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Analysis of Frost Damage Risks in Peach Orchards around Tokat, Turkey

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Abstract

The aims of this study were: i) to introduce a developed frost risk analysis model, ii) to test the model for the peach orchards located around the Tokat city for the last 35 years, and iii) to measure the frost damage prediction performance of the model with the measured peach yield data from 1972 through 1977. The model uses hourly temperature data and dates of bud development stages to predict damages due to late spring frosts, and then, to estimate the yield in percentage. The hourly temperature data and the dates of bud development stages of peach (J.H. Hale) tree for the growing period of 1972 through 2007 (except 1995) were obtained from the Turkish State Meteorological Service. The model produced frost damages in 13 years out of 35 (37%) for the orchards around Tokat. In 12 of 13 years, the damage rates were higher than 57%. Furthermore, the yearly average peach yields measured in a research study carried out at the Research Institute of Soil and Water Resources in Tokat were compared with those predicted by the model to validate the performance of model. An 8.7% average difference between the measured and predicted yield was found.

Key words: frost risk model, late spring frost, bud development stage

INTRODUCTION

The peach is one of the fruit species, which blooms early in spring. Its buds are very sensitive to the late spring frosts [1]. In Tokat province there are about 20 peach varieties that are common and economically valued [2]. Günbatılı [2] also states that more than 3 tons yield from one-tenth of a hectare could be obtained with a normal growing condition. According to the State Institute of Statistics Prime Ministry Republic of Turkey [3], the number of bearing peach trees was 359,550 in 2003. Furthermore, from the statistics of Tokat City Agricultural Directorate, the peach orchards in the province cover about 1,122 ha.

In the orchards around Tokat city, frosts are rarely controlled by frost protection methods such as fans or wind machines, heaters, sprinkler irrigation, or any combinations of them. However, in some valleys such as the lower valley of Chubut river in Argentina, the percentage of frost protected peach orchards by over-plant sprinkler irrigation is around 57% [4]. Installation and managing of these measures are expensive, and deciding which one of them can be effective requires the types (advection, radiation or both) and frequencies of the frost events occurring in the province. For instance, a sprinkler frost protection system designed for protection of peach buds during spring frosts (bud temperatures in the range of -3 or -6.7 ^{o}C) will not assure the grower to protect from frost damage [5, 6]. In addition, we may need how far the temperature is dropping below 0 ^{o}C in these events.

Plant response to frost depends on plant type and variety, tissue maturity, size of crop and pruning history, rate of temperature drop, minimum temperature, length of time that the tissue remains at the minimum temperature [7] as well as phenological stage of development which is a function of temperature history to which the plant has recently been exposed. In spring with increasing temperature, vegetation process and bud development start in peach trees satisfied with enough chilling requirement. The hardness of buds to cold diminishes as the development progress. The continuous low weather temperature in early spring decreases the speed of bud development, causes late flowering. This increases the bud hardiness against frost. However, if the weather temperature continues over normal, the speed of bud development increases. This results with early flowering. If a sudden cold air hits the orchard during the developed bud stage, frost injury may become serious level [8]. In addition, bud temperature can be higher than air temperature during calm daylight times. This difference may diminish when wind speed arrives 7 m/s. Furthermore, on a clear cloudless calm night, the bud temperature can be 3-5 ^{o}C lower than air temperature due to heat loss by radiation from bud.

