SEVERE WEATHER CLIMATOLOGY IN THE MIDWEST AND ARBORICULTURE[1]

by Richard G. Semonin

Abstract. The temporal and spatial distribution of severe weather events which impact on trees is presented. Severe weather is defined to include wind, hail, glaze, lightning, drought, and freezing temperatures. These weather phenomena are divided into those which affect the tree structure by immediate impact and those which affect tree growth as a result of long-time exposure to abnormal weather. The probability of occurrence of these events is presented with the purpose of eventual modification, by use of such information, of currently defined hardiness zones.

The dependence of shade tree growth on weather and climate has largely been determined by nature and some slight interference through man's ability to create hybrid trees. When deciding upon the use of a specific tree for its shade properties, fruit production, and other less industrially oriented uses, the common technique to assess adaptability in a particular area of the United States is to refer to the published hardiness zones. These maps are based upon temperature range with little consideration for the other weather variability that can occur across North America. While it is recognized that the hardiness ratings are meant only as a guide, it is also indicated that little dependence on weather has specifically been used to derive a complete adaptability map for various species.

Such a map of hardiness would be a compilation including such weather variables as temperature extremes, precipitation as a function of season, lack of rainfall during the growing season, and other severe weather events such as hail occurrence, ice storms, and lightning. In the following material, the climatology will be presented for many of these variables as they pertain to the state of Illinois.

The impact of weather on arboriculture can be considered as falling into two classes. The first are those weather and climatic variables that cause physical damage to trees which will be called "structural impact factors," and secondly, those variables that affect tree development which will be labeled as "growth impact factors."

Structural Impact Factors

Wind. Using Urbana, Illinois to typify the agricultural middlewest, the average daily windspeed varies from a maximum of approximately 15 km/hr in February and March to a minimum of 6 km/hr in August. The average maximum daily windspeeds, however, are considerably more variable than the daily average speed with the largest average maximum of 42 km/hr again occurring in March and the minimum, 26 km/hr in August. However, these winds are not those that are of most concern to arboriculturalists. Of considerably more importance are the peak gusts that may occur in association with the passage of severe storms or intense cyclonic disturbances during the year. These peak gusts range between 75 km/hr in January to 112 km/hr in November. Interestingly, in all months of the year the peak gust commonly is associated with winds from a southerly direction. A non-tornadic wind of hurricane force was recorded in 1947 at Moline, Illinois with a speed of 123 km/hr from the southwest.

Quite frequently, the strong gusty winds are associated with thunderstorm activity and as a result additional stress is placed upon trees due to water loading and even at times from hail (which will be discussed separately). Changnon and Jones (1964) reported that for 5-minute periods of heavy rainfall (defined as 8 mm or more) the 5-minute sustained mean wind speed was 30 km/hr with a maximum gust of 45. The highest 5-minute sustained windspeed during these heavy rain periods between 1954 and 1963 was 71 km/hr with a maximum gust of 105 (Table 1). The weight of a fully leafed branch due

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to rain loading, depending upon the type of tree, may increase by greater than 10% and is then subjected to a wind velocity and turbulence which may indeed cause severe damage to the branch structure.

Table 1.
Wind speeds during 5-minute heavy rainfall at Urbana, 1954-1963.

	5-minute sustained wind speed	*Maximum gust*
	(kilometers per hour)	
Mean	30.6	45.0
Median	25.9	33.8
Highest	70.9	104.8
Lowest	17.6	24.1

One of the most serious problems in attempting to relate wind damage to trees is the health of the particular tree in question. So many times, meteorologists are asked to give expert opinion concerning damage from severe wind events and it is not possible for them to also be experts in tree disease to determine whether or not the observed damage is truly a result of wind alone.

Of course one of the more difficult things to determine is the effect of wind blowing downward on the tree in addition to the horizontal component. In many cases, the wind associated with these severe events is very turbulent and may set tree branches into motion with a vibrational frequency which amplifies at a resonant frequency resulting in destruction. This situation is not unlike the damage sustained by other man made structures such as the famous Puget Sound suspension bridge in Washington.

