın, CFD is 3 days for 70% probability and for TMIN≤0.0°C. It means that there is 70% probability that TMIN is less than or equal to 0.0°C for consecutive three days or less. At 50% probability, consecutive frosts generally last one or two days, even mostly single-day events. Frosts that occur consecutively for more than 2-days for all TMIN thresholds are possible at 30% in Aydın, Nazilli and Sultanhisar. These stations may experience frost events consecutively for more than 3 or 4 days at 10% probability. The lowest probabilities are observed at Kuşadası, followed by Söke. In Kuşadası, no frost event occurs in consecutive 2 days at 90% probability, and the probability of consecutive frost days that last more than 1 day is 10%. Söke has higher probability of frost that may last consecutively for more than 2 days in comparison to Kuşadası.

Conclusions

- Onsets of FFF and LSF vary considerably among stations. FFF (LSF) generally takes place earlier (later) in inland stations than in coastal stations. FFF (LSF) occurs as early as before first half of December (in Lanuary), and as late as in February (in April). The longest FPs are observed in Nazilli, with even more than 100 days for the threshold 0.0 °C. The shortest FP takes place in Kuşadası and Söke, even none at 50% probability particularly at lower thresholds.
- Frosts at higher temperature thresholds occur more frequently than the lower thresholds. The highest number of frost events in a year occurs in Nazilli, followed by Sultanhisar. Coastal stations (Söke and Kuşadası) have the lowest frost frequencies.
- Frosts are mostly single-day events accross the study area, particularly in Kuşadası and Söke. Frosts which may take place consecutively 3 days or more are rare, with the probability of less than 30%.
- Among the stations in this study, Nazilli is the station which is the most exposed to frost events in terms of frequency, intensity and duration, followed by Sultanhisar. Plants at these sites need more protection against frost.
- Kuşadası and Söke have the most favourable conditions in terms of frost events, with the least frequency and intensity as well as the latest FFF, earliest LSF and shortest FP.

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