Microclimates, Peach Bud Phenology, and Freeze Risks in a Topographically Diverse Orchard

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SUMMARY. Peach [*Prunus persica* (L.) Batsch.] production in the southeastern United States has suffered a decline in the past several decades due to late and severe spring freezes. Much of the peach production in Tennessee is located on topographically diverse sites. Peach producers do not have adequate information about the effects of microclimates within their orchards on peach bud development and subsequent freeze risk. Such information may help them select the best adapted cultivars based on microclimate. The objectives of this study were to use a 'Redhaven' peach bud development model to compare and contrast the phenology and freeze risks at five sites within the orchard, and to study the freeze characteristics (advective vs. radiative) of these same sites. Automated weather stations were located in topoclimatically different areas of a peach orchard in Dandridge, Tenn., from October 1990 to April 1992. Hourly weather data included average air temperature, chill units (CUs), growing degree hours (GDHs), and wind speed. The data show that the microclimatic factors that affect peach bud development and freeze risk, such as CUs, GDHs, and minimum temperatures, can vary in a topographically diverse orchard, but the effects are not as straightforward as previously reported. For instance, peach buds at a site at a lower elevation may break

dormancy later due to slower accumulation of CUs, which could be beneficial to the grower. Then the buds may develop more slowly due to cold air drainage to the lower elevations, which would also be desirable. However, the lower temperatures due to cold air drainage could be damaging to the bud and cause more problems with injuries. Over the two seasons, there were more radiative freezes than advective freezes, but the advective freezes were more severe. Small differences in wind speed can account for surprisingly different freeze conditions during radiative situations. Any improvement in cold air drainage should help decrease the duration and severity of radiative freezes.

Peach is a major fruit crop in the southeastern United States. A growing concern has emerged about peach crop losses due to late spring freezes, especially in Tennessee. Tennessee's mild springs with warm spells interrupted by incursions of cold air is conducive to rapid, early development of buds and serious freeze problems. Little or no commercial state peach production occurred in 1989, 1990, 1992, 1994, 1996, and 1997 (Tennessee Agricultural Statistics Service). Logan et al. (1990) determined that problems with spring freeze damage to peach buds at Knoxville, Tenn., appear to be due to later freezes rather than to earlier bud development. Many types of freeze protection are employed, but they are costly. Peach could be a better crop choice for fruit growers if the problem with spring freezes could be lessened.

Eastern Tennessee is an area of diverse topography with elevations ranging from 200 m (656 ft) to greater than 2000 m (6560 ft). Therefore, peach orchards tend to be located in topographically variable sites. Most producers choose cultivars based on market factors and maturity, and not on climatic factors. They have some general knowledge of the influence of elevation, exposure and air drainage on crop development and freeze risks, but information about specific effects is limited. Hocevar and Martsolf (1971) stated that good site selection is the best method of protecting crops from freeze damage. They added that a knowledge of the temperature field over locations containing sites under consideration or an ability to predict this field is a prime prerequisite to the selection of good sites. There is considerable controversy about

proper site selection for peach trees. Savage and Cowart (1942) reported that southern and southwestern slopes in Georgia have greater tree damage than northern or northeastern slopes due to southwest injury. Trees on northeast slopes have delayed development, which may help in avoidance of freeze damage.

Freeze damage refers to low temperature damage to crops. Proebsting (1985) defines T50 as the temperature required to kill 50% of the buds. For any particular crop, such as peach, critical minimum temperatures have been determined. Below these temperatures some damage to flower buds is sustained at various stages of floral development. The amount of freeze injury is also influenced by the duration of the freezing temperatures. Table 1 shows the critical temperatures for blossom buds developed by Ballard et al. (1971) for 'Elberta' peaches. In the small green fruit stage, the freezing point is -1.6 (29) to -0.6 °C (31 °F) (Ballard and Proebsting, 1978).

In Tennessee, advective freezes occur when cold Canadian air masses migrate southeastward into the United States. They are characterized by cloudy, windy conditions and a long duration of freeze, even during the daytime. Air drainage becomes less likely and lower sites will be ventilated as the wind increases. Under these conditions spatial temperature differences are generally small. Under very windy conditions, the atmosphere becomes fully mixed and the minimum temperature change with elevation will approach the dry adiabatic lapse rate (Laughlin and Kalma, 1987).