In Logan et al. [5], analyses of long-term (1951-1989) daily temperature data from four locations in Tennessee were used to evaluate the frost risks for ‘Redhaven’ peach tree buds. In this study, the actual dates of frosts with air temperature at or below -2.2 ^{o}C and the estimated bud developmental stage on the date of each frost were determined using the model they developed. The model was tested using peach orchard frost records. They determined the locations having the highest or lowest frost risk for peach growing. On the other hand, Cittadini et al. [4] developed a comprehensive method to quantify frost damage risk in different sweet cherry production areas of South Patagonia and to estimate the potential impact of frost control systems on risk reduction. The authors assumed frost damage for any specific day occurs when the minimum temperature on that day is below the specific lethal temperature for the phenological stage predicted at that moment. In their study, frost damage risk was compared for cultivars and locations. In addition, the MS Excel Damage Estimator application program-DEST.xls [9] can be used to compute the expected frost damage and the yield, using site-specific maximum and minimum temperatures for the crops having no protection against frost and for the crops having protection up to 11 different frost protection methods. In this program, the critical temperatures associated with 90% (TC_{90}) and 10% (TC_{10}) damage and their corresponding specific phenological dates are input.

Especially during the last decade, the late spring frosts on the orchards around Tokat city have caused severe yield variability from year to year. Lately, many peach orchard owners deserted peach growing and started to grow alternative species especially at the locations which are level and close to the Yeşilırmak river bed. This is may be due to fact that frost risk is high at the floor of Yeşilırmak valley since air temperatures measured especially during cold calm clear nights are lower than those measured at hillside [10]. This kind of unusual temperature variation in the atmosphere is called temperature inversion. In this condition, the temperature of atmosphere layer at about 30-35 m is higher than those of lower layers of atmosphere. The temperature of this layer can be 4-4.5 °C higher than that of air above 1.5 m from soil surface [10]. Furthermore, Koc et al. [11] found the coldest temperatures at the ground level, a few degrees higher with lower bud and at 1.5 m, and the warmest temperatures at the upper bud level. During this type of frost conditions, the orchard temperature can be increased using wind machines by mixing the air in these layers having different temperatures [12].

Considering the yearly required investment for a peach orchard without guaranteed yield, the question arises is that whether the peach growing at the orchards around Tokat city is still being a profitable agricultural investment. Knowing the probability and risk of frost for peach trees around Tokat is important because it helps farmers to decide whether and what species or varieties to plant at their particular locations. Therefore, searching the frequencies of these frost events occurred in the past and predict their damage rate was found a valuable research issue in this study. To carry out this aim, a computer program (model) was developed to predict frost damage due to late spring frosts for peach using the records of hourly average air temperature and the dates of phenological bud development stages measured in the past.

MATERIALS AND METHODS

The Tokat province (36°34' east longitude 40°18' north latitude, and mean altitude of 650 meter from sea level) located in the interior part of Middle Black Sea Region of Turkey. The climate of province is a characteristic of transition between the Black Sea and steppe Interior Anatolia climates. Considering the last 54 years climatic data records observed in Tokat city meteorological station, the coldest month is January with 1.9 °C average temperature and the hottest month is August with 22 °C. The annual average precipitation of the city is 456.4 mm [13]. In average, the early autumn frosts occur at the end of October and the late spring frosts occur at the beginning of April.

The soils at the floor lands located in the flood plain of Yeşilırmak river bed were developed in an alluvium over lacustrine materials [14, 15]. The soils at the hillside lands are brown forest soils. The chestnut, colluvial and reddish chestnut soils take place in the lands between floor and hillside [14]. Most of the peach orchards (about 60%) around Tokat city were established on the lands between floor and hillside with average slopes between 2 and 25%. The peach orchards at the floor lands (slope between 0-2%) occupy about 10%. Furthermore, the general slope around the city is in the direction from east to west, in the direction of Yeşilırmak river flow. The topography at the hillside lands is generally undulating and complex at some sections. The peach orchards had been become dense at the elevations between 550 and 700 m in the Yeşilırmak valley. Gerçekcioğlu [16] states that about 90% of the peach orchards around Tokat city are located at the north of Yeşilırmak river. He also reported that about 75% of the peach varieties in the orchards are J.H. Hale.

