

# Effect of White Latex Paint on Temperature of Stone Fruit Tree Trunks in Winter<sup>1</sup>

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**Abstract.** Tree trunks painted on the sunlit side with white exterior latex paint were found to be 30 C cooler than nonpainted trunks during midwinter in midlatitudes. The dependency of the cambium temp amelioration on wind speed and trunk diam is indicated through an argument based on convective transfer theory. The argument suggests that for trunks larger than 10 cm diam or for wind speeds less than 30 cm/sec around the trunk or both, the amelioration due to white paint may be greater than 30 C.

Short life of stone fruit trees, while complicated by many factors, is thought to be primarily the result of winter injury (15, 17). After accumulating a chilling requirement, exposure to temperatures (temp) permitting growth may result in rapid dehardening (9, 14). Subsequently, sudden drops in temp result in damage to tissues which later manifest symptoms known as winter injury (21). The accumulation of such damage, even though it may occur in only a few years of a tree's life, would apparently result in a reduction in the usefulness of the tree. If the mechanism of injury is in fact the sequence of high trunk temp followed rapidly by low temp (15), a point at which the problem may be attacked is the avoidance of high temp while there is yet danger of intolerably low temp following immediately (11).

In midwinter, low sun angles, absence of leaves and a tendency toward calm conditions during which temp inversions persist through the day all combine to permit the highest intensity of sunlight on a tree trunk that occurs during the year (5, 8). As early as 1894 (18), measurements of trunk temp indicated that the sunlit side of a tree may be considerably warmer than the shaded side (10, 12). Painting the trunk to increase the reflectivity of the surface has been shown to diminish the temp rise in the cambial tissues (9, 3, 13, 2). However, the need to frequently renew recommended whitewash coatings, the phytotoxicity of white paints and the failure to find an easily applied and harmless insulating material for this purpose seems to have discouraged wider acceptance of this practice (13, 17). The advent of new latex-based exterior white paints permits once per season application. Since latex paints appear (in many cases) to be nontoxic, interest in this procedure has been rekindled (1, 6, 16).

The purpose of this paper is to report the effect of white exterior paint on the temp of the bark of stone fruit trunks and to develop an equation to predict the effect under calmer conditions than those observed during the study.

## Materials and Methods

Copper/constantan thermocouples (tc), 24AWG (0.511 mm diam), were inserted into the northern and southern exposures of 2 yr old trunks of 11 nectarine, *Prunus persica* var *nucipersica*, on 29 Jan 72. These cultivars, 'Nectarest', 'Nectared No. 6', and 'Nectared', had attained a diam of approx 5 cm at the height of insertion (30 cm). The length of insertion beneath the bark was approx 2 cm but at an acute angle so that the tc rested but a fraction of a cm beneath the surface (5). The following summer, 30 cm lengths of 36AWG (0.127 mm diam) tc wire were spliced to these leads to reduce heat conduction (3, 4). The bark was slipping so that 6 cm of the twinlead to the tc was layed beneath the bark of 4 yr old trunks of 10 'Redskin' peach trees, *Prunus persica*, averaging 8.75 cm in diam at 30 cm height. Figure 1 diagrams the site and the connection of 6 to 9 m lengths of 24AWG tc

leads through weather proof junction boxes with screw down connector to shielded 6-channel 20AWG extension cables, all 76 m in length, then to a common reference oven and a data acquisition system.

Prior to insertion both sets of 24AWG and 36AWG tc were calibrated through the connectors, extension cables, reference junction and DAS used in the field study by interrogating their outputs when in an agitated water bath. Analyses of the results revealed that differences in trunk temp greater than  $\pm 0.06$  C have less than a 5% chance of being the result of differences in the tc or the logging circuitry and therefore a better than 95% chance of being due to differences in the environment of the tc when it is near OC and 24AWG. This confidence deteriorates slightly as the temp increase to 36C to the extent that differences greater than  $\pm 0.13$  C can be attributed to differences in the environment with confidence. The confidence intervals with 36AWG tc were approx double that of the 24AWG, i.e.  $\pm 0.1$  C for temp near OC and increasing to nearly  $\pm 0.2$  C as the temp nears 36 C.

The following relationship was used to reduce the perforated paper tape output from the DAS by means of a computer:

$$T = (5/9)(a + bv + cv^2) - 32$$

where T is temp in deg C, v is millivoltage, a is 149.155, b is 39.6199 and c is 1.32802. The latter 3 terms were developed by matching a curve (within 0.04F) to tc tabular values between those for 0F and 100F when the reference temp is 150F.

During the 1973 study air temp was sensed with an aspirated 24AWG tc from the calibrated set used in the trunk temp study, by means of a Gill Aspirated Temperature-Radiation Shield with its intake at 30 cm approximately in SE of the trunk of one of the test trees. Air temp data taken during the 1972 trials with shielded but nonaspirated probes were not reported since they appeared to rise several degrees above air temp in bright but calm conditions.

An Eppley Precision Spectral Pyranometer, fitted with WG-7 clear glass in both the inner and outer hemispheres, was used to sense the solar radiation (approx 285–2800 millimicrons) impinging on a horizontal surface assuming the factory calibration of 4.09 mv/ly/min to be correct. Two Thornthwaite light-chopper anemometers (cup type) and a wind direction indicator (WD) were exposed on a mast at 38 and 300 cm, W during the 1973 study approx 1.5 m SE of one of the test trees. The wind speed was integrated over the period between the scans by the data acquisition system while only sample readings of the Eppley and the wind direction were recorded. Scan periods were typically 3 min during the day and 5 or 10 min at night.

The data acquisition system consists of a crossbar scanner, preamp and digital volt meter (DVM) with automatic ranging, a serializer which has incorporated accumulators to log the pulse data from the anemometers, and finally a paper tape punch output. It resolves 1  $\mu$ v and has a reported accuracy when reading millivoltages the magnitude of those near OC of 0.08 C. Statistical analyses of the 24AWG tc data would indicate that discrimination on a relative basis is closer to  $\pm 0.05$  C even with the connectors and extension cables included in the test.