Additional consideration during these times of energy shortages must be given over to introducing trees as windbreaks in residential areas and low office building facilities. While the agricultural community has elected to remove most fence rows or tree rows in their fields for the purpose of gaining additional acreage for cash grain crops, more consideration must be given in urban areas to retain available energy. Very recently even this practice of removing tree windbreaks has been discouraged by the Department of Agriculture due to the increased chance for the erosion of topsoil, particularly in the Great Plains area.

Obviously, the choice for trees in an urban neighborhood would call for deciduous varieties in south-facing areas to permit incoming solar radiation during the winter months for heating, and provide shade during the summer months to maintain a degree of comfort. The north-facing areas would naturally be better planted in evergreen varieties to provide the important windbreak from the chill north winds. It is exactly this point that is of concern with respect to severe weather and winds. Many deciduous varieties are subject to damage by winds which, as we have seen in the above, are commonly associated with southerly direction. Therefore, only the strongest varieties of deciduous trees should be recommended for this south-facing planting to minimize the potential danger to buildings from wind-damaged plants.

Hail. The distribution of hail events at a point in the U.S., Figure 1, shows two major belts of relatively high frequency (Changnon, et al., 1977). The first of these is in the extreme northwest along the coast of Washington and is caused by unique meteorological circumstances in that area. This high frequency of hail (greater than 10 days per year) is of little consequence since the impacted area is largely forested and the hail is small.

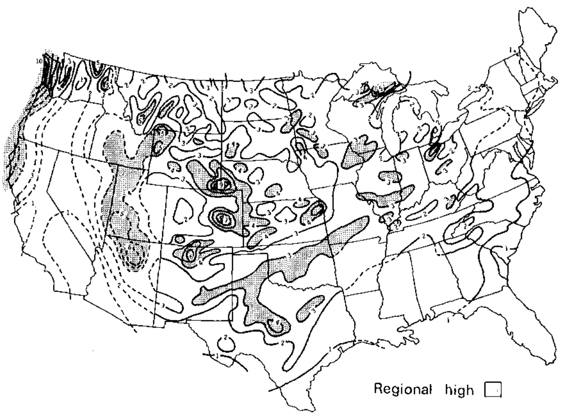

Figure 1. The average annual number of days with hail at a point in the U.S.

The second large area of high frequency, generally greater than 6 days per year, extends from SE Wyoming to east central Colorado. The dry-land farming practices of the Great Plains is sensitive to this form of severe weather which is reflected in the relatively high crop insurance rates over the region.

Huff and Changnon (1959) showed the annual hail frequency variation across Illinois (Figure 2). There are three maxima in the state and the most intense is W of Springfield with 3.3 days per year. The second maxima is in the extreme NW corner of the state and the third (less than 3 days per year) centered just N of the Shawnee Hills. The lowest frequency of hail in Illinois is along the Indiana border from S of Chicago to N of Danville with less than 2 days of hail per year.