Critical temperature depending on plant variety and stage of development is the temperature below which, of the plant parts held for 30 minutes, a percent will be killed [17, 11, 6]. These temperatures for the plants are determined in freezing chambers which can not adequately emulate radiant cooling of buds [6]. In the chambers, generally air and bud temperature is close to each other, however, as stated before during radiation frosts, depending on the height of bud from soil surface or the level of air temperature measurement in a standard weather station temperature, the differences between air and bud temperatures can be 3-5 °C. The model does not consider radiant cooling of buds. Improvement of the model by estimation of bud temperature from air temperature by considering the heat balance of a bud with radiant cooling [18, 19] will be studied further.

In this study, a computer program in FORTRAN was developed to estimate frost damage for peach trees. In the program, the concept of frost risk was acknowledged in the spread of 30 minutes air temperature among 10, 50 and 90% kill critical temperatures (TC_{10}, TC_{50} and TC_{90}, respectively). The model uses hourly average temperature and assumes same temperature value for both 30-minute halves of an hour. The model reads hourly temperature data from an input data file. The model needs at least one of the dates for the phenological development stages of full bloom or fruit set. To estimate the unknown dates of other bud development stages, the model employs the mean day differences among observed bud development stages in Tokat by different associations (Tokat Meteorological Station, Tokat Garden Cultures Station, Tokat Agricultural Province Directorate, Gaziosmanpaşa University-Gerçekcioğlu and Köksal [20], Filiz [21], Gerçekcioğlu [22]). The determined day differences among the bud development stages for Tokat province are 10- for the first swelling-calyx green, 6- for the calyx green-calyx red, 5- for the calyx red-first pink, 4- for the first pink-first bloom, 6- for the first bloom-full bloom, 20-days for the full bloom-fruit set, and equal interval from post bloom to both full bloom and fruit set. Furthermore, if user of the model does not have the dates of bud development stages of peach, a chilling model such as the one by [23] to predict these phenological dates for peach and apples can be employed. As given in Table 1, in the model the eight peach bud development stages with the critical temperatures of TC_{10}, TC_{50} and TC_{90} are used, which are given by Logan et al. [5]; Ballard et al. [24] and Ward [25]. Since ripe fruit with higher sugar content may resist cold temperatures slightly better than young green fruit [17], one week after fruit set, it is assumed that the plant is not under frost damage. In the model, the hourly temperatures during bud development stages starting one week earlier than the date of first swelling and ending one week later than the fruit set stage [5] (analysis period) are used for the analysis of frost risk. The frost damage (in unit of percentage of yield loss) for 30 minutes of any hour on any specific day of the analysis period is assumed to occur on that day when the hourly air temperature is at least lower than the TC_{10} determined by linear interpolation for the TC_{10}s of phenological stages predicted at that moment. The degree of frost damage is determined by the following steps: i) determine the phenological stage or stages the specific day is between them; ii) determine TC_{10}, TC_{50} and TC_{90} for the specific day by linear interpolation between the TCs for the determined stages in the previous step; iii) if the temperature is lower than the TC_{90} of specific day determined in the previous step, assume 90% damage; if it is higher than the TC_{10}, assume no damage; if it is between TC_{10}-TC_{50}, use linear interpolation between the percentages of 10 and 50; use similar interpolation if it is in the interval of TC_{50} and TC_{90}. In this analysis, frost damage was assumed to be multiplicative as used by [9]. The values of calculated frost damages with their occurrence hours, days, and months; number of damaged frost events with their occurrence stages; and cumulative yield losses are written into an output file.

