in Ann. Rep. Northern Nut Growers Assoc. 81 (1990).

Microclimate Evaluation and Modification for Northern Nut Tree Plantings

K. M. Davies, Jr.[1]

Introduction

Nut trees are sensitive to low winter temperatures which can cause freeze injury. They may also be damaged by early spring frosts if they have already broken dormancy, and they require certain minimal amounts of heat during the growing season in order to mature a crop. Many publications on northern nut tree culture have used the U.S.D.A. plant hardiness zone map to indicate areas where various species of nut trees are likely to survive and be productive (e.g. MacDaniels 1980, Lee et al. 1986). Most publications have set the northern edge of zone 5 as the limit for reliable nut production (Figure 1). Cumulative growing degree day (GDD)[2] maps provide additional climatic information for areas such as the Northeast (Dethier and Vittum 1963, Figure 2). MacDaniels (1980) recommended a minimum of 2250 GDD_{50} and 150 freeze free days (FFD)[2] for most nut tree species. Cooling degree day (CDD)[2] maps have also been used to predict where certain species of nut trees are likely to be productive (Cadillac 1982).

More recently, a publication on nut growing in Ontario (Gardner 1989) provided additional measures of climate suitability and also made specific suggestions for temperature requirements of the major nut tree species. The suggestions were based on the experience of many nut growers in Ontario and the measures included average minimum winter temperature, freeze free season, and corn heat units (CHU).[2] Gardner suggested a minimum temperature tolerance of -20° F for Carpathian walnut and Chinese chestnut, and recommended a minimum of 150 freeze free days and 2900 CHU for these species. Heartnut and filbert, he suggested, would tolerate somewhat lower minimum temperatures and would require 130-140 FFD and 2500-2600 CHU. Other species considered briefly in the report included pecan, which would require 150 to 180 FFD and 3300-3500 CHU. Almond and alpricot would have requirements similar to Carpathian walnut and Chinese chestnut; butternut, black walnut, hickories, and hicans would have requirements similar to filbert and heartnut. Maps of Ontario showing isolines for the above indicated measures are presented in figures 3 and 4.

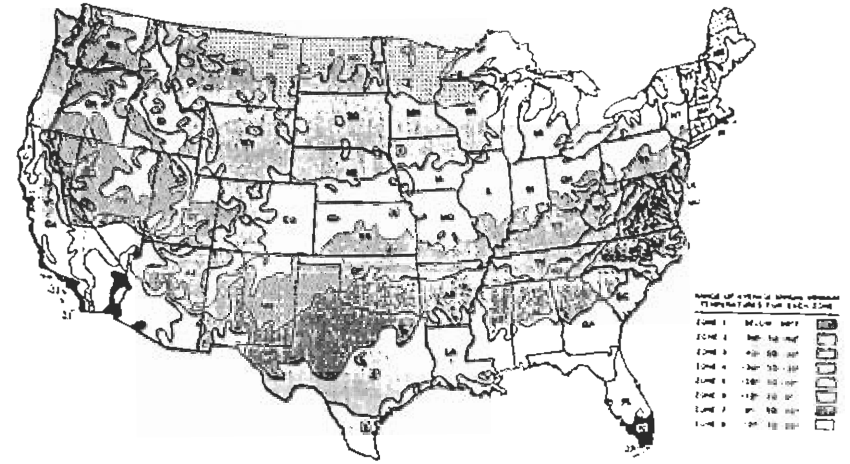

Figure 1. Plant hardiness zone map for North America (U.S.D.A. 1990).

The maps used by Gardner are quite helpful but unfortunately not available for many other parts of the ranges of northern nut trees. However, a conversion factor from GDD_{50} to CHU is useful where GDD_{50} but not CHU are known ($CHU = GDD_{50} + 600$ when cumulative GDD_{50} are between 2000 and 2500) (Brown 1990). Long term average GDD are available for most of over 2000 cooperative weather stations in the U.S. and are published in 'Annual Degree Days to Selected Bases' (N.O.A.A. 1982). FFD are available in the newer climatological summaries (N.O.A.A. 1950-present) for particular weather stations[3]. Relevant Canadian publications are Canadian Climate Normals Vol.4 (Degree Days) and Vol.6 (Frost Data)[3].

Where local weather station data are available, this paper will be useful in explaining methods for estimating growing season temperature measurements for particular sites. These methods are especially useful for areas with significant microclimate variation due to changes in elevation, where GDD_{50} can vary as much as 400-500 units and FFD can vary as much as 70-90 days between hilltop and hollow. The methods described in the next two sections will be less applicable for areas with flat terrain or with large bodies of water which moderate temperature extremes. Following sections will describe methods of improving climate measures for particular sites.

