THE NATURE OF GROWING SEASON FROSTS IN AND ALONG THE PLATTE VALLEY OF NEBRASKA[1]

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ABSTRACT

Historical frost events (minimum shelter temperature $\leq 32°$ F.) were studied at 10 locations within and adjacent to the Platte Valley of Nebraska and the cause of these frosts was determined with the aid of synoptic maps. Frost series based upon last spring or first fall advection or radiation are defined and found to be random and normally distributed. The "potential growing season", defined as the interval between last spring and first fall advection frosts, is found to be from 15 to 32 days longer than the "growing season" defined by the interval from last spring to first fall occurrences of minimum shelter temperature of 32° F. or below. The numbers of annual spring and fall radiation frosts and the number of days between last two spring and first two fall radiation frosts are presented to permit estimates of the practicality of frost protection for specialized crops in the area of study.

1. INTRODUCTION

Such statistics as mean frost[2]-free period, mean date of last frost in spring, and mean date of first frost in fall have been determined for many States. Since frost dates within a frost series based upon minimum temperatures have been shown by Thom and Shaw [1] to be randomly distributed and to adhere to normality, the computation of probability tables has been facilitated. This information has served as an aid in planning various operations, particularly those of an agricultural nature.

An intensity factor has been employed to increase the usefulness of frost statistics by the introduction of various threshold temperatures. For example, the dates of last spring and first fall occurrence of minimums of 32° F., 28° F., 16° F., etc., have been computed in many States.

The anticyclonic *radiation* frosts which occur within homogeneous air masses during calm and fair nights have been differentiated by Biel [2] from the *advection* frosts which result from large-scale air mass transportation. In the case of radiation frosts which are characterized by the presence of temperature inversions, protection is possible when heaters are used to warm air which rises to such a height that the temperature of the rising air is equal to the ambient temperature. Protection is also possible when, due to the inversion, air warmer than 32° F. is accessible to propellers which may be used to mix it with the colder air below.

In the case of advection frosts, whose arrival is unaccompanied by temperature inversions, neither ventilation nor heating provides effective protection. Radiant heating by infrared has been proposed as a protective measure for use in the case of advection frost [3].

The terms "radiation" and "advection" frost are somewhat arbitrary. Cool, clear, dry air, advected into a region, sets the stage for unobstructed radiation of heat from soil and plant. Radiative processes contribute to the heat exchange during an advection frost. Considerable loss of heat is due to the conduction of energy into the cold air and its subsequent transport.

It is generally stated that the late spring and early fall frosts are radiative in origin. Schaal et al. [4] and Decker [5] have described weather conditions which precede the advent of these radiative frosts. It appears to the authors, however, that the nature of late spring and early fall frosts has not been adequately documented. In all cases, determination of mean frost dates and calculation of the period between first fall and last spring frost dates has been based upon the minimum temperatures recorded at Weather Bureau first-order stations or climatological substations.

An attempt was made, and is reported herein, to distinguish the nature of late spring and early fall frosts by the study of weather records used in conjunction with maps of historical synoptic situations. The information obtained is applied to redefinition of the concept of "growing season" in Nebraska.

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[2] The term *frost*, as used in this paper, refers to a minimum shelter temperature of 32° F. or below.

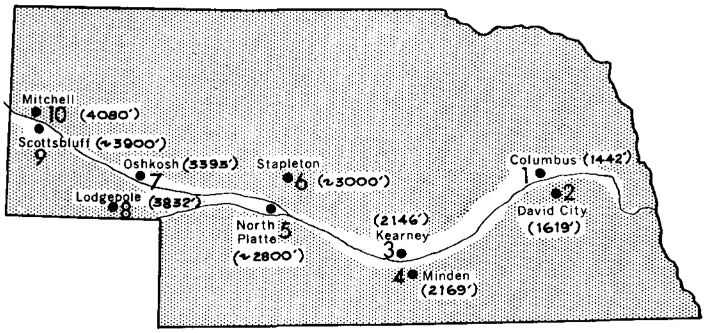

FIGURE 1.—Location of climatological substations used in the study. Odd-numbered stations are within the Platte Valley, even-numbered stations are on the adjoining uplands. Numbers in parentheses are station elevation in feet.