Radiational freezes occur when a relatively cool but very dry air mass moves into the area. The daytime temperatures, generally with considerable sunshine, reach afternoon highs above 15 °C (59 °F). After sunset, radiational cooling from the earth's surface cause temperatures in the very lowest layers of the atmosphere to fall below freezing (Valli, 1970). This type of freeze is characterized by little wind, clear skies, and freezes occurring only for several hours near sunrise. During a radiative freeze, minimum temperatures in a particular region generally decrease with a decrease in elevation. This is caused by an increase in wind sheltering at lower elevations, resulting in a more stably stratified near-surface air layer which in turn reduces heat transfer to the surface. At lower elevations, there is also an increase in the potential catchment area

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Table 1. Critical temperatures (Ballard et al., 1971) and growing degree hour (GDH) requirements for peach blossom buds (Richardson et al., 1975).

Bud stage ^z	Bud stage						
	1	2	3	4	5	6	7
Avg. temp for 10% kill (°C)	-7.8	-6.1	-5.0	-3.9	-3.3	-2.8	-2.2
Avg. temp for 90% kill (°C)	-17.2	-15.0	-12.8	-9.4	-6.1	-4.4	-3.9
GDH (base 4.4 °C)	1981	2643	2963	3667	4204	4923	5863

^z1 = First swelling, 2 = calyx green, 3 = calyx red, 4 = first pink, 5 = first bloom, 6 = full bloom, 7 = postbloom.

^y°F = 1.8 (°C) + 32.

for cold air drainage (Laughlin and Kalma, 1987). Hocevar and Martsolf (1970) found temperature ranges as high as 18 °C (64 °F) to exist near dawn under calm and clear conditions in a central Pennsylvanian valley. Boyer and Feldhake (1985) studied plant growth environments as a function of topography in a steep pasture watershed in southern West Virginia. They found that minimum temperatures differed the most, with west slopes having the highest minima and north slopes the lowest.

The date when the peach tree completes its rest period can be estimated (Richardson et al., 1974) using a chill unit (CU) model. A CU is defined as 1 h at the optimum temperature at the optimum chilling time. Optimum chilling occurs between 2.5 (37) and 9.1 °C (48 °F). Chilling negation occurs above 16 °C (61 °F). To predict bud phenology following rest completion, the growing degree hour (GDH) requirements have been estimated for critical bud stages (Richardson et al., 1975) and are listed in Table 1. GDHs are considered to begin accumulation after rest is completed. This model was tested with success in Tennessee (Logan et al., 1990).

The objectives of this study were to use a 'Redhaven' peach bud phenology

model to compare and contrast the microclimates and freeze risks at five sites within the orchard, and to study the freeze characteristics (advective vs. radiative) of these same sites.

Materials and methods

We selected a 17-ha (42-acre) peach orchard in Dandridge, Tennessee (latitude 36°02' N, longitude 83°27' W, 334 m or 1096 ft above sea level) as a good example of a topographically diverse site. We set up Campbell (model CR10; Campbell Scientific, Inc., Logan, Utah) automated weather stations at topographically diverse locations in the orchard and collected hourly and daily data from October through April 1990–91 and 1991–92. Four sites (1, 2, 4, and 5) were located along a transect up a north/northeast-facing ridge, while site 3 was located some distance (500 m or 1640 ft) from the other sites, and had a southeast exposure.

We used a CU model (Richardson et al., 1974) to estimate the completion of rest (870 CUs) of 'Redhaven' peaches. The estimated daily number of CUs were accumulated from the day after the occurrence of the highest negative accumulation of CUs. GDHs (Table 1) were used to predict the rate of subsequent peach

bud phenology (Richardson et al., 1975). Threshold temperatures (Table 1) were used for each developmental stage to determine the possible number of hours of exposure to a damaging freeze.

To characterize the freeze characteristics of the sites, the freezes occurring in February and March were divided into advective freezes (higher wind speeds, longer duration) and radiative freezes (lower wind speeds, shorter duration).

Results and discussion

CU AND GDH MODEL TO ESTIMATE CRITICAL STAGES OF 'REDHAVEN' PEACH BUDS. Data from four stations in 1990–91 and three stations in 1991–92 were used. The other environments (Site 4 in 1990–91, Sites 2 and 5 in 1991–92) were missing too much data, but were used in some of the general site comparisons.