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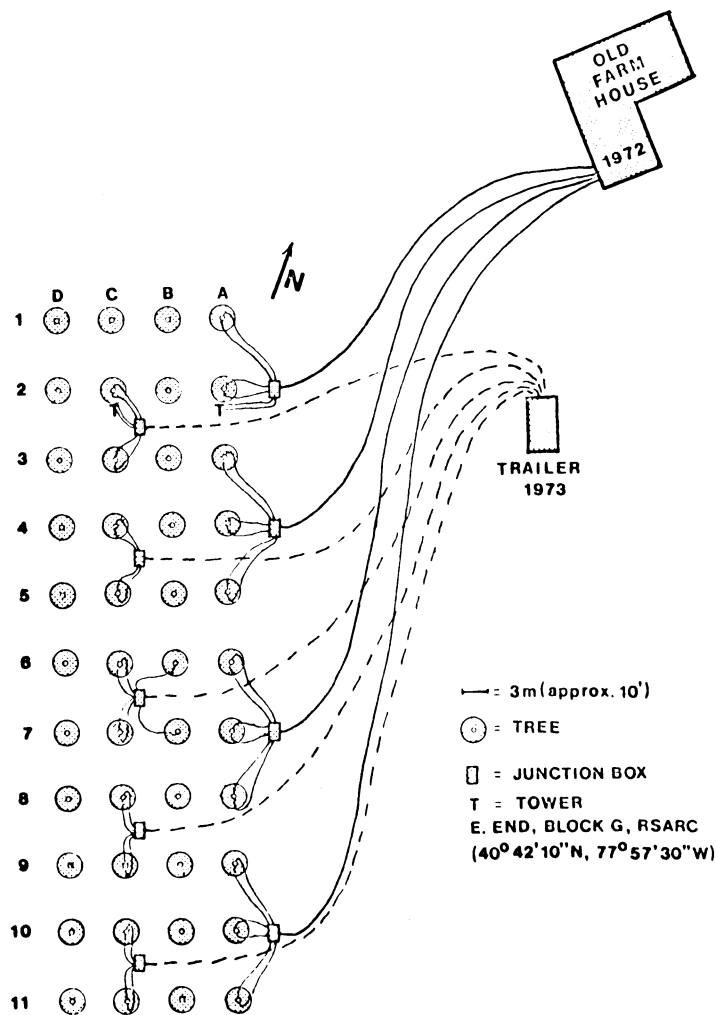


Fig. 1. Diagram of site on north slope of Tussey Ridge indicating relative locations of trunks wired, junction boxes and extension cables conducting signals to the DAS.

The paint used was an exterior grade, white latex paint of low oil content obtained locally.

The site is approx 380 m above MSL, on a 1/17 slope to the NW, about 20 m elevation above the Nittany Valley floor with Mt. Tussey rising to 567 m on Gobbler's Knob and ultimately to 640 m just SE of the site. This is mountain-valley topography and both slope and valley winds (8) may be expected to influence the microclimate.

### Results and Discussion

The advection of cold, dry air into a locality in winter results in a surface microclimate of the sunlit side of vertical tree trunks that exhibits the largest diurnal temp variations experienced throughout the entire year. Two mechanisms combine efforts to make this physically possible. One is a dry, clear atmosphere that permits the sun (at low angles during this period) to impinge with a higher intensity on vertical surfaces than at any other time of the year. Heat is absorbed from the impinging solar radiation driving the temp of the bark, and, by conduction, the cambium upward. As the temp gradient between the trunk surface and the air increases, convective heat transport from the trunk to the air increases, driven by this temp gradient. The second mechanism is the wind upon which the efficiency of this convective transfer is most dependent. By comparison, during bright days in summer the high sun angle results in horizontal surfaces warming most rapidly and the warmer air next to them becoming buoyant resulting in thermals that turbulently mix the air near the ground through a deep layer. This mixing couples momentum of the upper air effectively toward the ground driving turbulent breezes deep

into the tree layer, even to the trunk region. In winter, however, (and especially if snow reflects most of the solar energy from horizontal surfaces) these buoyancy effects are damped out by the stable inversion layer near the ground. The air tends to remain calm permitting the largest temp gradients, between the bark and air to build up, that occur throughout the year.

Time series, in summary form, of 2 days during which the conditions described above were approached in 1972 and 4 days observed during 1973, which failed to meet these conditions as closely as those in 1972, are plotted in Figs. 2 through 4. The vertical bars in these graphs give an indication of the dispersion of data about the mean by delineating the area in which 95% of the data would be expected to fall as indicated by the sample analyzed. The data have been summarized in both time and space to a mean which is plotted at 20 min intervals. When the scan period was 10 min, 2 scans of temp from the 5 replications were averaged and by the same token when the scan period was 3 min, 7 scans of these replications were averaged to produce the data point plotted.

It is suggested that these observations of the magnitude of this stress do not contain perfect examples of the phenomenon, which is submitted to exist periodically. This leads to speculation that these conditions may not occur in every location every year. However, it may be necessary for them to occur only a few times during the life of the tree to contribute to a reduction in growth and yield. The closest that the observations presented come to documenting the mechanism that is alleged to stress the cambium is depicted in Fig 2. The nocturnal cooling curve on 8-9 Feb 72 would be extraneous to this problem if it did not indicate that radiational cooling had the potential of taking the cambium temp beneath a critical value. The temp trace gives evidence that the dewpoint was reached resulting in fog formation that interrupted further radiational cooling during the early morning of 9 Feb 72. Cloud cover associated with vertical motion westward of the high pressure system was forecasted to move in during the afternoon of the 9th and the DAS was shut down when this occurred. However, when the subsidence under the high pressure dissipated the cloud cover about 9 p.m. the DAS was restarted. The cloud cover provided sufficient interruption in the radiational cooling mechanism that the temp did not fall as rapidly and consequently as far on the morning of the 10th. Apparently, winter damage was avoided by cloud cover overhead from about 4:30 to 9 p.m. on 9 Feb 72.