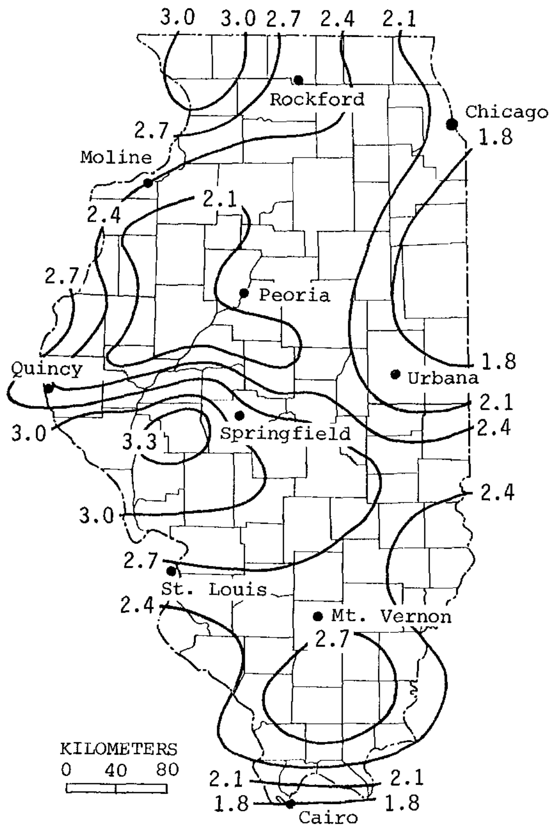

Figure 2. The average annual number of days with hail at a point in Illinois.

In addition to information on the spatial variability of hail occurrences, it is most important to also consider the physical properties of hail events to better understand the resulting damage. The first obvious characteristic to consider is the number concentration of hailstones larger than 6 mm diameter and the second is the energy imparted by the total hailfall. For the 3 major Illinois crops (corn, soybeans, wheat), Changnon (1971) has shown that one or both of these parameters correlate extremely well with crop damage. At least 80% of the variation in crop loss attributed to hail is explained by these parameters.

It is not surprising, however, that damaging hailstorms are frequently accompanied by winds of sufficient strength to inflict damage in the absence of hail. The structural damage to trees, then, is very likely a complex mixture of rain loading, strong wind, and hail. Thus, a model for tree selection should include the combined frequency of these parameters.

Near large cities, as exemplified by St. Louis, Missouri, the frequency of each of these events is altered due to urbanization (Changnon and Huff, 1973; Principal Investigators, 1976). The location of urban-related weather anomalies is within 40 km of the urban center and downwind (east in the case of St. Louis). The severe weather climatology (Table 2) is different within the short distance of 100 km from W to E across the St. Louis metropolitan area. Such a variation can impact on tree selection as much as the development of pollution-resistant species for urban plantings.

Glaze. The glazing of trees by the freezing of rain on contact produces severe structural damage which frequently extends over a large area. During the 1900 to 1960 period, 92 glaze storms occurred in Illinois (Changnon, 1969). The geographic distribution of glaze, Figure 3, shows that the central third of Illinois is most frequently subjected to this type of storm damage.

The geographical distribution of glaze occurrence by month is shown in Table 3 for the 92 storms. Of those glaze storms observed in the north section of Illinois, nearly half (6) of the 13 occurred in March. However, in the central sec-

Table 2.
Hailfall in proximity to St. Louis, Mo., 1971-1972.

	Urban effect	*No urban effect*
Median hail energy ($j\ m^{-2}$)	1.09	0.18
Average number of stones by size		
$\leqslant$ 3 mm	43	30
6-12 mm	12	4
12-20 mm	6	3
$\geqslant$ 20 mm	1	0.5
Total	62	37.5
Average hail duration (min)	3.6	3.6