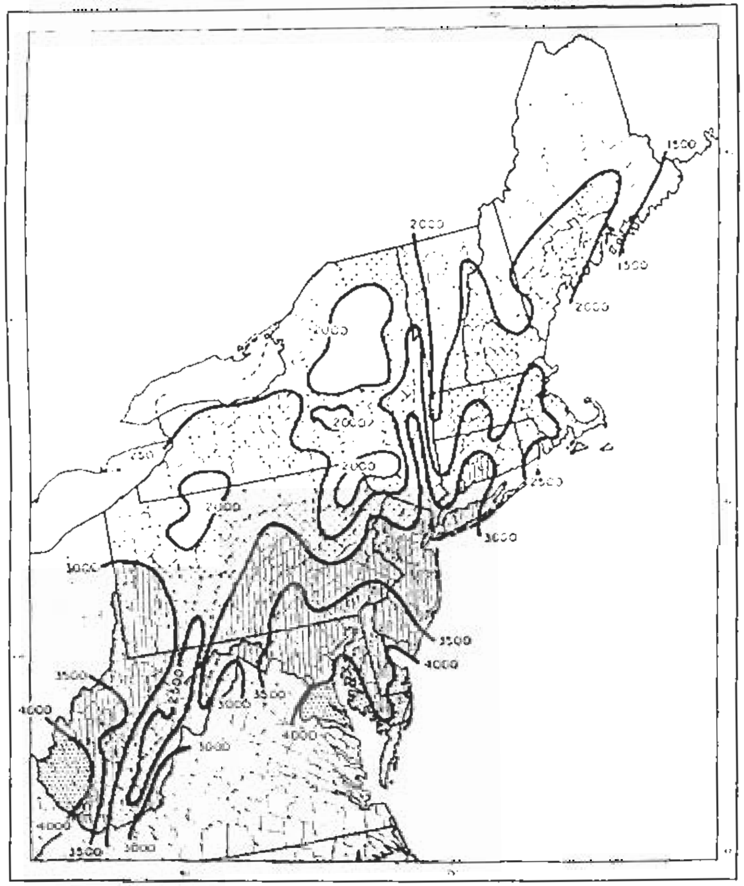

Figure 2. Cumulative growing degree days for the Northeast. Base temperature equals 50° F (Dethier and Vittum 1963).

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[1] Consulting Forester, P.O. Box 601, Northampton, MA 01061

[2] See appendix for definition.

[3] American climatological data is available from the National Climatic Data Center, Federal Building, Asheville, NC 28801-2696
Canadian climatological data is available from the Canadian Climate Center, 11905 Dufferin Street, Downsview, ONT M3H 5T4.

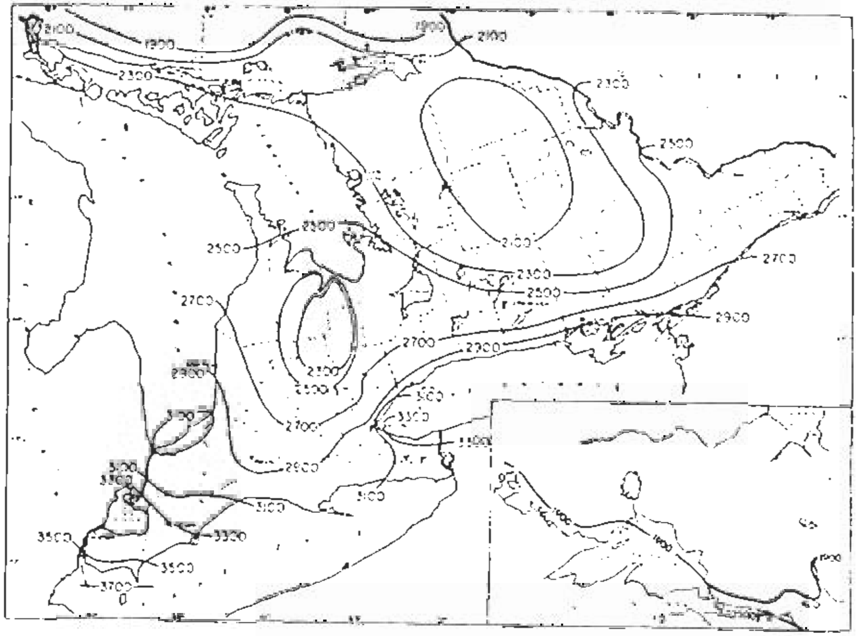

Figure 3. Mean annual corn heat units (CHU) accumulated for the freeze-free season in southern Ontario (Gardner 1989).