2. METHODS

The records of five pairs of stations on an east-west line along the Platte Valley were used in this study. Five valley stations of long record were chosen. These were paired with corresponding upland stations which were chosen on the basis of continuity of record. To accomplish this pairing, certain upland stations are located north of the valley and others to the south.

A map of the stations used is given as figure 1. Station description and histories are presented in table 1. For further details refer to [6].

The dates in April-May and September-October, on which minimum temperatures of 32° F. or below occurred were recorded for each of the stations. The period of record used was 1929–1958. Dates of frost occurrences were marked on calendar sheets which facilitated study of the data. Synoptic situations which prevailed on nights during which a minimum temperature of 32° F. or lower had been recorded were studied using Northern Hemisphere sea level maps and 500-mb. charts [7].

The separation of frosts that are primarily due to advection from those due to radiation must, in the absence of the vertical temperature distribution of the immediate area, be somewhat subjective. In some cases it is necessary that empirical decisions be reached. Nearly all radiation frosts are preceded by the advection of cool air into the area. The problem resolves itself into determining whether the advection in itself is sufficient to cause freezing temperatures or whether the air movement must become light enough to permit the formation of a radiation inversion.

It is not the purpose here to advocate the use of a certain system to distinguish between radiation and advection frosts. The following is offered only to provide an insight into the meteorological criteria employed by the authors to assist them in classifying the observed frosts.

1. Determination of whether the shelter air temperatures in the subject air mass were above or below 32° F. during periods when the immediate effects of net radiation were at a minimum in the lower layers. Factors considered included daytime vs. nighttime temperatures, wind speed, cloud cover, precipitation, etc.

2. Flow pattern at the 500-mb. level in relation to the movement of systems in the lower levels.

3. Temperature at the 500-mb. level in relation to

TABLE 1.—*Station descriptions and histories* [1]