The measured peach yields (trial subject D-irrigate when available moisture content decrease to the level of 65% for the soil depth of 0-90 cm, this subject was chosen since the highest yields were obtained from this subject during the analysis period except 1974) by Günbatılı [2] during the years of 1972 through 1977 were used for preliminary validation of the model performance. We assumed that the yield variation in the years is due to damages by freezing. The percentage of measured yield for each year was obtained by dividing the total yield of each year to the maximum yearly yield (1,244.5 kg from 300 m^2) obtained in 1976. The field trial of Günbatılı had been done in the orchard of Research Institute of Soil and Water Resources in Tokat with the old name of TOPRAKSU. The institute was located almost at the floor of Yeşilırmak valley with elevation of 585 m (12 km distance and 23 m lower to/than Tokat weather station). Furthermore, the orchard is located on the north aspect. For the years of field trial, we do not have hourly temperature data recorded at the institute. However, we have hourly temperature data for 2006. The linear regression equations between March and April hourly temperatures of Institute and Tokat weather station for the hours of 1, 2, 3, 4, 5, 6, and 7 were developed. The values of coefficient of determination (R^2) for these equations were between 0.79 and 0.92 (significant at the 0.001 level for two-tailed *t* test). These regression equations with hourly temperature data of Tokat city were employed in the model for this validation. Due to the aspect and elevation differences between institute and weather station and based on the differences between the dates of bud development stages observed in the gardens of weather station and the research and practice orchard of Gaziosmanpaşa University, Agricultural Faculty, Department of Horticulture (the orchards of both of university and institute almost have same aspect and elevation) in the year of 2007, the dates of bud development stages for the validation years were taken one week backward from those of test years.

RESULTS AND DISCUSSION

The mean and standard deviations for the dates of bud development stages of peach (J.H. Hale) trees around Tokat city were given in Table 2. The results are based on 35-year recorded data. The mean dates for both stages of full bloom and fruit set were based on observed dates in the weather station of Tokat. The dates of 33 of 35 years for the post bloom stage, 25 of 33 for the first bloom stage, 30 of 35 for the first pink stage, 31 of 35 for the calyx red stage, 32 of 35 for the calyx green, and 26 of 35 for the first swelling stage were predicted. The standard deviation value for the mean dates of bud stages is about one week. The longest duration was predicted between the stages of post bloom and fruit set with 11 days. The durations between the first swelling and calyx green, and between the full bloom and post bloom are also high with the value of 9 days for both intervals. The values of these durations may change from location to location. For instance, Ballard et al. [24] indicated 10 days between the stages of first swelling and calyx green, 3 days between calyx green and calyx red, 10 days between calyx red and first pink, 5 days between first pink and first bloom, 8 days between first bloom and full bloom, and 7 days between full bloom and post bloom for Elberta peach trees at Prosser (Washington State University Research & Extension Center). Except the values for the stage of calyx red, the values obtained in Tokat region are similar to those of Prosser. It is needed to clarify that even though the dates in Tokat city given in Table 2 may not represent all the peach orchards around the city, it may represent better the orchards that are with south aspect and

Table 1. The peach (Elberta) bud development stages and critical bud temperatures (oC) for blossom buds

Property	Bud Development Stage							
	First Swelling	Calyx Green	Calyx Red	First Pink	First Bloom	Full Bloom	Post Bloom	Fruit Set
TC10	-7.77	-6.11	-5.00	-3.88	-3.33	-2.77	-2.22	-1.10x
TC50+	-12.14	-10.55	-8.89	-6.67	-4.26	-3.33	-2.78	-1.64
TC90	-17.22	-15.00	-12.77	-9.44	-6.11	-4.44	-3.88	-2.70x

x : from Özçağıran et al. [26] and Aküzüm et al. [27].

+ : Values for temperatures were obtained by interpolation between TC_{10} and TC_{90} for peach with the assumption that the critical temperatures of TC_{50} for apple (Golden Delicious) [28] follow same trend for peach.

located on slope of hill and at around the same elevation with the weather station of Tokat.

over sprinkler irrigation system has a potential to prevent frost damages in the peach orchards around Tokat city.