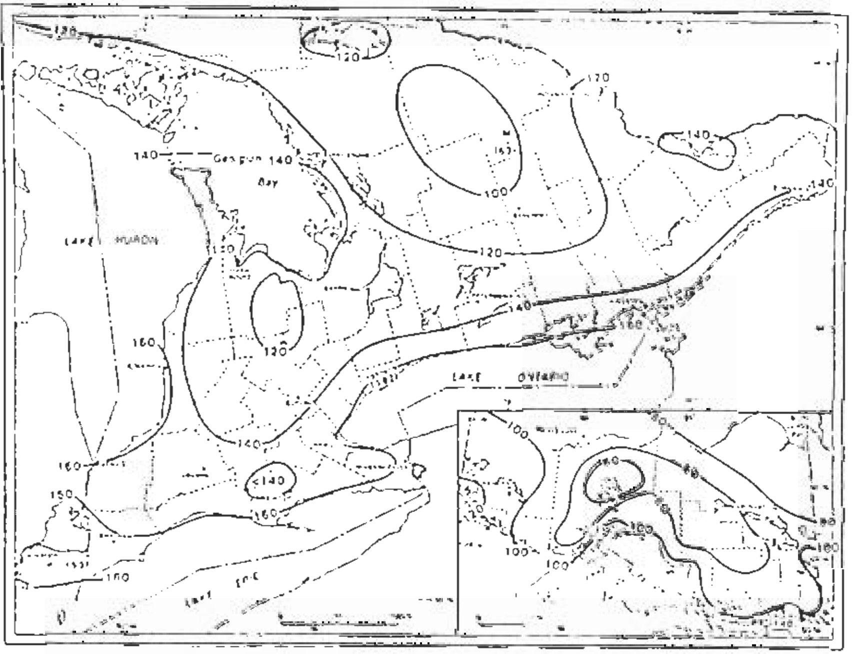

Figure 4. Mean annual freeze free days in southern Ontario (Gardner 1989).

Methods for Estimating Growing Season Temperature Measurements

Where published GDD_{50} information is inappropriate due to significant differences in elevation between the local weather station and the site, the nomogram developed by Dethier and Vittum (1963, Figure 5) can be used to estimate GDD_{50} if the mean July and annual temperatures are known. In order to correlate temperatures at a particular location with those at a nearby weather station, use a maximum-minimum thermometer at the location to measure temperatures for crucial months (i.e., April, July, September and January). Be careful that the thermometer is housed in the same way as the one at the nearby weather station. Obtain measurements for the same time periods at the weather station. Establish the average differences in temperature and add them to or subtract them from the published mean temperatures at the cooperative weather station (NOAA 1950-present), and use the results in the Dethier and Vittum nomogram. If time does not allow for measurements over a year's time, the June, July, or August mean temperature difference can also be used to approximate the annual difference. Differences in other months of the year are likely to be greater (N.O.A.A. 1980).

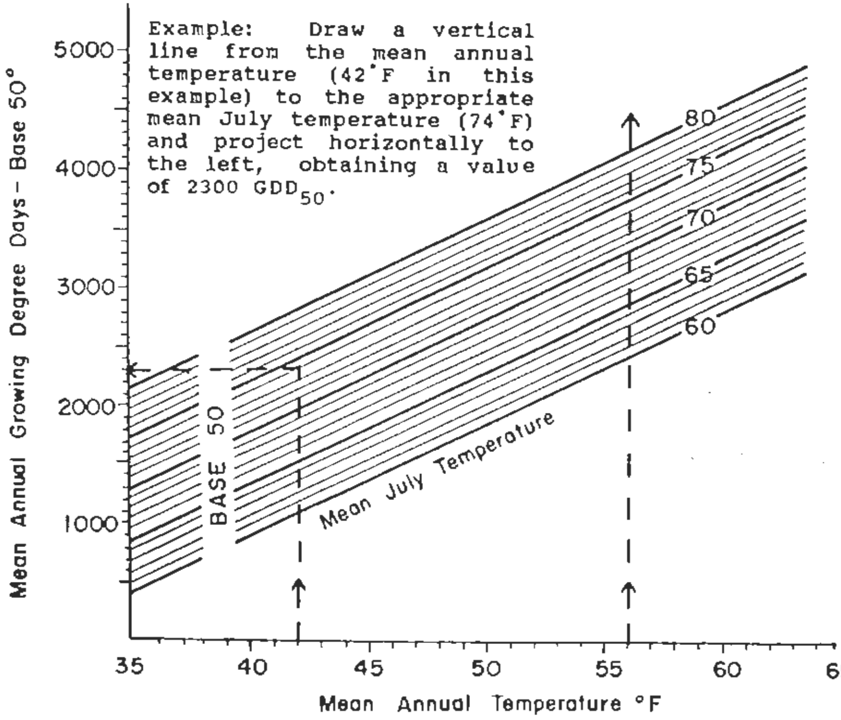

Figure 5. Nomogram for determining cumulative growing degree days (Dethier and Vittum 1963).

Geiger (1965) described differences in mean temperature between the warm nighttime "thermal belt" near the top of the slope and the "cold air lake" at the bottom of the slope of about 1.4° C (2.5° F) in May and June in a mountainous area. This difference would be very close to the July and annual differences between hollow and hilltop for hilly terrain where the thermal belt and cold air lake phenomena are also found (Bootsma 1976). A 2.5° F mean temperature difference for July and the year indicates a difference of about 450 GDD_{50} between hollow and hilltop according to Dethier and Vittum's (1963) nomogram.

Mean temperature and GDD$_{50}$ differences between a particular site and the nearest weather station can be estimated without using a thermometer by finding their relative slope positions. This is done by locating the site and the weather station on topographic maps, noting their elevations and the elevations of the tops and bottoms of the slopes where they are located. Bottom elevations are subtracted from site and station elevations. The differences are divided by the differences between top and bottom elevations. Expressed as percentages, the station position is subtracted from the site position to get relative slope position. The resulting percentage difference is multiplied by 450 to find the difference in GDD$_{50}$ between station and site. In order to simplify calculations, this procedure assumes a uniform mean temperature gradient along the slope. However, in most cases the gradient will be more gradual near the top of the slope and steeper at the bottom (Geiger 1965, Bootsma 1976). The example in the next section illustrates this procedure.