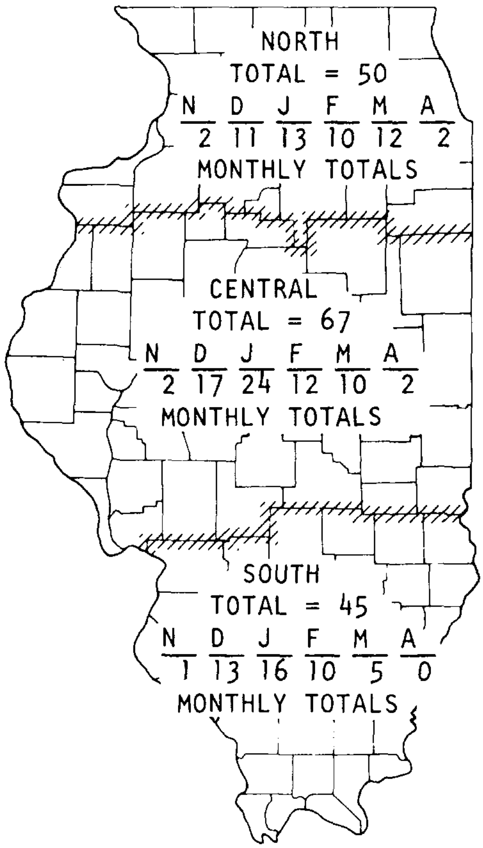

Figure 3. The geographical distribution in Illinois of the number of times in each month that glaze occurred in each area during the period 1900-1960.

tion 10 of 18 storms occurred in the 2 months of December and January. The months of December and February with 4 events each accounted for 67% of the glaze storms in the southern section.

The 28 storms which involved 2 sections simultaneously showed a preference toward January through March in the north-central section, but a dominance by January alone in the central-south section. There were 21 storms which affected all 3 sections and 67% of these occurred in December and January. Considering the entire 6 month glaze storm season, 29.3% of the events occurred in January, followed by 23.9% in December, 19.6% in both February and March, 4.3% in April, and 3.3% in November. To compound the severity of glaze, such storms frequently are accompanied with heavy snowfall (greater than 150 mm). The 61-year record reveals that 58 of the 92 storms were associated with snowfalls of great depth. Unfortunately, the month of greatest frequency, January, is also a month when trees are brittle and easily subject to damage.

The central region of Illinois experienced 67 glaze storm events while the north and south suffered 50 and 45 storms, respectively. The average area of the state covered by a storm ranges from 6.3% in November to 20.7% in January. The maximum areal coverage, however, was 46% in December, 1937.

There are various ways to estimate the intensity of glaze storms, but in spite of the extensive damage resulting from them no consistent measurement method has been adopted. One simple technique is to measure the accumulation of ice on a set of wires of standard but varying diameters. A few observations have been recorded on a 30 cm length of number 12 copper wire which ranged from 56 g to more than 2 kg. A few measurements of the ratio of the weight of accumulated ice to the weight of a 6 mm long twig indicate a range of 12:1 to 17:1. Some extremes have been reported of 32:1, and, while the total weight of ice on trees is dependent on the size of the tree, a 15 m tall evergreen was estimated to bear 45 metric tons.

The simultaneous occurrence of high winds

Table 3.
Geographical distribution of Illinois glaze storms.

Areas	*Nov*	*Dec*	*Jan*	*Feb*	*Mar*	*Apr*	*Total*
North	1	1	1	2	6	2	13
Central	1	5	5	2	3	2	18
South	0	4	2	4	2	0	12
North + Central	0	3	5	4	4	0	16
Central + South	0	2	7	2	1	0	12
North + Central + South	1	7	7	4	2	0	21

with a glaze storm is not uncommon. An examination of 148 glaze storms which occurred in the U.S. between 1926 and 1937, revealed that 31% of the cases were associated with sustained 5-minute wind speeds of 24-30 km/hr. It is this combination of events that is responsible for most of the observed tree damage. A selection of the 5 storms which had the greatest 5-minute wind speed and the greatest ice thickness on wires is shown in Table 4. The motion of the glaze-generating storm is most frequently from the WSW, but the surface winds may have a northerly component.

As with the previous weather events, the probability of a glaze storm is a consideration for species as well as planting location of trees. While this factor may not be too important in the

Table 4.
Five storms with greatest combined glaze thickness and wind speed.

	Five greatest 5-minute wind speeds		*Five greatest ice thicknesses*	
Rank	*Speed kph*	*Ice thickness mm*	*Ice thickness mm*	*Wind speed kph*
1	80.0	4.8	72.9	48.0
2	73.6	20.1	43.4	28.8
3	72.0	6.6	38.1	33.6
4	64.0	7.6	27.9	44.8
5	56.0	19.8	25.4	28.8

extreme northern or southern states, a limited area of the U.S. paralleling the major cyclonic storm track between the Rocky Mountains and the East Coast is subject to this fall-winter season severe storm event.