Mean differences between each combination of painted and non-painted trunks were computed for similar periods during which the nonpainted trunks were experiencing their highest temp during 10 days (Table 1). Two of these days were used for uniformity trials during which the mean difference was 0.98 C in 1972 and -0.63 C in 1973. In the latter case the trees that were to be painted had a slightly warmer temp during the trial period than those to be left nonpainted. White paint coating diminishes maximum cambium temp dramatically. This effect averaged over 20 C on 10 Feb 72 and in specific instances was in excess of 30 C (Fig 2). The extent to which the paint may be expected to ameliorate high cambium temp under even calmer conditions than those occurring during these observations is predicted later through a deductive process.

Wind speed (Table 1) is integrated over time but other parameters, i.e., temp and solar radiation, are samples in time. All days were quite clear with the uniformity trial day of 8 Feb 72 and the relatively windy day of 10 Feb 73 having the lowest maximum solar radiation reading. Scattered cumulus clouds on these days periodically shaded the surface resulting in the low minimum observations and in the lowered mean. The radiational loading on the trunks may be considered constant over the midday portions of 8 of the 10 periods observed (Tables 1 and 2) and certainly during the last 5 days.

It may be noted in Fig. 2 through 4 that the mean temp maximums for the painted and nonpainted trunks do not occur simultaneously. A computer simulation by Derby and Gates (5) of the elevation of trunk temp above air temp with inputs approximating the conditions under which Eggert (3) made his observations indicates that the max temp of painted trunks lags the point in time that the max for the nonpainted

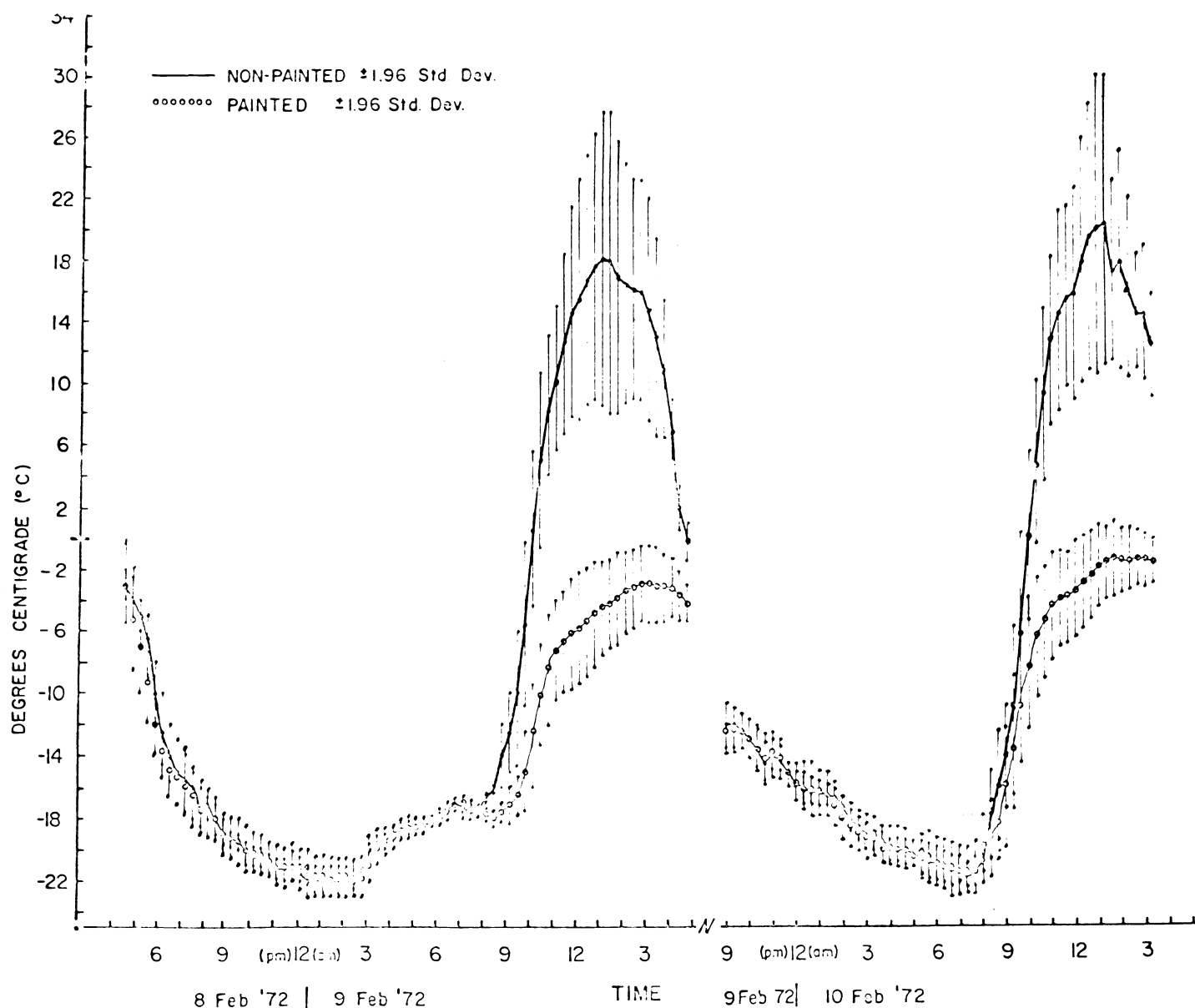


Fig. 2. A time series (EST) of temp data summarized in both time and space, indicating the dispersion of the data about the mean but depicting the effect of white latex paint.

trunk occurs by almost an hour. Consequently, the temp difference at a particular point in time would tend to overestimate the extent to which the white paint can be expected to diminish the max temp experienced by the cambium.