Calculations of FFD at a particular location may also be made when FFD data from a nearby cooperative weather station are available. Figure 6 shows that the difference in minimum temperature is 4-7° C between hilltop and hollow on clear, calm nights when radiative frosts occur. The difference in temperature depends upon the difference in elevation. Bootsma (1976) found that for each 1° C difference in minimum temperature during radiative frost conditions there was a corresponding difference of 12 FFD for the year. If average minimum temperatures are known for the particular site and the weather station during radiative frost conditions, the calculations are quite straightforward. Find the difference in minimum temperature between the station and site in degrees centigrade and multiply by 12. The product is the difference in FFD. If average minimum temperatures at the site are not known, they can be estimated by finding the difference in slope position between the site and the weather station and multiplying by 4-7° C. (4-5° C would be appropriate for slopes with 20-60 m differences in elevation, 5-6° C for 60-100 m differences, and 6-7° C for 100-300 m differences). The product is then multiplied by 12 to get total additional or subtracted FFD for the site. This procedure could also be used to estimate the difference in minimum winter temperatures which also vary by 4-7° C (7-13° F) between hollow and hilltop on clear, calm nights. The example below illustrates this procedure.

An Example: Ireland Street Orchards, West Chesterfield, MA

The following calculations are for a particular site in the Berkshire Hills of western Hampshire County, Massachusetts (Figure 7). The site elevation is 360-384 m and is on a gently sloping ridge top which drops off to a stream valley at 312 m elevation on the west, and the Westfield River Valley at 194 m elevation on the east. The nearest cooperative weather station, at the Knightville Dam, is about 9 km to the south-southeast at an elevation of 192 m (not shown). This station is in the Westfield River Valley. The average frost free season there is 124 FFD (N.O.A.A. 1950-present) and the average GDD$_{50}$ are 2087 (N.O.A.A. 1982).

The relative slope position is calculated as follows. The station, at 192 m, is upslope and east of the 158 m elevation bottom of the valley which has a ridge at about 354 m elevation to the east. Thus the station is at (192-158)/(354-158) = 34/96 = 17% of the slope elevation. The site, at an average of 372 m and near the top of the ridge, is upslope and east of the 312 m elevation bottom of the valley which has a ridge at 384 m elevation to the east. Thus the site is at (372-312)/(384-312) = 60/72 = 83% of the slope elevation. The relative slope position is therefore 83-17 = +66%. Using the procedure described above, we multiply the relative slope position times 6° C which equals 4° C. Four degrees times 12 FFD equals +48 FFD relative to the station site. Since the station site has 124 FFD so we can conclude that the orchard site has 124 + 48 = 170 FFD. The GDD$_{50}$ difference would be approximately +66% x 450 = +297, which when added to the 2087 GDD$_{50}$ at the station yields 2384 GDD$_{50}$ at the orchard site. The CHU would be 2384 + 600 = 2984 CHU.