Number	Location	Description
1	Columbus	A valley station about 1 mi. north of the Loup and 1½ mi. north of the Platte. The flat bottom land extends several miles south of the river and terminates at the foot of rather steep bluffs. The flat land extends farther to the north of the city, beyond which there is a gradual rise that builds into a rolling terrain. The station had several sites during the period, all of them within the city limits and with no appreciable change in the elevation of 1,442 ft.
2	David City	An upland station 17 mi. southeast of Columbus. The terrain is generally level in the vicinity of the station and to the south. David City is about 5 mi. south of the bluffs that separate the upland from the Platte Valley and 8–10 mi. south of the river. The station was moved several times during the period but never outside the city limits nor with any appreciable change in the elevation of 1,619 ft.
3	Kearney	A valley station, about 3 mi. north of the Platte River and located near a small diversion canal. Kearney is in a very broad and flat section of the Platte Valley. Rolling hills rising 100 to 200 ft. lie northwest of the city and also beyond the Wood River about 5 mi. to the north. The station was moved once during the period. Both sites are within the city limits at about the same elevation of 2,146 ft.
4	Minden	An upland station, 15 mi. south-southeast of Kearney. Lies on the relatively flat area that extends southwest, south, and east of Kearney. A very low east-west ridge lies about 20 mi. north of Minden separating it from the Platte Valley. There were three station sites during the period, all within the city limits and at about the same elevation of 2,169 ft.
5	North Platte	A valley station, with the present site about ½ mi. from the northern edge of the North Platte River. The valley floor is flat and rather narrow at this point, being about 10 mi. wide and at an elevation of 2,780 ft. Prior to 1949, observations were made at the City Office near the center of the city at an elevation 2,806 ft. This location is midway between the North Platte and South Platte Rivers which are about 2–3 mi. apart.[2]
6	Stapleton 5 SSE	An upland station 25 mi. northeast of North Platte. Station is located over rolling terrain at near 3,000 ft. elevation on the high ground between the Platte and the Loup Rivers. Prior to 1952, the station was located in Stapleton, 5 mi. to the north-northwest. At this site the terrain is also rolling but is north of the ridge and about 90 ft. lower than the present location.
7	Oshkosh	A valley station located just outside the south edge of town. There were several moves during the period, with all the other locations being within the city limits. Oshkosh is located in the bottom of the flat North Platte Valley. The valley is 2–3 mi. wide at this point with rather sharp height rises on either side of the valley. The elevation increases from 3,400 ft. at either edge of the valley to about 3,800 ft. in a distance of 4 mi. The station elevation is 3,393 ft.
8	Lodgepole	An upland station about 23 mi. southwest of Oshkosh. The terrain is rolling. The station has been within a block of its present location during the entire period. There is a sharp rise in elevation along the edge of the North Platte Valley, south of which the climb is gradual to an elevation slightly over 3,900 ft. and then falls off slowly to the station elevation of 3,832 ft.
9	Scottsbluff	A valley station, located in the heart of the flat North Platte Valley which is approximately 20 mi. wide, with ranges of hills parallel to the river on both sides. To the south, the hills average 600–700 ft. above the river with some projections upward to 1,000 ft. To the north, rolling hills are elevated 300 to 400 ft. The station has been located at the Municipal Airport since August 1940. There have been several airport sites with distances from the present site ranging from about 800 ft. to 2 mi. Elevations ranged from 3,849 ft. to 3,948 ft. Prior to the airport sites, the station was within the city limits about 5 mi. west-northwest of the first airport location, at an elevation of 3,888 ft.
10	Mitchell 5 E	Located about 5 mi. north-northwest of Scottsbluff station. Classified as an upland station. There is rolling farm land to the east and west and a mesa about 100 ft. higher than the station to the north. The station is at an elevation of 4,080 ft., which is 130 ft. above the current Scottsbluff station. The station has been at the same location throughout the period.

[1] All temperature data are from shelters at standard 5 ft. above ground except as noted at North Platte.
[2] Thermometers 7 ft. above ground; prior to 1949, 11 ft. above ground.

surface temperatures, to gain some appreciation of the overall frigidity and stability of the air mass.

4. Finally, sky, wind, and weather conditions at the site on the night in question.

5. The study being historical, properties of the air mass could be examined following the frost as well as prior to it.

Each frost event occurring after the last spring advection frost and including the last spring 32° F., regardless of cause, was studied. The corollary fall period was treated similarly. In consideration of the findings of Decker [5], who noted the 28° F. threshold to be a meaningful division between light and moderate frost, the following three types of frost were defined:

(R) Light radiation frost; weather shelter minimum 32°–29°F.

(R^*) Moderate radiation frost; shelter minimum 28°F. or below.

(A) Advection frost.

(F) The usual frost series based upon last spring or first fall 32°F. or below (regardless of cause).

3. STATISTICS

The mean dates of occurrence of last spring and first fall frosts (F) were computed for all 10 locations. Last spring and first fall advection frosts (A) were similarly computed. Mean dates of those last spring and first fall frosts which were due to radiation (R or R^*) were also computed, although those do not comprise a continuous series.

Thom and Shaw [1] have shown that freeze series in Iowa are randomly and normally distributed. Therefore, standard deviations and means are meaningful and were computed. Thom and Shaw were also able to show that series of spring and fall frost dates based on certain minimum temperature thresholds are independent and therefore the length of the frost-free period may also be described by the mean and standard deviation. Since new series, supplemental to the mean last spring or first fall minimum temperature-based frost dates (F) were being developed, it was felt that tests of randomness and adherence to normality should be applied to the following:

1. Date of last advection frost in spring (A_s) and first in fall (A_f). Subscripts s and f refer to spring and fall.
2. Length of potential growing season (A_s to A_f).
3. Possible increase in growing season $(F_s-A_s)+(A_f-F_f)$.
4. Number of radiation frosts (R or R^*) after last spring and before first fall advection frost.
5. Days intervening between last two spring frosts if the final frost was radiative; similarly for the first two frosts in fall.