Table 2 reports the results of a search of the data for the time at which the max temp occurred for both the painted and the nonpainted trunk. The lag on the 2 days in 1972 and on all the days in 1973 during which the drift was from the NW varied from 34 to 87 min with a mean of 58 min. However, on the days during which the wind was from the NE the lag reversed, i.e. the painted trees appeared to reach their max temp before the nonpainted by 23, 14 and 24 min respectively. These results led to a re-examination of the location of the tc in terms of compass angle revealing that the southern locations varied from 140 to 205 deg CW from grid North with a mean of 165 deg and a SD of 21 deg. The trunks also varied slightly in their departure from the vertical. However, it is reassuring that the tc no 25 was found to be 205 deg from north while Derby and Gates model (5) predicted the highest temp to occur at approx 200 deg near 1500 hrs. Figure 5 indicates the highly variable nature of the temp traces in time under field conditions which contrasts with the smooth curves that models produce. Noting that compass, wind direction, and especially

windspeed all affect the location on the trunk that experiences the highest temp as well as the time at which this max temp occurs it seems advisable to estimate amelioration, i.e. the extent to which white paint may be expected to depress trunk temp, by assuming it to be better indicated by the difference between the max temp observed on a nonpainted trunk and that observed on a painted trunk (see last column of Table 2). These results would indicate that the observed amelioration in 1972 was approx 30 C while only 20 C was observed in 1973.

A question concerning the magnitude of error that might be expected due to conduction of heat down the 24AWG tc leads from outside the trunk to the tc beneath the bark was of concern since Eggert (4) warns of its presence and Derby and Gates (5) mention that they were advised to avoid the potential error. Since some of the 36AWG tc failed early in the 1973 runs, the possibility of replacing them with 24AWG tc in a manner similar to that used with the 1972 runs provided an opportunity to compare the differences sensed by the 2 methods. Table 3 presents a description of these differences which seem to indicate that under the conditions in which these observations were made (Table 2) that those made with the 24AWG tc were not systematically higher in temp than those made with the 36AWG. It

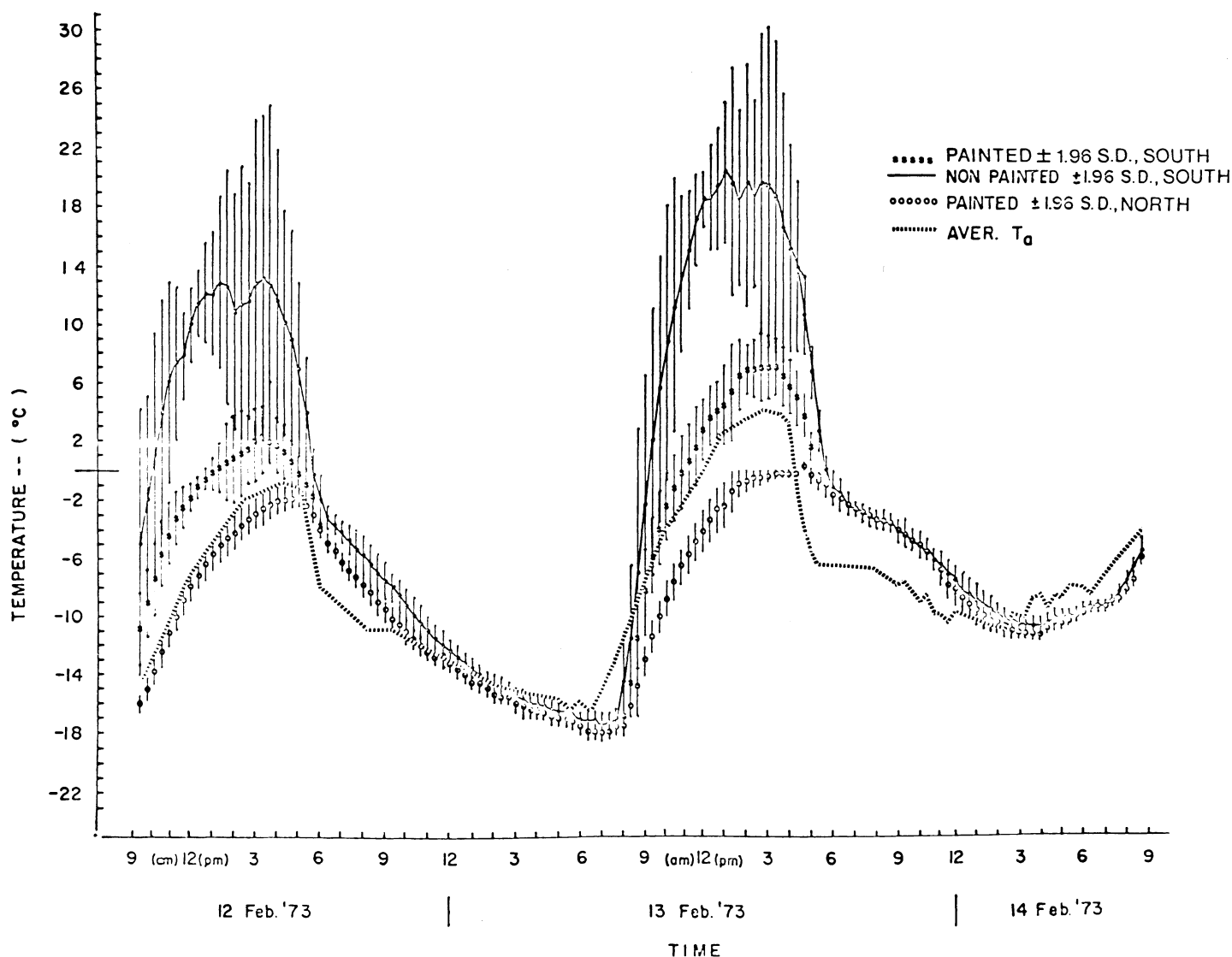


Fig. 3. A time series (EST) depicting the high daytime trunk temp followed immediately by low nocturnal temp which demonstrates that this process is formidable even in the absence of snow cover.

seems unlikely that a conduction error could account for an appreciable part of the amelioration observed in 1972. This argument should not be construed to prove the absence of such errors. For example, the largest positive differences occurred when new snow was present (Table 3).