Table 2. Average dates, standard deviations and differences for the dates of bud development stages of peach (J.H. Hale) trees around Tokat city

Property	Bud Development Stage							
	First Swelling	Calyx Green	Calyx Red	First Pink	First Bloom	Full Bloom	Post Bloom	Fruit Set
Mean Date	7 March	16 March	22 March	27 March	31 March	6 April	15 April	26 April
Std. Dev. (days)	6.34	6.87	6.88	6.95	7.14	7.01	6.51	7.40
Difference(days)	- 9 - 6 - 5 - 4 - 6 - 9 - 11 -							

Running the model in hourly time interval in place of 30 minutes with the consideration of each frost event individual and independent from each other in place of multiplicative frost damage, the damage rate for each hour was calculated and depicted in Figure 1. From the Fig. 1, it is clear that most of the damaging events (78%) for 35-year analysis period produced 50% or less yield loss due to frost damage. To further search the degree of frost damages and possibilities to prevent from these damages by employing any frost protection method, the temperature differences from the temperatures of threshold TC_{10} at that moment were calculated and the histogram of them was given in Figure 2. Considering the data given in Fig. 2, for instance employing over sprinkler irrigation system with the potential increase of surrounding temperature about 3 ^oC may prevent about 95% of the hourly frost events. This indicates that

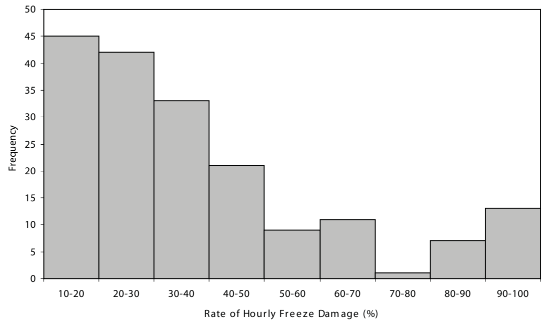

Figure 1. The histogram of hourly frost events causing damage on the peach trees at the orchards around Tokat, Turkey.

Table 3. The summary of predicted rates of frost damages and dates according to the bud d evelopment stages of peach trees around Tokat city for last 36 years (except 1995)

Year	Frost Damage (%)	# Frost Events	Bud Development Stage									
			Prior First Swelling	First Swelling	Calyx Gren	Calyx Red	First Pink	First Bloom	Full Bloom	Post Bloom	Fruit Set	Post Fruit Set
1972	62	6			22 22 March	40 26 March						
1982	97	20			97 26-27 March							
1983	100	22	100 5-6 March									
1985	77	10	77 9 March									
1986	100	42			97 1-2 March			2 17,20 March	1 21 March			
1987	100	56			97 14-16 March	1 20 March	1 21 March				1 26 April	
1990	99	14			99 17 March							
1997	100	14						100 10 April				
2000	62	4					62 25 March					
2001	23	2	23 21 February									
2002	58	4									58 10 April	
2003	100	88						97 22-29 March	3 30 March			
2004	100	28	54 8 March								46 4-5 April	

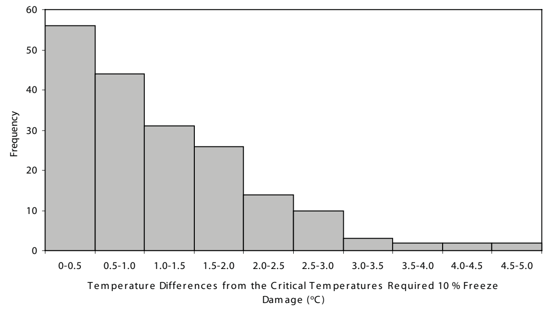

Figure 2. The histogram of temperatures causing yield loss due to each hourly frost events for 35 years analysis period for peach trees (J.H. Hale) in the orchards around Tokat, Turkey.