Lightning. The statistics related to lightning frequencies is quite likely inadequate as it pertains to tree damage. Damaging lightning is only reported when there is loss of life or excessive property damage and is very subject to reporting procedures (Changnon, 1964). As a guide to expected damaging lightning occurrence, the number of reports recorded in each of the 9 crop-reporting districts of the state of Illinois for the period 1914-1947 is shown in Figure 4. The greatest number of reports is in the WSW section followed by the NW and NE sections. Of the 597 reports of property damage and/or one or more persons killed or injured, 58% occurred in these 3 sections.

However, since the crop reporting districts vary in size, the number of lightning occurrences per 10,000 km^2 is shown in Figure 5. Little change in the areal pattern of damaging lightning frequency results from the normalization by area with nearly 22% in the WSW section, 12% in the SW, 16% in the NE, and 15% and 11% in the NW and central sections, respectively.

The distribution of damaging lightning by months is shown in Table 5. The average maximum number of days, 3.4, occurs in July followed closely by August with 3.2, and June with 2.8. The minimum is 0 in December, but always remember that because of other seasonal

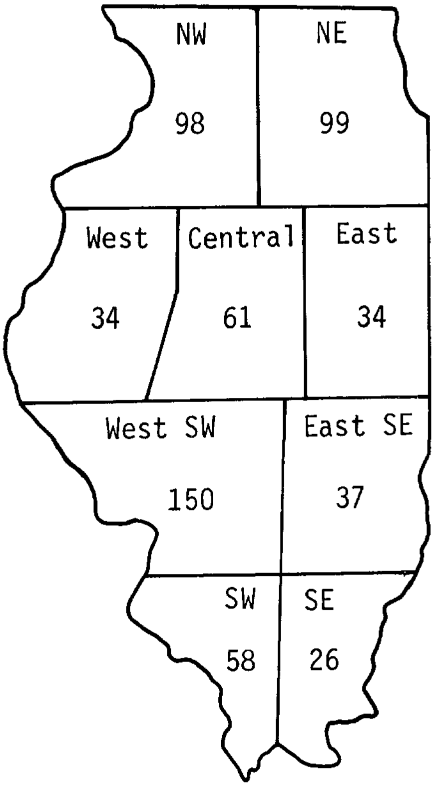

Figure 4. The number of damaging lightning occurrences in each of the 9 Illinois crop reporting districts during the years 1914-1947.

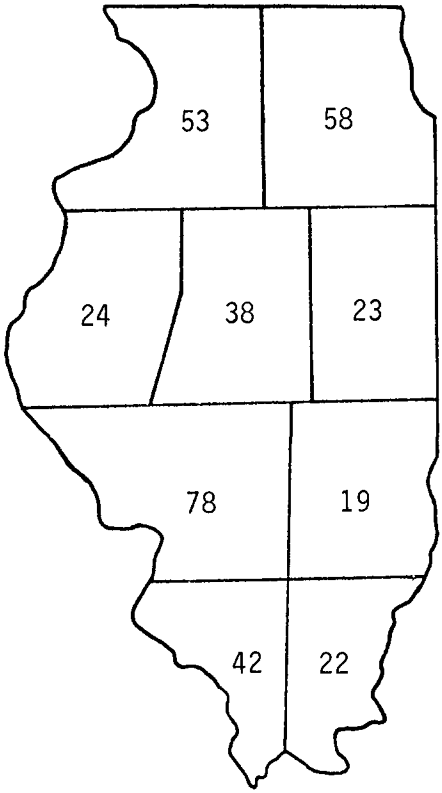

Figure 5. The number of damaging lightning occurrences per 10,000 km^2 in each crop reporting district in Illinois for the period 1914-1947.

weather factors it is less likely to experience lightning injuries in the colder months since there is little outdoor activity. The maximum number of days with damaging lightning was reported for June with 12. The months of July and August suffered with maxima of 10 and 9 occasions of lightning, respectively. While this geographical pattern of lightning statistics is realistic, the absolute values of the frequency of lightning is undoubtedly much lower than the true occurrence.