The effect that deserves further discussion would seem to be that the wind speed during all the observations is higher than that which may be expected periodically in orchards and especially those on more level terrain. How may these samples of real periods during which the wind speed may have been greater than that which is to be occasionally expected in nature indicate temperature differences more likely under calmer conditions? The following argument suggests a method.

The quantity of heat transferred from the nonpainted trunk surface to the air ( $H_n$ ) by convection is primarily a function of the gradient (7, 19) between the surface temp ( $T_n$ ) and the air temp ( $T_a$ ):

$$H_n = h (T_n - T_a) \quad (2)$$

Where  $h$  is a transfer coefficient that is in turn highly dependent upon wind speed and the shape of the surface transmitting (in this case the diam of a cylinder). A similar equation describes the convective transfer from the painted trunk:

$$H_p = h (T_p - T_a) \quad (3)$$

which is assumed to have the same transfer coefficient since the design of the experiment dictated that both the wind speed (and direction) and the diam are virtually the same for both painted and nonpainted trunks. In other words it is assumed that the surface roughness has not been changed enough by the paint to make these coefficients sufficiently different to affect this argument.

Subtracting eq (3) from eq (2) yields:

$$H_n - H_p = h (T_n - T_p) \quad (4)$$

where the quantity ( $T_n - T_p$ ) is the difference between the nonpainted and the painted trunk temp which we defined as amelioration. Let us refer to this difference as  $T_a$ , and clarify its dependence upon the wind speed which to this point has been implicit within  $h$ .

Tanner (19) discusses the dependence of the transfer coefficient ( $h$ ) on wind velocity and size which may be written:

$$h = C D^{-1/2} V^{1/2} \quad (5)$$

where  $C$  may be considered constant if the wind direction remains constant (note that the wind direction is confined to the north quadrant in the cases summarized in Table 2). Let  $D$  indicate the trunk diam and  $V$  the wind speed.

Simplify ( $H_n - H_p$ ) to  $H_a$ . With these substitutions eq 4 may be written:

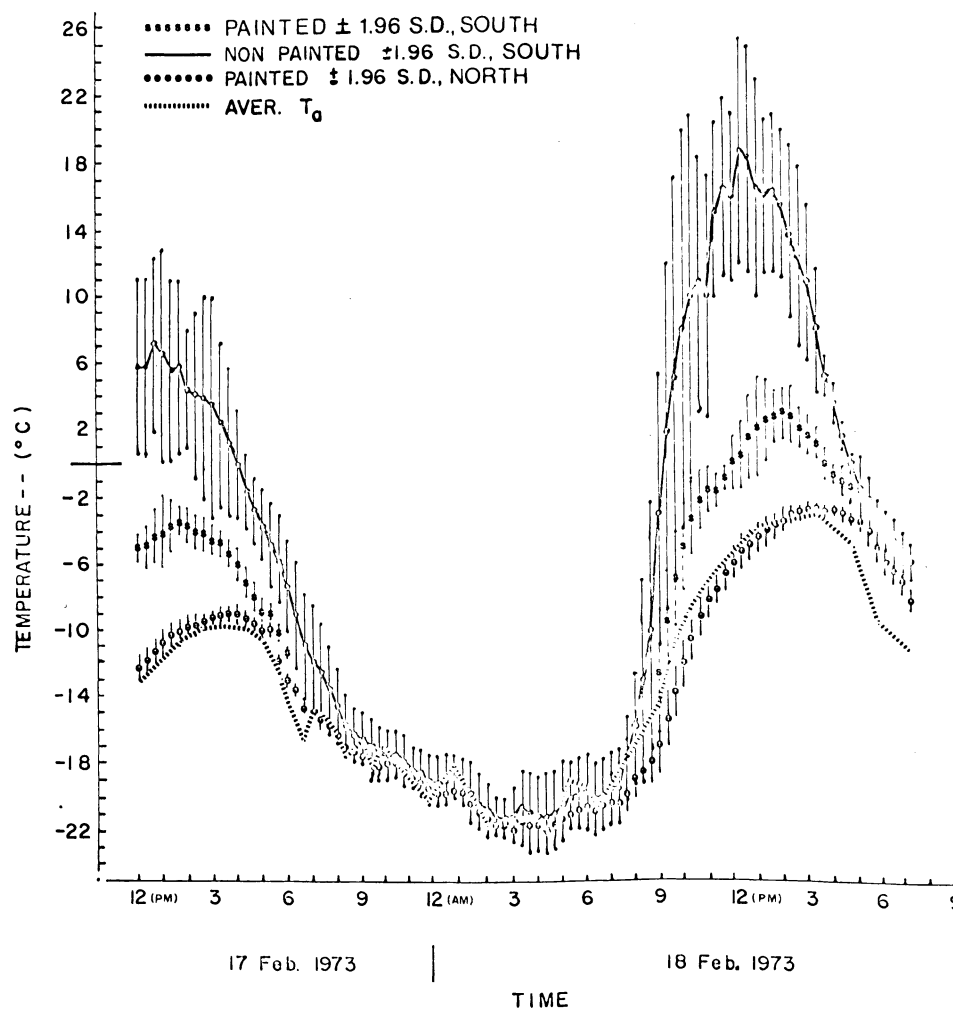


Fig. 4. Magnitude of cambium temp amelioration during a period when new snow cover was 25 cm in depth but that the wind was only relatively calm. The time scale is solar time (approx EST—26 min.).