The results obtained by the model were summarized in Table 3. In the Table, the years for which frost damages estimated, the total rates of frost damages estimated for these years, the number of frost events based on 30 minute-time interval, the occurrence bud development stages of these events, the occurrence dates, and the rates of damages were given in Table 3. The model predicted frost damages in 13 years out of 35 (37%). In 12 years of 13, total damage rates are higher than 57%. The overall annual mean yield loss due to frosts was predicted as 31% (sum of all frost damages/3500). The highest numbers of frost events were estimated for the years of 1986, 1987 and 2003. The complete yield losses were estimated for these years. The first damaging event was estimated on 21'st of February in 2001 with 23% yield loss. The latest damaging frost event was estimated on the date of April 26 in 1987. Most of the events were predicted in the month of March. The numbers of events are randomly distributed among the bud development stages. While three events were seen prior to first swelling, no event was estimated after the stage of fruit set. The model also predicted the hours of the day of these frost events. The histogram for the event hours was given in examining these hours indicated that, almost all the frost events occurred during nights and mainly morning hours such as 4, 5, 6 and 7 am. These results may indica te that the frost damages of peach are mostly radiation caused frost. For further analysis to decide types of these frost events, hourly wind speeds recorded at the weather station of Tokat city during the hours the frost occurs can be analyzed.

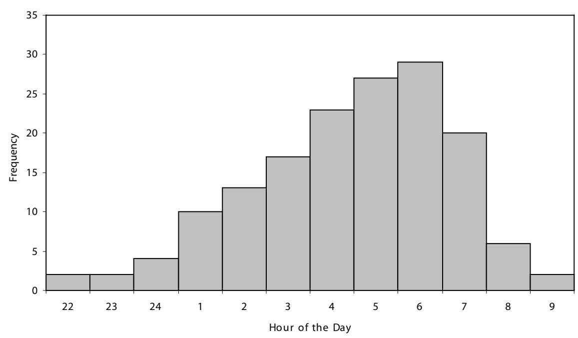

Figure 3. The histogram for frost occurrence hours of the day for 35 years analysis period of peach trees around Tokat city.

For the validation results of the model, the predicted and observed yield percentages with the differences between them were given in Table 4. For two years (1972 and 1976), the model prediction is accurate. For other two years of four (1973 and 1975), the model predictions are higher than those of observed. The highest differences were obtained in 1974 and 1977 with 13 and 26% prediction, respectively. Since all the frost events occurred during night, one of the reasons for under predictions may be due to radiant cooling of the bud. The other reason can be due to false predicted dates of bud development stages. However, considering the average values, it seems the performance of the model is good. We believe that the value of 8.7% difference seems a small value, therefore we may state that the model performance is adequate. Furthermore, the model performance can be better if all dates of observed bud development stages and weather data representative for the interested garden are used in the model. When we compare these results to those given in Table 3, while no frost damage was predicted in 1974, 1975 and 1977 under the weather conditions of Tokat, the frost damages were seen in these years under the weather conditions of Institute. In addition, the frost damage in 1972 increased at the Institute. This kind of result is may be due to frost pockets locating at the bottom of Yeşilırmak valley and around the Institute. This situation is further analyzed by computing average minimum yearly temperatures for the months of March, April and May by considering the minimum temperature records for these months of last 31 years. The average monthly minimum temperatures of March, April and May for the minimum temperature data measured at Tokat weather station are -5.4, -0.1, and 3.2, respectively. The temperatures for same months measured at the Institute are -7.9, -2.8, and 0.9, respectively. Considering the general knowledge that the minimum temperature of the day is seen at the morning hours of day such as 5 and 6 am which have the highest frost risks (Fig. 3), these temperature results indicates that the air surrounding the peach trees around the Institute is about 2.5 ^{o}C colder than that around the Tokat weather station at least during morning hours of days in the months of March, April and May. From these results, we can draw the conclusion that it is normal to expect higher frost damages at the bottom of valley than those at hillside. These temperature differences also indicate high degree inversion occurrences during frost events. Thus, the employment of wind machines in the orchards around Tokat city seems also as another alternative to protect peach trees from frost damage. Furthermore, the analysis of April daily average wind speeds during the days on which minimum temperatures measured from both Tokat weather station and Institute indicated that