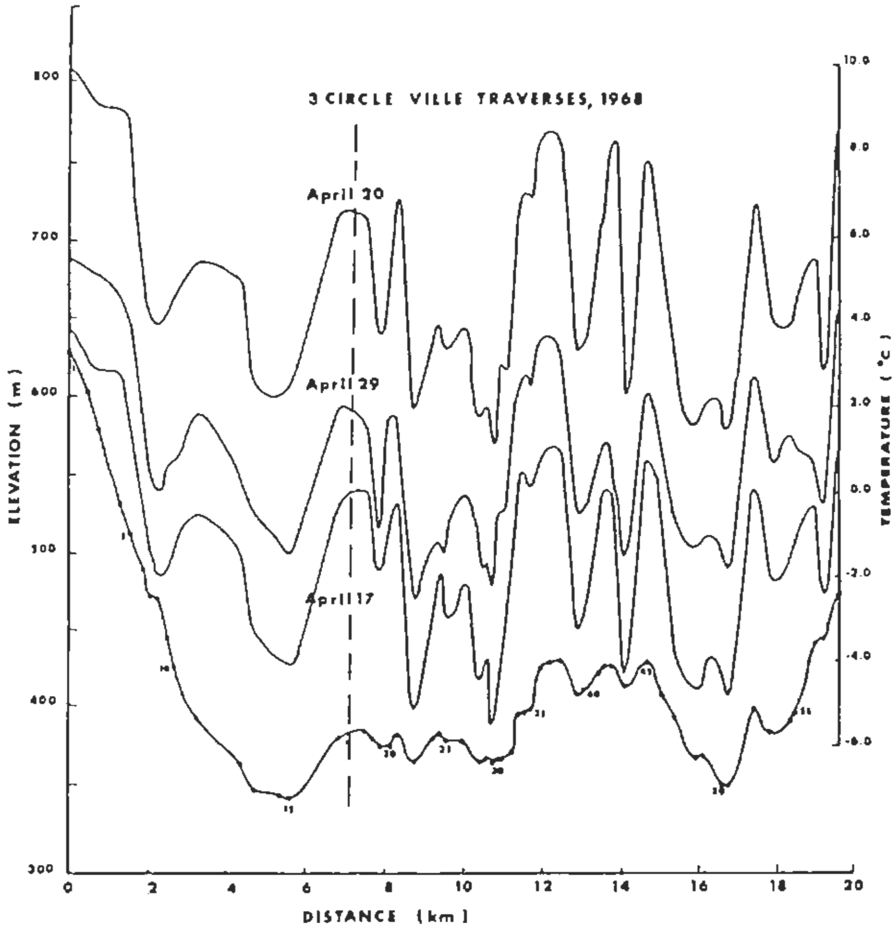

Figure 6. The variation of temperature for three mornings in relation to relief (Hocevar and Martsolf 1971).

Thus, according to Gardner's (1989) guidelines, the site evaluated above would have adequate heat for all species of nut trees except pecan even though it is located in an area which, according to weather station data, would be too cold for most nut trees. This may often be the case in hilly terrain where weather stations are frequently located in river valleys. And, of course, the converse would be true where the site is located at a lower slope position than that of the nearest weather station.

Windbreaks for Increasing Growing Degree Days

The body of research accumulated over more than 40 years indicates that windbreaks will increase daytime temperatures in fields and orchards by 1-3° C for a horizontal leeward distance 6-8 times the difference between the height of windbreak and the height of crop (Rosenberg et al. 1983). This effect is due to a reduction in convective heat loss from plant and soil surfaces to the atmosphere as a result of the action of the wind. Windbreaks have the additional benefits of reducing evaporation and increasing relative humidity, daytime soil temperature, soil moisture, and, of course, crop yield. These effects are illustrated in Figure 8.

Other benefits specific to orchards include improving pollination by increasing air temperatures, reducing mechanical damage to buds, leaves, twigs and fruit by reducing wind speeds, and enhancing early tree growth by reducing shaking. Shaking increases ethylene production which retards growth (Norton 1988). Potential negative effects from windbreaks, especially with poorly designed, thick ones, are lower nighttime temperatures, improved habitat for harmful insects, and slower drying rates which can encourage diseases (Norton 1988). Windbreaks on sloping sites which are impermeable near the ground can also impede cold air drainage. Higher springtime air temperatures behind windbreaks may cause earlier formation of reproductive tissues which may be damaged by early spring frosts. Higher temperatures may also delay the onset of dormancy in the fall which can cause early winter freeze damage. These effects may be mitigated by using deciduous trees in windbreaks. Fast-growing hybrid poplars and willows may be particularly useful in these applications.

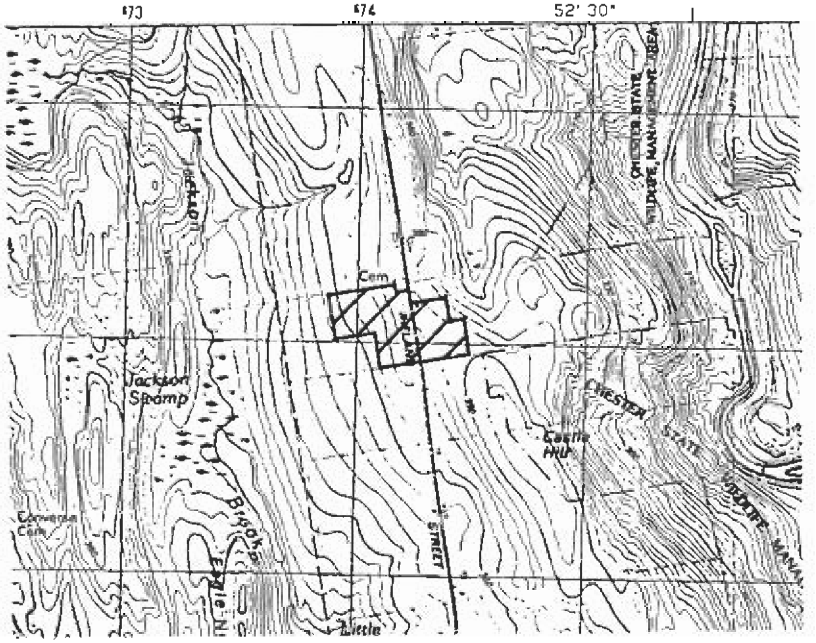

Figure 7. Topographic map section showing Ireland Street Orchards, West Chesterfield, MA.

Windbreak effects on GDD_{50} and FFD can be estimated as follows. If the mean daily temperatures for July and the year increase by 1.8° C (3.3° F) behind shelter (Marshall 1967) then, according to Dethier and Vittum's (1963) nomogram, the GDD_{50} increase is about 600 in shelter. The CHU increase would be about the same. However, since FFD are largely a function of spring and fall dates of nighttime radiative cooling under calm conditions, and since those dates are determined by local climate and slope position and not shelter (Rosenberg et al. 1983), FFD would not increase behind windbreaks. In fact, FFD may decrease where thick windbreaks reduce nighttime air mixing above crops, which reduces radiative cooling by creating an inversion layer. Furthermore, as implied above, frost risk may increase when windbreaks impede cold air drainage on sloping sites. Therefore, on such sites the windbreaks' lower branches should be progressively removed as the trees grow.