Table 1. Summary of the differences between all the combinations of temp of painted and nonpainted trunks (southern exposure) with documentation of the solar radiation impinging upon a horizontal surface and the wind speed at the 38 cm level near one of the trunks.

Date	Period (solar times)	N	Differences (C)					Solar radiation (mw/cm <sup>2</sup> )			Wind (cm/sec)	
			Mean	Std. Dev.	Max.	Min.	Range	Mean	Max.	Min.	Mean	Max.
2/8/72	1329-1547	870	0.98	2.81	9.5	-6.8	16.3	33	54	10	—	—
2/9/72	1039-1519	1680	19.64	4.33	31.6	10.0	21.6	48	59	25	—	—
2/10/72	1224-1414	330	20.34	4.38	32.4	12.1	20.3	49	59	46	—	—
2/9/73	1031-1442	1020	-0.63	1.46	3.7	-7.1	10.8	41	73	13	229 <sup>y</sup>	—
2/10/73	1212-1500	340	5.21	2.48	9.7	1.1	8.6	30	54	16	184	426 <sup>z</sup>
2/11/73	1159-1439	640	9.09	3.67	17.5	1.8	15.7	54	64	43	163	319
2/12/73	1158-1440	720	11.34	4.02	21.0	4.6	16.3	53	63	42	122	267
2/13/73	1156-1437	1000	13.66	3.63	22.6	6.3	16.3	55	63	44	89	173
2/17/73	1201-1437	1040	9.48	2.57	15.8	2.5	13.3	58	67	46	285	582
2/18/73	1201-1437	1040	14.32	3.13	24.1	7.2	16.8	55	65	34	130	279

<sup>z</sup> The maximum wind is the average wind over a scan period, 3 min in most cases but as much as 10 min in one case.

<sup>y</sup> This means wind was scaled from the 100cm wind which was the only one available on this date by the factor  $V_{38}/V_{100} = 0.58$  derived from data at both levels on 10 Feb 73 during the period indicated.

$$T_d = C^{-1} H_d V^{-1/2} D^{1/2} \quad (6)$$

If wind velocity is held constant (speed and direction) then eq 6 may be rearranged to describe the effect that the trunk diam (D) has upon the temp amelioration that may be expected:

$$T_d = K_1 D^{1/2} \quad (7)$$

This equation indicates that as the diam of the trunk increases (i.e.,

the tree ages), the difference between the painted and nonpainted trunk temp (amelioration) will also increase. Since this experiment was run on trunks of relatively constant size (8.75 cm) we will now lump the size factor into the constant term and concentrate on the dependence on wind speed. Maintaining the radiation, size and wind direction constant with respect to wind speed allows us to write eq 6:

$$T_d = K_2 V^{-1/2} \quad (8)$$

Table 2. The results of a search of the data for the maximum temp on the southern exposure of nonpainted (NP) and painted (P) trunks with a listing of the environmental conditions at the time of the maximum. Ameliorations is the difference between the nonpainted and painted temp.

Date	Treatment	Solar time <sup>z</sup>	tc no.	Temp. (C)	Solar radiation (mw/cm <sup>y</sup> )	Wind speed (cm/sec.)	Wind direction <sup>y</sup> (deg.)	Amelio-ration
2/8/72	NP	1434	7*	6.3	50	—	—	
2/8/72	NP <sup>3</sup>	1429	9*	5.9	52	—	—	0.4 <sup>w</sup>
2/9/72	NP	1239	7*	25.4	56	—	—	
2/9/72	P	1419	5*	-1.7	42	—	—	27.1
2/10/72	NP	1244	7*	27.6	58	—	—	
2/10/72	P	1334	9*	-0.1	51	—	—	27.7
2/9/73	NP	1127	11	10.4	49	462	300	
2/9/73	NP <sup>3</sup>	1132	3	10.9	46	438	281	-0.5 <sup>w</sup>
2/10/73	NP	1102	1*	11.4	46	287	305	
2/10/73	P	1222	13	0.3	48	426	353	11.1
2/11/73	NP	1444	25	15.1	41	134	53	
2/11/73	P	1419	17	-0.2	47	157	52	15.2
2/12/73	NP	1445	25	21.7	40	100	50	
2/12/73	P	1431	17	2.9	43	94	37	18.8
2/13/73	NP	1443	25	27.4	43	54	46	
2/13/73	P	1419	17	8.4	45	98	30	19.0
2/17/73	NP	1236	1*	9.4	65	301	276	
2/17/73	P	1310	3	-2.7	62	247	294	12.0
2/18/73	NP	1222	25	23.4	64	88	264	
2/18/73	P	1349	13	3.9	55	115	268	19.4

<sup>z</sup> Solar time = EST - 26 min, approx at RSARC on these dates.

<sup>y</sup> Direction from which the wind comes with zero degrees = Grid North.

<sup>3</sup> 24AWG thermocouples (tc), all others are 36AWG.

<sup>w</sup> Uniformity trials conducted prior to painting trunks that served later as painted trunks.