In the 1990–91 season, among the four sites, there was a 6-d range in the estimated dates of rest completion, a 7-d range in dates of first bloom, but only a 1-d range in postbloom dates. (Table 2). Peach buds at site 5, at a higher elevation (355 m or 1164 ft) and east exposure, broke dormancy the earliest (9 Jan.), whereas peach buds at site 3, at a lower elevation (340 m or 1115 ft) and

Table 2. Estimated dates of critical stages of 'Redhaven' peach buds at topographically diverse sites in a peach orchard in Dandridge, Tenn., for the 1990–91 and 1991–92 seasons.

Site	Critical bud stage								
	Start rest	Finish rest	First swell	Green calyx	Red calyx	First pink	First bloom	Full bloom	Post-bloom
1990–91									
1	18 Oct.	11 Jan.	19 Feb.	25 Feb.	1 Mar.	6 Mar.	13 Mar.	20 Mar.	23 Mar.
2	18 Oct.	11 Jan.	13 Feb.	22 Feb.	25 Feb.	2 Mar.	7 Mar.	17 Mar.	22 Mar.
3	18 Oct.	15 Jan.	19 Feb.	27 Feb.	1 Mar.	7 Mar.	14 Mar.	20 Mar.	23 Mar.
5	18 Oct.	9 Jan.	12 Feb.	22 Feb.	24 Feb.	2 Mar.	7 Mar.	17 Mar.	22 Mar.
1991–92									
1	5 Oct.	30 Jan.	25 Feb.	2 Mar.	4 Mar.	6 Mar.	9 Mar.	17 Mar.	29 Mar.
3	5 Oct.	29 Jan.	23 Feb.	28 Feb.	2 Mar.	5 Mar.	7 Mar.	10 Mar.	24 Mar.
4	5 Oct.	30 Jan.	23 Feb.	28 Feb.	1 Mar.	4 Mar.	6 Mar.	9 Mar.	19 Mar.

^zSite 1 = bottom of slope, 335 m (1099 ft) elevation, north aspect, 9% slope; site 2 = top of slope, 377 m (1237 ft) elevation, northeast aspect, 8% slope; site 3 = open area, 340 m (1115 ft) elevation, southeast aspect, 5% slope; site 4 = midslope, 355 m (1164 ft) elevation, northeast aspect, 7% slope; site 5 = midslope, but closer to trees, 355 m elevation, east aspect, 7% slope.

Table 3. Comparison of freeze risks based on estimated dates of critical stages of 'Redhaven' peach buds at topographically diverse sites in a peach orchard in Dandridge, Tenn., for the 1990-91 and 1991-92 seasons.

Site	Critical stage	Temp threshold (°C) ^z	Date	Hours (no.) below threshold
1990-91				
1	First pink	-3.9	11 Mar.	4
	Postbloom	-2.2	31 Mar.	3
2	First swell	-7.8	15-16 Feb.	22
	Postbloom	-2.2	31 Mar.	1
3	First pink	-3.9	11 Mar.	4
	Postbloom	-2.2	31 Mar.	1
5	First swell	-7.8	15-16 Feb.	28
	First bloom	-3.3	11 Mar.	1
	Postbloom	-2.2	31 Mar.	1
1991-92				
1	First bloom	-3.3	11-14 Mar.	22
	Full bloom	-2.8	24 Mar.	5
			28 Mar.	3
3	Full bloom	-2.8	11-14 Mar.	27
			16 Mar.	7
	Postbloom	-2.2	24 Mar.	7
			28 Mar.	4
4	Full bloom	-2.8	10-12 Mar.	20
			16 Mar.	3

^z°F = 1.8 (°C) + 32.

southeast exposure, broke dormancy the latest (15 Jan.). The results at site 3 were expected because locations at lower elevations and southerly exposures should have warmer temperatures during the winter, which will negate some of the CU accumulations. However, peach buds at site 1, at the lowest elevation (335 m or 1099 ft) and north exposure and site 2, at the highest elevation (377 m or 1237 ft) and northeast exposure broke dormancy on the same (11 Jan.). These data show that the accumulation of CUs may be affected by factors other than elevation and exposure.