Table 4. The measured [2] and predicted yield percentages for peach trees located at the orchard of Research Institute of Soil and Water Resources in Tokat

Year	Measured Yield (%)	Predicted Yield (%)	Difference (%)
1972	0	0	0
1973	97	100	+3
1974	57	44	-13
1975	48	58	+10
1976	100	100	0
1977	36	10	-26
Average	56.3	52.0	8.7

the average wind speed of Tokat (2 m/s) is more than twice higher than that of Institute (0.85 m/s). High wind speed means low rate frost damage since the wind prevents occurrence of radiation frost. Choosing orchard locations at high elevations and far from the bottom of valleys is another alternative for protection from frost damages.

CONCLUSION

To assess the late spring frost risk of a peach orchard, a computer program in FORTRAN was developed. The model was tested by predicting the frost damages in yields for the orchards located around Tokat city during last 36 years except 1995. Due to late spring frosts, the average annual mean yield loss for the orchards with same elevation and aspect of Tokat weather station was predicted as 31%. The higher rates of damages for lower elevated orchards and lower rates of damages for higher elevated orchards than the elevation of Tokat weather station can be expected. In addition, the performance of the model was quantified by comparing the predicted yields to those measured by Günbatılı [2] for six years. Overall, an 8.7% average difference between the measured and predicted annual yield was found, suggesting that the model performed adequately. Furthermore, the use of some frost protection methods such as over sprinkler irrigation system and wind machines may supply adequate protection at the peach orchards around Tokat.

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REFERENCES

[1] Demirören S. 1988. Şeftali Yetiştiriciliği. Çiftçi-Üretici Yayınları No:309-41, Tarım Orman ve Köyişleri Bakanlığı, Ankara.

[2] Günbatılı F. 1979. Tokat-Kazova koşullarında şeftalinin su tüketimi (J. H. Hale). Tokat Bölge TOPRAKSU Araştırma Enstitüsü Müdürlüğü Yayınları No. 35, Tokat.

[3] The State Institute of Statistics Prime Ministry Republic of Turkey. 2005. Agricultural Structure (Production, Price, Value). Publication Number: 2949, Ankara.

[4] Cittadini ED, de Ridder N, Peri PL, van Keulen H. 2006. A method for assessing frost damage risk in sweet cherry orchards of South Patagonia. Agricultural and Forest Meteorology. 141:235:243.

[5] Logan J, Deyton DE, LockWood DW. 1990. Using a chill unit/growing degree hour model to assess spring frost risks for 'Redhaven' peach trees. HortScience. 25:1382-1384.

[6] Barfield BJ, Perry KB, Martsolf JD, Morrow CT. 1992. Modifying the Aerial Environment, In: Management of Farm Irrigation Systems (ed. Hoffman GJ, Howell TA, Solomon KH) ASAE Monograph Number 9, pp:827-869, ASAE, MI.

[7] Rosenberg NJ, Blad BL, Verma SB. 1983. Microclimate. John Wiley & Sons, N.Y.

[8] Korukcu A., Yazgan S, Gündoğdu KS, Özder E. 1992. Meyve ağaçlarında yağmurlama sulama yönteminin çiçeklenmenin geciktirilmesi üzerine etkinliği. IV. Ulusal Tarımsal Yapılar ve Sulama Kongresi Bildirileri, Erzurum.

[9] Snyder RL, Melo-Abreu JP, Matulich S. 2005. Frost Protection: Fundamentals, Practice, and Economics. Vol. 2, Environment and Natural Resources Series 10, FAO, Rome.

[10] Sezgin F, Özgürel M. 1992. Don olayı ve mücadele yöntemleri. Ege Üniversitesi Ziraat Fakültesi Dergisi. 29:159-166.