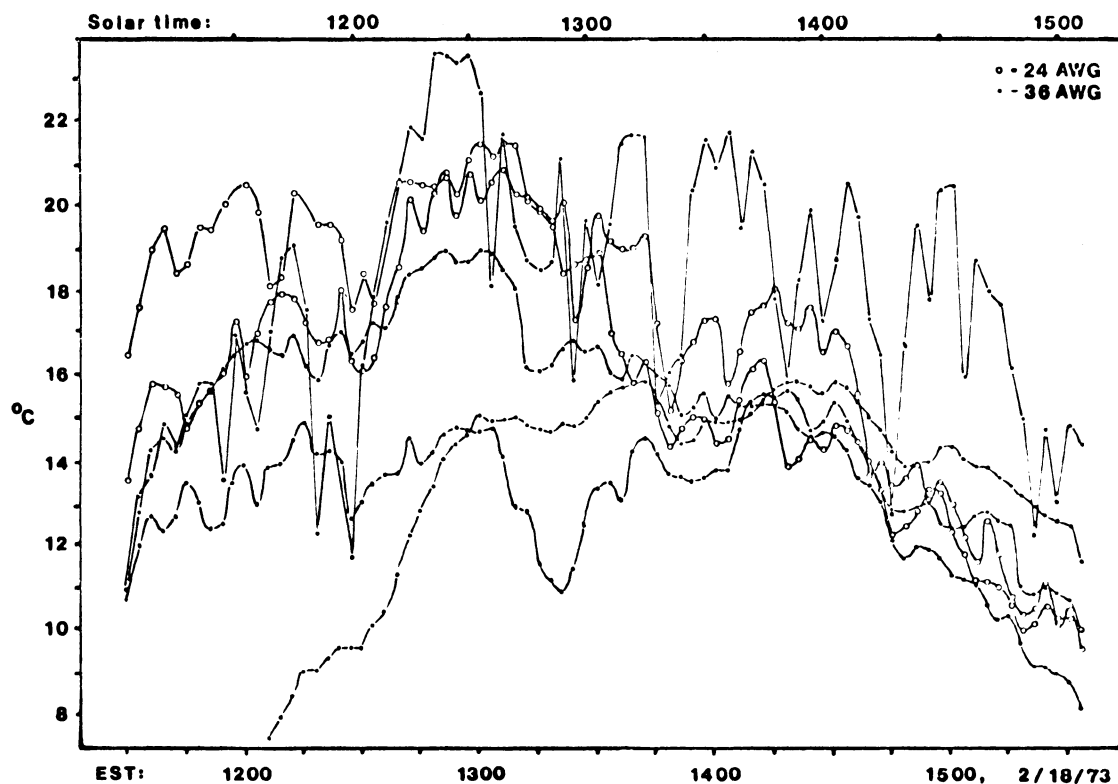


Fig. 5. A time series of individual traces of 6 tc (2 of which were 24AWG) through data points 3 minutes apart for nonpainted southern exposures demonstrating some of the temp variation that the cambium is experiencing in time during a bright and somewhat calm day (sporadic breeze).

Using the wind speed ( $V$ ) and amelioration ( $T_d$ ) data in Table 2 and solving for  $K_2$  for each of the 6 days, 10 Feb 73 on, yields values from 166 to 210 with a mean of 189 and a standard deviation of the values from this mean of  $13.8 \text{ C (cm/sec)}^{1/3}$ . This curve is plotted in Fig 6. Note that this relationship predicts that the wind speeds in the 1972 tests were 48.6 and 46.5 cm/sec respectively and further that as the wind speed falls below 25 cm/sec that the amelioration would be expected to have climbed to more than 38 C. However, the  $1/2$  power relationship may not be a static choice, e.g., Tanner and Goltz (20) indicated that  $2/3$  power fit the data from the onion umbel much better than the  $1/2$  power. On the other hand, Gates (7) considers eq 5 as:

$$h = C_2 D^{-2/3} V^{1/3} \tag{9}$$

Proceeding with a similar argument as before through eq 6 and 7 and equation equivalent with eq 9 becomes:

$$T_d = K_3 V^{-1/3} \tag{10}$$

Using the wind speed and amelioration data from Table 2,  $K_3$  is found to range from 78 to 90 with a mean of 82 and a standard deviation of  $4.3 \text{ C (cm/sec)}^{1/3}$ . For comparison this relationship is plotted on Fig. 6. This relationship predicts the wind speeds for the 1972 cases to be 28 and 26 cm/sec respectively and that the amelioration would approach 30 C as the wind speed dropped below 20 cm/sec. Care should be exercised that these relationships are not extrapolated to predict the maximum amelioration possible as the wind speed approaches zero. There is probably a point at which the convection induced by the hot surface surrounded by cooler air would set up a flow that would prohibit  $T_d$  from increasing further even as

the wind speed is progressively decreased. This argument has concentrated on the convective transport alone since our purpose was to predict the probable temp difference ( $T_d$ ) if the wind velocity had been reduced during the observations, a condition that we suggest may occur only infrequently. Having done this we must admit that perhaps the problem would benefit from a more full-fledged treatment in which the entire energy budget is considered following the example of Tanner and Goltz (20) or picking the problem up at the point that Derby and Gates left it in passing (5). For example, consider the energy budget of the sunlit surface trunk:

$$R_n = H + S + E \tag{11}$$

in which  $R_n$  is the net radiant energy at the surface of the trunk,  $H$  the convective transfer from the trunk to the surrounding air that has been discussed in the previous paragraphs,  $S$  the heat that is exchanged with the interior of the trunk, i.e. storage, and  $E$  the latent heat transfer. If eq 11 is written for the painted and nonpainted trunks using the subscripts  $p$  and  $n$  respectively and the 2 equations are subtracted one from the other and solved for  $H_d$  the result is

$$H_d = (R_{nn} - R_{np}) - (S_n - S_p) - (E_n - E_p) \tag{12}$$

The implicit assumption in the foregoing argument is that the storage term and the latent heat term in eq 12 are either small enough compared to the net radiation term to be negligible or that their sum is negligible, i.e. they have opposite signs and similar magnitudes. Except in those cases in which the water is being fused to ice or ice being melted the latent heat term may be argued to be negligible. However, as Derby and Gates emphasized this freezing and thawing period is of special interest in this problem. The storage term would appear to become more and more important as the size of the tree increases, working in opposition to the effect of increasing diameter in the convective term. Then a prediction of the effect of increasing diameter would seem to rest upon an analysis of which of these 2 effects were the most powerful. Such an analysis or model is recommended.