Shelter from wind occurs when trees are planted in the lee of established forests or in forest clearings. Although the shelter effects of established forests have not been researched (McNaughton 1989), the hypothesis has been advanced that the leeward distance affected would not be as great as with thin windbreaks since greater turbulence would occur in the lee of a thick forest. But since established forests normally have much greater heights than planted windbreaks would have for many years, the relatively greater turbulence could be considered a negligible factor for the short to mid term. Furthermore, if the forest were thinned to make it more permeable, the turbulence effect could be reduced. Thus, planting in forest clearings (or lees) could have advantages beyond initial investment savings suggested by Davies (1984).

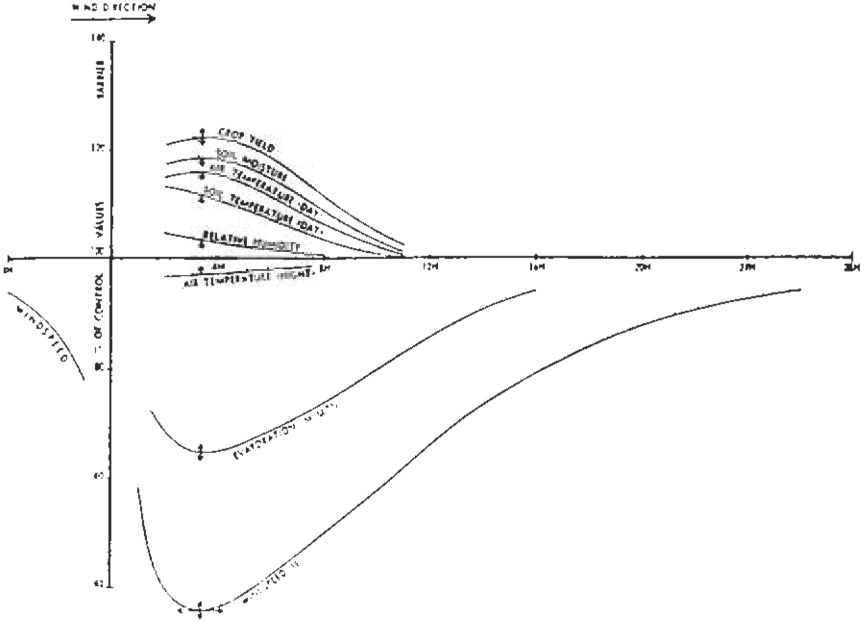

Figure 8. Summary diagram of the effect of barriers on micrometeorological factors. The arrows indicate the directions in which values of different factors have been found to vary relative to the control values measured in unsheltered areas. H = height of barrier. (Marshall 1967).

order to determine overall site suitability. But since Amstey et al. (1959) and van Vliet et al. (1979) found that climatic variables are as or more significant than soil or management variables for fruit production, climate and microclimate should be given very careful consideration.

Acknowledgments

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Appendix

GDD_b = [(max + min)/2] - b where b = base temperature below which no plant growth occurs.; max = daily maximum temperature; min = daily minimum temperature. All GDD_b less than zero are recorded as zero.

FFD = average number of days between last 0° C (32° F) reading in the spring and first 0° C reading in the fall.

CDD = GDD_{65}

CHU are GDD_{50} specifically modified for field corn. When the daily maximum exceeds 86° F it is entered for computational purposes as 86° F, and when the daily minimum is less than 50° F it is entered as 50° F.

Soil heat significantly influences many aspects of plant growth. Small increases in soil temperature can increase water and nutrient uptake, soil respiration, and root extension (Rosenberg et al. 1983). Earlier ripening of fruit and nuts can also result. Soil temperatures are affected by slope and aspect, with southerly and southwesterly being the most favorable aspects. Shelter from wind will increase orchard soil temperatures by up to 3° C (Norton 1988). Although mulches are normally used to conserve soil moisture, they can also affect soil temperature both positively and negatively. A thick layer of mulch with low heat conductivity and high albedo (e.g., straw) will actually lower soil temperatures, whereas a thin layer of mulch with high heat conductivity and low albedo (e.g., gravel) will increase soil temperatures (Rosenberg et al. 1983).

A study done in Colorado (Fairbourn 1973) indicated that while row crops mulched with chopped cornstalks (similar to straw in conductivity) and natural gravel had approximately the same soil moisture regimes, the soil temperatures between rows differed by 2-3° C at the 15 cm depth (Figure 9). On the gravel plots seed germination and plant emergence were hastened, and plant growth increased dramatically. The effects on yield were similarly dramatic, with the gravel plots yielding 40%-195% more than the cornstalk and control plots under normal growing conditions. In a year with unusually cool spring conditions, the gravel mulch plots yielded over 600% more than cornstalk mulch plots.