[11] Koc AB, Heinemann PH, Crassweller RM, Morrow CT. 2000. Automated cycled sprinkler irrigation system for frost protection of apple buds. Applied Engineering in Agriculture. 16:231-240.

[12] Oğuzer V. 1989. Meteoroloji I. Çukurova Üniversitesi Ziraat Fakültesi Ders Kitabı, No:57, Adana.

[13] Anonymous. 2007. www.tokat.meteor.gov.tr.

[14] Anonymous. 1970. Yeşilırmak Havzası Toprakları. TOPRAKSU Genel Müdürlüğü Yayınları: 241, Ankara.

[15] Durak A, Gunal H, Akbas F, Kılıc S. 2006. Long term cultivation effects on soil properties in pastures. Asian J. Chemistry. 18:1953-1962.

[16] Gerçekcioğlu R. 2007. Personal Communication.

[17] Braud HJ, Hawthorne PL. 1965. Cold protection for Louisiana strawberries. Louisiana State University, Agricultural and Mechanical College, Agricultural Experiment Station, Bulletin No. 591, LO.

[18] Yamazaki T, Kondo J, Watanabe T, Sato T. 1992. A heat-balance model with a canopy of one or two layers and its application to field experiments. J. Applied Meteorology. 31:86-103.

[19] Welles JM, Norman JM, Martsolf JD. 1979. An orchard foliage temperature model. J. Amer. Soc. Hort. Sci. 104:602-610.

[20] Gerçekcioğlu R, Köksal AI. 1992. Tokat yöresinde yetiştirilen J.H. Hale şeftali (*Prunus persica L.*) çeşidinin hasat öncesi ve hasat sonrası fizyolojisi üzerinde araştırmalar. Türkiye I. Ulusal Bahçe Bitkileri Kongresi Cilt 1. (Meyve), Bornova, İzmir.

[21] Filiz A. 2004. Tokat Ekolojik Koşullarında Yetiştirilen Bazı Şeftali ((*Prunus persica L. Batsch*) çeşitlerinin Derim Kriterlerinin Saptanması Üzerine Bir Araştırma. Yüksek Lisans Tezi, Gaziosmanpaşa Üniversitesi Fen Bilimleri Enstitüsü, Tokat.

[22] Gerçekcioğlu R. 1991. Tokat yöresinde yetiştirilen Cardinal şeftali (*Prunus persica L.*) çeşidinde olgunluk ve kalite değişkenleri üzerinde bir araştırma. Cumhuriyet Üniv. Ziraat Fakülte Dergisi. 7:37-47.

[23] Öztekin T. 2007. Farklı iki soğuklama modelinin Tokat koşullarında yetişen elmanın çiçeklenme zamanını

tahminine uygunlukları üzerine bir araştırma. V. Ulusal Bahçe Bitkileri Kongresi, Erzurum.

[24] Ballard JK, Proebsting EL, Tukey RB. 1994. Peaches. Critical temperatures for blossom buds. Washington St. Univ., Coop. Extension Bull. 0914, WA.

[25] Ward KW. 2000. Fruit trees damaged by spring cold snap ?. K-State Research & Extension News, KS.

[26] Özçağıran R, Ünal A, Özeker E, İsfendiyaroğlu M. 2005. Ilıman İklim Meyve Türleri-Sert Çekirdekli Meyveler, Cilt-I. Ege Üniversitesi Ziraat Fakültesi Yayınları No. 553, İzmir.

[27] Aküzüm T., Erözel AZ, Evsahibioğlu AN, Kodal S, Tokgöz A, Özturk F, Beyribey M, Selenay F, Yurtsever E. 1994. Meteoroloji I. Ankara Universitesi Ziraat Fakültesi Yayın No:1325, Ankara.

[28] Mexal JG, Sammis TW, Herrera EA. 1993. Cold-hardiness and dormancy of apple trees. http://weather.nmsu.edu./nmcrops/trees/apples/coldhard_dorm/cold-hardines.htm.