### Conclusions

The difference between the maximum temp that the sunlit side of a trunk or lower limb (approx 9 cm in diam) which is painted white is likely to be as much as 30 C lower than that of a nonpainted check when low sun angle, clear skies and temp inversions near the surface occasionally combine to present optimum conditions for this microclimatic phenomenon. If such high temp are related to damage from

Table 3. Summary of the differences between temp sensed by two 24AWG tc and three 36AWG tc on the southern exposure of 5 trunks at the 30 cm level. The difference is calculated by subtracting the 36AWG reading from the 24AWG reading.

Feb. 1973 Day	Period (solar times)	N	Mean diff. (C)	Std. dev. (C)	Max. diff. (C)	Min. diff. (C)	Range of diff.	Snow cover
9	1031-1442	306	0.55	1.69	7.6	-3.5	11.1	NS
10	1212-1502	102	-0.39	0.81	2.0	-1.9	3.9	NS
11	1159-1439	192	-1.16	4.56	6.8	-11.7	18.6	NS
12	1158-1440	216	-1.66	4.94	6.5	-13.3	19.8	NS
13	1156-1437	300	-1.25	4.30	6.1	-11.8	17.8	NS
17	1201-1437	312	0.73	3.07	9.5	-5.7	15.2	S
18	1201-1437	312	0.90	3.47	9.2	-8.1	17.3	S

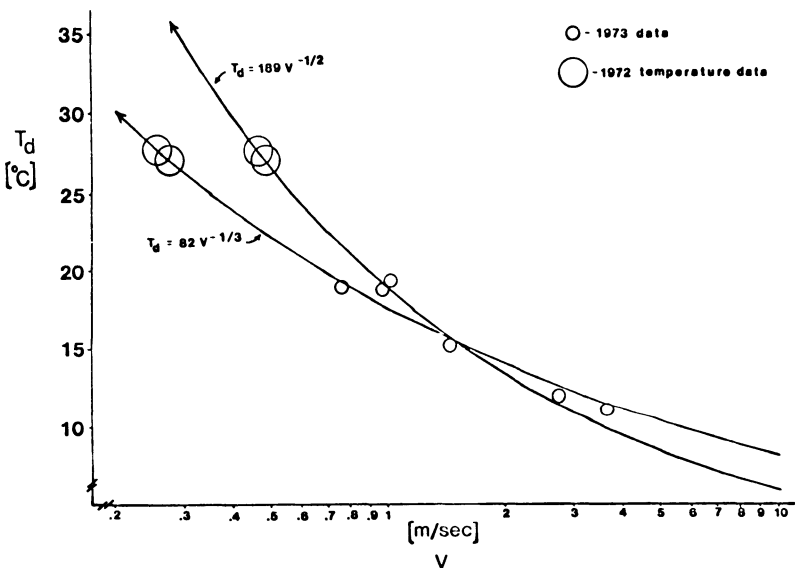


Fig. 6. A plot of the 2 predictive equations representing the range which amelioration values ( $T_{np} - T_p$ ) are expected to fall for given wind speeds in microclimate of the trunk. The curves were calibrated with 1973 data and indicate plausible wind speed values for the 1972 amelioration values as well as predicting an amelioration range for 20 cm/sec or less.

subsequent contrasting cold temp, the white latex paint treatment to the southwestern quadrant of the tree seems justified to avoid this possibility.

Convective transfer theory clearly reveals that the larger the diam of the cylinder (trunk) the less efficient is heat transfer to the air. Consequently the surface temp may be expected to rise further and further above air temp as trunk diam increases. In other words the larger the trunk the more likely it is to reach deacclimating temp under the sun and wind conditions. A more complete analysis using additional energy balance terms would seem to provide opposition to this possibility suggesting the need for such analysis before complete acceptance of this possibility.

Data from a sloping site (side of a mountain) were used to solve for the constants in the predictive equations (8 and 10) supporting the 30 C+ amelioration. Micrometeorological considerations would suggest that extremely calm conditions are more likely on level sites, hence, the probability of observing magnitudes closer to those occasionally possible in nature would be greater on a more level site. Conversely, the potential avoidance of winter injury may well be added to the long list of advantages of good site selection.

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## The Effect of Mechanical Harvesting on Yield, Quality of Fruit and Bush Damage of Highbush Blueberry<sup>1</sup>

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**Abstract.** On 15 occasions, either Wolcott, Jersey, Morrow or Murphy cultivars of highbush blueberry (*Vaccinium corymbosum* L.) were harvested by commercial hand-pickers and over-the-row mechanical harvesters in eastern NC during 1970 and 1971. Compared with hand-harvesting, machine-harvesting reduced yield of marketable ripe fruit 19 to 44%. Compared with commercially hand-harvested fruit, machine-harvested fruit was 10 to 30% softer in compression tests; and when held for 7 days at 21°C, the fruit developed 11 to 41% more decay. Machine-harvested fruits sorted on a commercial cleaner were softened still more and developed 5 to 10% more decay than fruit mechanically harvested but not sorted.

Fifty times as many canes were damaged by mechanical harvesting as by hand-harvesting.

Before mechanical harvesters became available, all highbush blueberries were picked by hand and placed directly into containers for shipment, or into pails for later transfer to shipping containers. No additional direct handling of the fruit was necessary.

The large amounts of hand labor for short-term employment, minimum-wage legislation, and the shortage of labor willing to do the menial task of picking blueberries were key factors stimulating the development and adoption of mechanical harvesters.

Large, over-the-row blueberry harvesters have been available to the industry since 1966 (2). These machines vibrate and knock fruit from the bush. Detached fruit drops to a catching pan, rolls to a conveyor, and is moved to the rear of the machine, where an air blast ejects trash and leaves. Fruit is collected in field lugs and transported to a building where fruit is prepared for shipment to market. Fruit from lugs is poured into an air-blast cleaner that removes the remaining trash and small green berries. The ripe fruits bounce down to a sorting belt for final inspection and then drop from the belt into the shipping container. The mechanical procedures required for detaching and moving masses of fruit from the bush to the shipping container allow

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