Growth Impact Parameters

Drought. The tremendous transpiration by trees exacerbates the need for water during dry periods. The water deficit incurred frequently under cloudless days is also almost entirely compensated by absorption of water during the night. Even though both the absorption and transpiration at night are less than during the day, the greater absorption rate results in replenishment of the water needs of a tree. However, during periods of drought, the atmospheric conditions of relative high temperature and low humidity encourages transpiration with less water available for absorption. The potential for severe stress on trees as a result of drought is obvious.

Few statistics are available for short duration dry periods (a few days), but considerable work has been accomplished to determine the frequency of droughts of 3-months and longer duration (Huff and Changnon, 1963). Even some exploration has been completed of the atmospheric conditions during droughts and the possibility of drought amelioration through weather modification (Semonin, 1960; Huff and Semonin, 1975).

The severity of a 3-month drought expected once every 5 years is shown in Figure 6a. The rainfall is expressed as a percent of the normal precipitation during a 3-month period. In south-

Table 5.
Monthly and annual frequencies of days with damaging lightning, 1914-1947.

Months	*Average days per year*	*Maximum number of days*
January	0.06	1
February	0.2	2
March	0.5	4
April	0.6	3
May	1.3	6
June	2.8	12
July	3.4	10
August	3.2	9
September	1.0	6
October	0.5	3
November	0.06	1
December	0	0
Annual	13.6	34

western and southeastern Illinois only 36% of the normal rain would be expected increasing northward to nearly 50% in the extreme northwest corner of the state.

A similar statewide pattern is seen in Figure 6b for the 6-month droughts, but with greater than 50% of the normal 6-month precipitation expected over the entire state. As in the case of the 3-month droughts, the lowest precipitation is expected in the southern part of Illinois with the highest values NE and NW.

The 12- and 18-month, 5-year drought frequency are shown in Figures 7a and 7b. A selected number of stations show the annual precipitation to illustrate the absolute magnitude of the drought severity. The annual drought frequency map is very simple with decreasing severity from SW across the state to the NE. The geographical distribution of 18-month drought frequency is more complicated than the annual with precipitation less than 82% of normal in the north-central and extreme SE regions. However, greater than 88% of normal precipitation could be expected in the extreme NW and over a sizeable area across south-central and south-

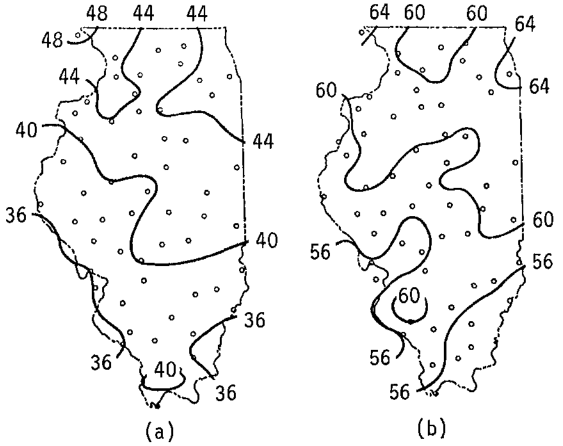

Figure 6. The once in 5 years 3-month (a) and 6-month (b) drought severity expressed as a percentage of the normal 3- and 6-month normal precipitation.