Similar results would presumably be found with other mulches having similar properties, including those which hold water and are good conductors of heat when kept moist (Rosenberg et al. 1983). Thus muck and dark peat should have positive effects on soil temperature when kept moist (Campbell 1990). Bare soil is also a good conductor of heat, and can be maintained by use of herbicides. Figure 9 also shows how bare soil will increase soil temperature. Landscape fabrics and sheet plastics increase soil temperatures but the permeability of landscape fabrics gives them an advantage over sheet plastics in terms of soil moisture and aeration status (Rist 1990). Gravel over landscape fabric may be an optimal combination in terms of weed control, moisture status, and heat conductivity (McCully 1990).

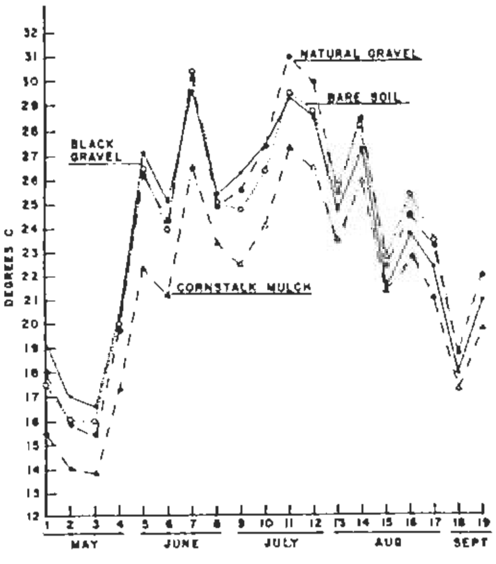

Figure 9. Average of twice weekly measurements of crop-row soil temperatures at the 15.0 cm depth starting May 5, 1968 (Fairbourn 1973).

Another very significant effect of higher soil temperatures is earlier maturity of the crop (Phipps and Cochrane 1975). Since the main climatic limitation for pecan, and to a lesser extent, Carpathian walnut and Chinese chestnut, is the lack of warm weather when the nuts are filling, earlier maturity could help avoid this problem. Where northern pecans are successfully grown, later maturing varieties could be used for higher yields, and earlier maturing varieties could be used in colder climates. Earlier maturing nuts would also have some marketing advantages.

Higher soil temperatures in early spring will not cause earlier formation of reproductive tissues (Hammond and Seeley 1978, Merwin 1990) and may offset the effects of higher air temperatures behind windbreaks since heat released at night by warmer soils can reduce frost damage (Fritton and Martsolf 1981). A 10° C increase in soil surface temperature would save an additional 35% of apple blossoms (Welles et al. 1978), and a 3° C increase at the 15 cm depth is the result of a 10° C increase at the soil surface (Geiger 1965). This would indicate that the gravel mulch studied by Fairborne (1973) would also have a considerable positive effect on nighttime air temperatures and thereby effectively increase FFD. Painting the trunks with whitewash or white latex is commonly practiced to delay new growth and increase winter hardiness with fruit and nut trees (Martsolf et al. 1975, Sparks and Payne 1977). This measure, in conjunction with increasing soil temperatures, could have very positive effects for northern nut trees which are susceptible to early spring frosts.

Summary and Conclusions

The preceding analyses indicate that local microclimate variations in hilly terrain, while sometimes extreme, are subject to quantitative evaluation in terms of several climatic measures. Certain locations in otherwise climatically unfavorable areas may have enough heat to grow sensitive northern nut crops. When the effects of microclimate modifications, particularly windbreaks, are added to the effects of optimal siting of the planting, the prospects for success improve. For example, at the Ireland Street Orchards site previously described, the 2984 CHU which occur naturally would be increased by 600 CHU with appropriate windbreak plantings to give a total of 3584 CHU. This amount of heat should be enough to mature early varieties of northern pecans according to Gardner (1989), and more than enough for all other nut tree species.

But some caution needs to be exercised in predicting benefits from microclimate modifications (Martsolf 1990). The fact that windbreaks may block cold air drainage and thereby reduce FFD has already been mentioned as have the possibilities for increased incidence of disease and insect infestation behind windbreaks. Other windbreak concerns to consider would be increased retention of snow which could delay warming of the soils in the spring, root competition for nutrients and water, and, particularly in east-west oriented windbreaks, competition for light. Concerns about using gravel mulch would include poorer nutrient status and soil structure compared to organic mulches. Careful design of windbreaks (Finch 1988) can avoid many of their potential problems. Other windbreak problems would have to be dealt with directly by applying extra labor and equipment.

Whether windbreaks and soil modifications are economical will depend upon their specific applications. Where they are crucial to growing and maturing certain nut crops, presumably the extra costs would be justified. Where they are less crucial, the cost-benefit ratios become smaller (Phipps and Cochrane 1974, Baldwin 1988) and the questions are more difficult to answer. At present, the type of meteorological, biological, and economic analyses necessary to answer these types of questions are not available. As we accumulate experience and data, however, these analyses should become possible and our forecasting abilities will be improved.