After rest completion, sites 1 and 3 had similar dates of critical stages of peach bud development (Table 2), which is not surprising since they are at similar elevations. Dates for sites 2 and 5 were alike, although the sites differ by 22 m (72 ft) in elevation. From first swell to full bloom, the buds at sites 2 and 5 developed more rapidly than at the lower elevation sites 1 and 3. This is surprising since we expected the sites at higher elevation to be cooler and the buds to develop more slowly. We suspect that there may have been some cold air drainage near sites 1 and 3, thereby slowing down the rate of accumulation of GDH, especially at night. The more rapid peach bud development at sites 2 and 5 resulted in an exposure to a damaging freeze during first swell of 22 and 28 h,

respectively (Table 3), whereas the buds at sites 1 and 3 had not yet begun to swell when the freeze occurred. Sites 1 and 3 experienced a freeze problem during the estimated first pink stage, with exposures of 4 h at both sites. The 11 Mar. freeze did not occur at site 2, and lasted less than 1 h at site 5 (Fig. 1). All sites had a short freeze exposure (1 to 3 h) during postbloom.

In the 1991-92 season, it took much longer for the Redhaven peach buds to break dormancy according to the model. Most of the later dates of phenological stages are similar for the three sites until near bloom when they start to diverge by as much as 7 d. This is the opposite of what happened in the previous season. Peach buds at site 1 reach full bloom one week later than at sites 3 or 4. Although peach buds at sites 3 and 4 have similar dates for full bloom, the date for postbloom is delayed by 5 d at site 3 due to cooler night temperatures. Site 1 has problems with damaging freezes during both the first bloom (22 h) and full bloom (8 h) periods. Site 3 has an even more damaging freeze during full bloom (34 h), and two other serious freezes during post bloom (11 h total). Site 4 experiences a total of 23 h below the threshold during full bloom. In this season, the sites at the lower elevations (1 and 3) had greater freeze problems than the higher elevation (site

4). Once again, we suspected problems with cold air drainage.

Overall, the data show that the microclimatic factors which affect peach bud development and freeze risk, such as CUs, GDHs, and minimum temperatures, can vary in a topographically diverse orchard, but the effects are not as straightforward as previously reported. For instance, peach buds at a site at a lower elevation may break dormancy later due to slower accumulation of CUs, which could be beneficial to the grower. Then the buds may develop more slowly due to cold air drainage to the lower elevations. Any delay in peach bud development is desired. However, the lower temperatures due to cold air drainage could be damaging to the bud and cause more problems with injuries.

FREEZE CHARACTERISTICS OF THE SITES (FEBRUARY TO MARCH ONLY). All five sites for each year were used in this study, since their data were complete for February to March. Due to the small number of freezes (n = 20) during this period, results were summarized over both seasons. There were more radiative freezes (n = 16) than advective freezes (n = 4). Note how much more severe the advective freezes were than the radiative freezes (Fig. 2). They lasted much longer (20 vs. 5 h) and reached a lower minimum temperature [-9.0 (16)

Fig. 1. Comparison of hourly temperatures at four topographically diverse sites in a peach orchard in Dandridge, Tenn., on 11 Mar. 1991 [$^{\circ}\text{F} = 1.8 (^{\circ}\text{C}) + 32$].

vs. -4.0°C (25°F)]. The duration of, minimum temperature reached, and average wind speed during the advective freezes were similar at all sites. Due to the larger number of radiative freezes, some significant differences were found. Sites 1 and 3 had greater numbers of hours below -2°C , along with the lowest mini-

um temperature reached. The differences between wind speeds were a little less clear. Sites 4 and 5 had greater wind speeds, while site 3 had the lowest. Small differences in wind speed can account for surprisingly different freeze conditions during radiative situations. Any improvement in cold air drainage should help decrease the duration and severity of radiative freezes.

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Fig. 2. Comparison of (a) number of hours below -2°C (28.4°F), (b) minimum temperature reached during freeze, and (c) average wind speed during the freeze for advective and radiative freezes at topographically diverse sites in a peach orchard in Dandridge, Tenn., for the 1990-91 and 1991-92 seasons. Different letters signify the LSD at $P = 0.05$. [$^{\circ}\text{F} = 1.8 (^{\circ}\text{C}) + 32$, $1 \text{ m s}^{-1} = 2.237 \text{ miles/h}$].