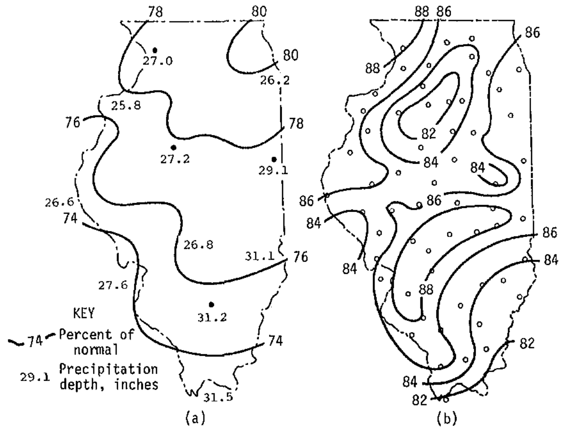

Figure 7. The once in 5 years 12-month (a) and 18-month (b) drought severity expressed as a percentage of the normal precipitation. The expected precipitation at selected cities is shown in (a).

western Illinois.

The data shown are for an expected drought of once in five years. Similar maps for 10-, 25-, and 50-year frequencies are also available with generally increasing severity. For example, the geographical pattern for the 3-month droughts is not significantly different from that of Figure 6a for the longer return intervals, but the magnitude of the expected percent of normal precipitation decreases to 24% in the southern areas to 32%

in the NW. As the length of the drought extends to 18 months, the expected rainfall decreases with increasing return interval. For example, the area shown in Figure 7b with 84% of normal rainfall expected once in 5 years in west-central Illinois, decreases to 70% once in 10 years, 60% once in 25 years, and only 56% once in 50 years.

Using Urbana data to exemplify shorter duration dry periods, the probability is quite variable that any date will be within a 5-day or longer period of less than 2.5 mm precipitation per day. During the period from the last week of July through the first week of February, the probability is approximately 70% with extreme values of 90% for January 28 and 43% on August 14. Between early February through the latter part of July, the probability is about 58% with extremes of 80% on July 23 and 39% on May 7.

Such drought statistics for broad areas of the nation should be considered by plant breeders as a guide for the development of drought-resistant trees. The probability statistics when viewed with the expected normal precipitation can provide the industry with valuable information related to the minimum resistance to drought desired for acceptable trees.

Frost and Freeze. This climate variable is not normally considered severe weather in the same context as damaging wind, lightning, hail, and tornadoes. and only falls into that category at the extremes of the probability distribution. The normally expected last freeze dates for Illinois are shown in Figure 8a along with the mean last date for a temperature of -2.2 deg. C (Figure 8b). In general, the N-S gradient of these dates reflects the gradient of the large-scale climate in the central U.S. The small departure near Lake Michigan from the relatively uniform change across the state is directly attributed to the influence of the cold lake on the surrounding air temperature.

The geographical distribution of the dates changes dramatically for only a 2.2 deg. C difference in the temperature. Of course, this is explained by the fact that the rate of change from winter to summer solar intensity is achieving a maximum during this time.

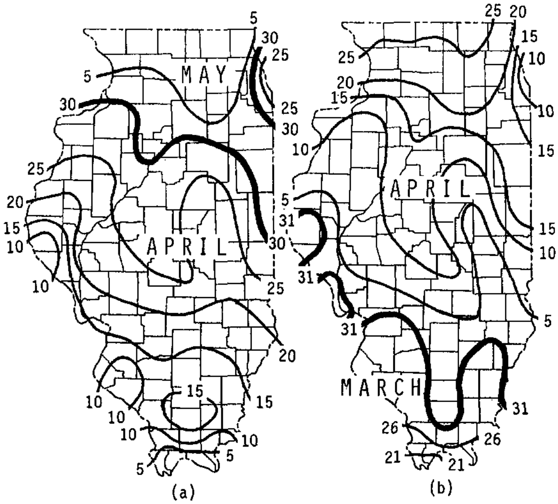

Figure 8. The mean dates for the last occurrence of 0 deg. C (a) and -2.2 deg. C (b) temperatures in Illinois.