Randomness of the series was evaluated by means of Swed and Eisenhart's tables as given by Tate and Clelland [8]. Normality was evaluated by Tate and Clelland's [8] simplification of the Kolmogorov-Smirnov test. The outcome of these statistical tests will be commented upon below.

TABLE 2.—*Percent distribution of last spring and first fall frost types*

Location	Spring frost types				Fall frost types			
	R (%)	R^* (%)	A (%)	$R+R^*$ (%)	R (%)	R^* (%)	A (%)	$R+R^*$ (%)
Columbus	64.4	17.8	17.8	82.2	71.5	10.7	17.8	82.2
David City	55.2	13.8	31.0	69.0	44.4	14.8	40.8	59.2
Kearney	53.5	35.7	10.8	89.2	53.6	10.8	35.6	64.4
Minden	78.6	10.7	10.7	89.3	50.0	7.1	42.9	57.1
North Platte	74.1	18.5	7.4	92.6	53.8	7.7	38.5	61.5
Stapleton	70.4	14.8	14.8	85.2	64.3	10.7	25.0	75.0
Oshkosh	65.5	20.7	13.8	86.2	32.1	25.0	42.9	57.1
Lodgepole	79.3	13.8	6.9	93.1	60.0	4.0	36.0	64.0
Scottsbluff	86.3	3.4	10.3	89.7	53.6	14.3	32.1	67.9
Mitchell	82.2	7.1	10.7	89.3	63.0	7.4	29.6	70.4

4. RESULTS

PERCENTAGE OF LAST SPRING AND FIRST FALL FROSTS ATTRIBUTABLE TO RADIATION AND ADVECTION

The percentage of last spring and first fall frost types at the 10 locations was computed. Results are shown in table 2. These percentages are highly variable. Analysis of variance of the percentage of advection frosts in spring and fall indicated no significant differences between valley and upland stations and no significant differences between east and west. However, the high percentage of all frosts due to advection, particularly in fall, indicated that further inquiry into the distribution of the two frost types would not be uninteresting.

MEAN DATES OF OCCURRENCE OF FROSTS OF DIFFERENT TYPES

Given in table 3a are the mean spring dates for last 32° F. minimum (F_s), last radiation frost (R_s or R^*_s), and last advective frost (A_s). Similar information for the fall season is given in table 3b. The spring and fall advection frost series were tested and found without exception to be random and normally distributed.

Application of the meteorological criteria given above resulted, as expected, in different mean dates for the newly defined frost series. The last spring radiation frosts (R_s or R^*_s) occur some 12–20 days after the last advection frosts (A_s) but closely approximate the mean date of last frost from all causes (F_s). The lack of difference between the latter two means reflects the fact that R_s or R^*_s constitute the final frost in most years. In a few cases when there was a very late outbreak of cold air, the individual A_s's were later than the mean of R_s or R^*_s. Last frosts of all types occur about 7–10 days earlier in the eastern part of the State than in the west.

The average gain of potential spring growing season (F_s-A_s) varies from 13 days in the east to 18 days in the western part of the State.

First fall frost (F_f) precedes first fall advection frost (A_f) by 8–16 days, the difference being greatest in the central portion of the Platte Valley. Frequently, the

TABLE 3.—*Mean and standard deviations of dates of various frost types in spring (a) and fall (b)*