Good tree nutrition, hardy cultivar selection, large size of planting stock, and seedling trunks are other important factors in reducing the risk of freeze injury to nut trees (Sparks and Payne 1977). And of course soil and precipitation conditions must also be carefully considered in

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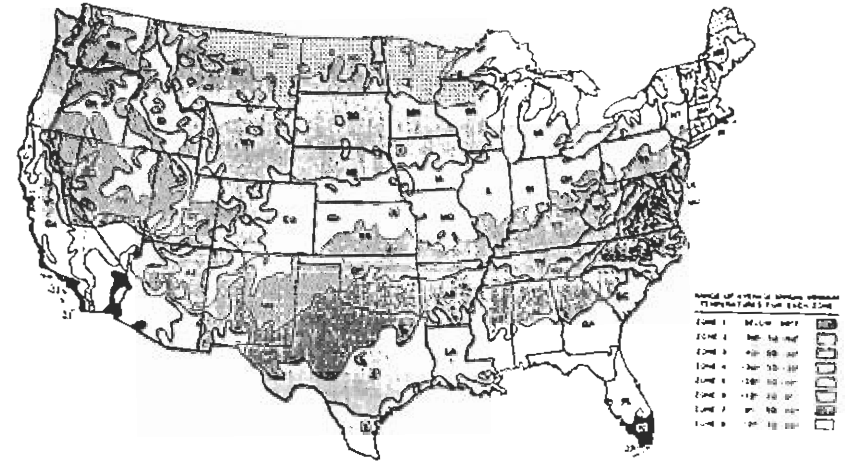

Figure 1. Plant hardiness zone map for North America (U.S.D.A. 1990).

The maps used by Gardner are quite helpful but unfortunately not available for many other parts of the ranges of northern nut trees. However, a conversion factor from GDD_{50} to CHU is useful where GDD_{50} but not CHU are known ($CHU = GDD_{50} + 600$ when cumulative GDD_{50} are between 2000 and 2500) (Brown 1990). Long term average GDD are available for most of over 2000 cooperative weather stations in the U.S. and are published in 'Annual Degree Days to Selected Bases' (N.O.A.A. 1982). FFD are available in the newer climatological summaries (N.O.A.A. 1950-present) for particular weather stations[3]. Relevant Canadian publications are Canadian Climate Normals Vol.4 (Degree Days) and Vol.6 (Frost Data)[3].

Where local weather station data are available, this paper will be useful in explaining methods for estimating growing season temperature measurements for particular sites. These methods are especially useful for areas with significant microclimate variation due to changes in elevation, where GDD_{50} can vary as much as 400-500 units and FFD can vary as much as 70-90 days between hilltop and hollow. The methods described in the next two sections will be less applicable for areas with flat terrain or with large bodies of water which moderate temperature extremes. Following sections will describe methods of improving climate measures for particular sites.

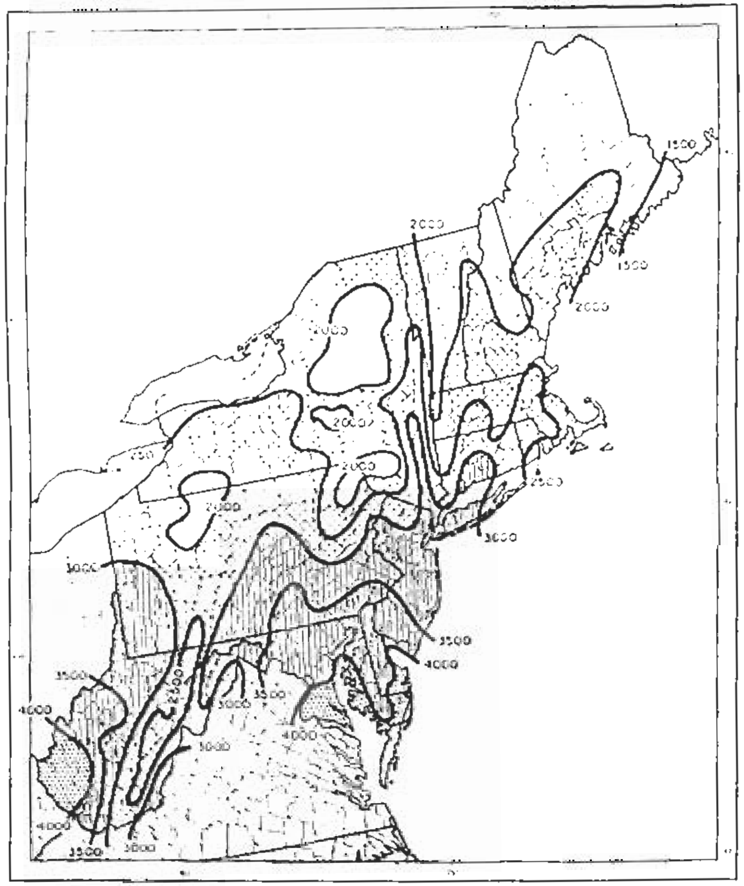

Figure 2. Cumulative growing degree days for the Northeast. Base temperature equals 50° F (Dethier and Vittum 1963).

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[1] Consulting Forester, P.O. Box 601, Northampton, MA 01061

[2] See appendix for definition.

[3] American climatological data is available from the National Climatic Data Center, Federal Building, Asheville, NC 28801-2696
Canadian climatological data is available from the Canadian Climate Center, 11905 Dufferin Street, Downsview, ONT M3H 5T4.