Of more interest, however, are the probabilities that these temperatures will be observed at significantly later dates than normal. Using Urbana to again exemplify the problem, the mean freeze date is April 25 and April 9 for -2.2 deg. C. The chances are 1 in 10 years that these dates will be May 12 and April 26, respectively. There is also a 1 in 20-year chance that these dates will be May 17 for the 0 deg. C temperature and May 1 for -2.2 deg. C.

The fall freeze and -2.2 deg. C temperature dates are shown in Figure 9. The first appearance of 0 deg. C is in October throughout all of Illinois except the extreme southern tip of the state. The moderating influence of Lake Michigan can be seen as a distinct feature in the NW-SW climatic gradient. The -2.2 deg. C temperature (Figure 9b) is observed to occur approximately 10 days later, but maintains the same geographical distribution as the 0 deg. C temperature pattern.

The normal dates at Urbana are October 21 for the first appearance of 0 deg. C and November 1 for -2.2 deg. C. Once in 10 years, the 0 deg. C temperature is expected by October 5, and in 1 out of 20 years by September 30. For the first occurrence of -2.2 deg. C, the once in 10 and 20 year probable dates are October 16 and October 11, respectively.

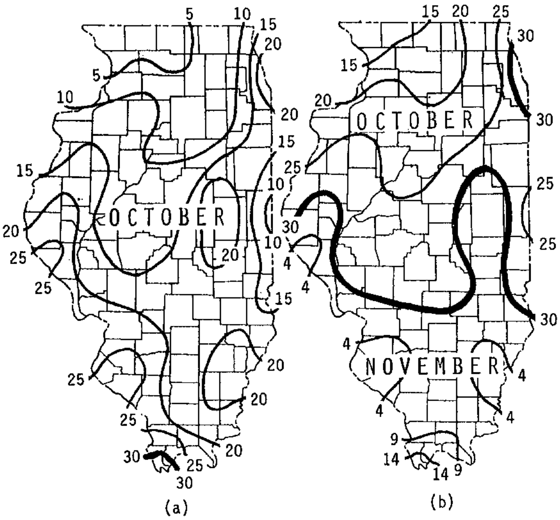

Figure 9. The mean dates for the first occurrence of 0 deg. (a) and -2.2 deg. C (b) temperatures in Illinois.

The annual growing season, defined as the number of days between the last spring freeze and the first fall freeze, is an important parameter for plant breeding and agriculture. A great deal of variability is observed in the length of the frost-free period at Urbana. The average growing season is 179 days with extremes of 129 days in 1928 and 220 days in 1931. However, the growing season is expected to be 146 days long once every 10 years and only 136 days once every 20 years.

Interestingly, the global weather patterns which dictate the length of the growing season also force some of the other aspects of weather related to plant development. For example, droughts are typically warm periods as well as dry and result in a longer growing season allowing some adjustment by the plant to the lack of rain. Conversely, a shorter growing season may be associated with greater than normal precipitation, again resulting in a somewhat compensating set of circumstances. These considerations point to the very complex problem of relating growth of trees and agricultural products to weather. The weather factors tend to frequently offset each other adding to the variability of the impact on various industries.

Summary and Discussion

A very brief description of a few relevant climatic variables for Illinois are given. These include wind, glaze, hail, lightning, drought, and freezing dates. The occurrence of tornadoes was not considered because of their unquestionable destructive power leaving little possibility for the survival of trees directly in their path.

While not presented here, the obvious step to be taken is the development of a climate model showing the geographic distribution of the combined probability of severe weather impact on trees. From the foregoing presentation of the severe weather climate for Illinois, the W-SW crop-reporting district is an area subjected to considerable weather impact. Damaging hail and lightning are relatively quite frequent in the area which is also subject to glaze storms, drought, and occasional short freeze-free periods.

Much more work is needed to quantify the effects of isolated climate components on tree growth for different species. Once the specific effects have been determined, the probability of departures from the average can be determined to guide the development of more weather resistant trees.

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