a. SPRING FROST TYPES

Location	A_s [1] $\bar{x}$ [3] day no.	A_s [2] S days	R_s or R^*_s $\bar{x}$ day no.	R_s or R^*_s S days	F_s $\bar{x}$ day no.	F_s S days
Columbus	107.2 [4] (28)	11.9	119.4 (23)	13.0	120.1 (28)	12.7
David City	106.1 (29)	10.6	118.2 (20)	12.0	114.9 (29)	13.1
Kearney	105.2 (28)	11.2	117.6 (25)	10.9	117.8 (28)	10.9
Minden	104.9 (28)	11.5	121.4 (25)	12.5	121.8 (28)	12.1
North Platte	108.0 (27)	11.2	121.7 (25)	13.2	120.4 (27)	13.5
Stapleton	109.8 (27)	14.7	125.9 (23)	12.5	124.9 (27)	12.4
Oshkosh	111.9 (27)	13.9	128.1 (25)	11.7	127.0 (29)	10.4
Lodgepole	112.6 (29)	13.7	131.5 (27)	11.5	130.3 (29)	11.9
Scottsbluff	114.2 (29)	14.4	130.8 (26)	10.1	130.5 (29)	9.9
Mitchell	114.3 (28)	14.1	133.0 (25)	8.7	132.1 (28)	8.8

b. FALL FROST TYPES

Location	F_f [1] $\bar{x}$ [3] day no.	F_f [2] S days	R_f or R^*_f $\bar{x}$ day no.	R_f or R^*_f S days	A_f $\bar{x}$ day no.	A_f S days
Columbus	279.6 [4] (28)	10.7	279.3 (23)	10.6	293.3 (28)	10.3
David City	285.8 (27)	10.5	283.9 (16)	8.9	293.1 (27)	10.3
Kearney	283.5 (28)	10.3	282.6 (18)	9.3	289.6 (28)	10.5
Minden	282.4 (28)	11.1	280.1 (16)	11.6	290.3 (28)	9.9
North Platte	278.5 (26)	12.7	277.4 (16)	14.3	289.2 (26)	10.5
Stapleton	273.0 (28)	10.1	271.2 (21)	10.3	289.0 (28)	10.4
Oshkosh	276.0 (28)	12.2	273.8 (16)	13.7	285.5 (28)	10.7
Lodgepole	274.0 (25)	11.2	271.2 (16)	11.1	283.7 (25)	10.8
Scottsbluff	270.5 (28)	11.0	267.3 (19)	10.2	282.3 (28)	11.2
Mitchell	270.7 (27)	9.8	267.9 (19)	6.4	282.3 (27)	11.2

[1] $\bar{x}$=Mean.
[2] S=Standard deviation.
[3] Based on the system of numbering days of the ordinary year as January 1=day number 1; April 1=day number 91; September 1=day number 244.
[4] Number in parenthesis refers to items composing the mean.

first frost in fall is not observed until an outbreak of cold air occurs. This accounts for the fact that the mean date of first fall radiation frost (R_f or R^*_f) precedes the mean date of first 32° F. minimum (F_f) by 2 to 3 days.

MEAN LENGTH OF GROWING SEASON

As has been mentioned earlier, Thom and Shaw [1] were able to show the mean difference between fall and spring frost thresholds (the frostless season) to be normally distributed. The assumptions of randomness and normality were tested on the newly defined "potential growing season" (A_f-A_s). All series were found to be random and normally distributed at, with but few exceptions, the 10 percent probability level. All were found to be random at the 20 percent level. The means and standard deviations stemming from these calculations are presented in table 4.

TABLE 4.—*Number of days between last spring and first fall frosts of various types*

Location	Frost Free Period F_f-F_s [1] $\bar{x}$ days	F_f-F_s [2] S days	A_f-A_s $\bar{x}$ days	A_f-A_s S days	Difference $(A_f-A_s)-(F_f-F_s)$ $\bar{x}$ days	Difference $(A_f-A_s)-(F_f-F_s)$ S days
Columbus	158.2	14.6	185.4	16.2	27.2	17.7
David City	170.3	13.5	185.9	14.5	15.6	13.4
Kearney	165.0	14.9	184.1	15.5	19.1	13.4
Minden	160.0	15.9	185.1	15.9	25.1	19.4
North Platte	157.5	17.9	181.0	17.4	23.5	17.6
Stapleton	146.0	16.3	178.0	18.1	32.0	20.9
Oshkosh	148.7	16.8	173.3	18.3	24.6	16.0
Lodgepole	142.2	12.9	170.5	16.7	28.3	20.5
Scottsbluff	140.2	16.1	167.2	19.3	27.0	19.5
Mitchell	138.8	15.4	167.6	16.7	28.8	18.2

[1] $\bar{x}$=Mean.
[2] S=Standard deviation.

The mean number of additional growing days $(A_f-A_s)-(F_f-F_s)$ varies between 15 and 32 days with a slightly greater advantage in the western end of the State.

NUMBERS OF SPRING AND FALL FROSTS

The utility of the information previously presented depends, in large measure, upon the numbers of radiation frosts which occur during the period between the last spring or first fall radiation frost and the related seasonal advection frost. Numbers of annual frosts for the periods under consideration were found to be randomly distributed but deviated significantly from a normal distribution. Numbers of such frosts and their range are presented in table 5. The modal number of these frosts, excluding years when advection accounted for the last spring or first fall frost is also given in table 5.

The mean number of radiation frosts is greater during both spring and fall in the western part of the State. The range in the number of radiation frosts is also greater, except in the case of the easternmost pair of stations (Columbus and David City) which experienced a single fall season (1932) of repetitive radiation frosts.

The modal numbers of radiation frosts after last advection in spring and before first advection in fall, even when zero years are excluded from consideration, are quite low. Distributions are heavily skewed toward the low frequencies.

FROSTLESS DAYS BETWEEN LAST TWO SPRING AND FIRST TWO FALL FROSTS

The number of days intervening between the next to last and the last spring frosts and first and second fall

Table 5.—*Number of frost events occurring between the last spring and first fall radiation and related seasonal advection*

Location	Seasonal Period: A_s to R_s			Seasonal Period: R_f to A_f		
	[1] $\bar{x}$ days	[2] Range days	[3] Mode days	$\bar{x}$ days	Range days	Mode days
Columbus	2.5 (28)[4]	0–7	2 (24)	2.3 (28)	0–12	1 (24)
David City	2.0 (28)	0–7	1 (20)	1.7 (25)	0–12	1 (17)
Kearney	2.1 (28)	0–9	1 (24)	1.5 (26)	0–5	2 (17)
Minden	3.7 (29)	0–13	2 (26)	1.2 (26)	0–4	1 (16)
North Platte	2.6 (27)	0–9	1 (25)	2.1 (26)	0–8	1 (11)
Stapleton	3.5 (27)	0–9	2 (23)	2.8 (28)	0–8	3 (21)
Oshkosh	3.4 (29)	0–13	2 (24)	1.9 (28)	0–8	2 (15)
Lodgepole	4.3 (29)	0–13	2 (26)	2.0 (25)	0–8	2 (16)
Scottsbluff	4.7 (29)	0–18	2 (26)	3.2 (28)	0–11	1 (18)
Mitchell	4.1 (28)	0–15	2 (25)	2.5 (27)	0–10	1 (19)

[1] $\bar{x}$=Mean number of frost nights, all years.
[2] Range, all years.
[3] Mode of frost night number for years when radiation frost was last in spring or first in fall.
[4] Numbers in parenthesis refer to years included in the computations.

Table 6.—*Numbers of intervening days between last two frosts in spring and first two frosts in fall*

Location	Season: Spring		Season: Fall	
	[1] Mean A days	[2] Mean B days	Mean A days	Mean B days
Columbus	6.4 [3] (28)	7.5 (24)	7.4 (28)	8.6 (24)
David City	5.4 (28)	7.6 (20)	4.3 (25)	6.0 (17)
Kearney	7.5 (28)	8.8 (24)	4.8 (26)	7.4 (17)
Minden	8.9 (29)	9.9 (26)	5.3 (26)	8.7 (16)
North Platte	7.8 (27)	8.4 (25)	6.8 (26)	11.1 (11)
Stapleton	5.6 (27)	6.5 (23)	10.0 (28)	13.3 (21)
Oshkosh	7.1 (29)	8.6 (24)	4.9 (28)	9.2 (15)
Lodgepole	6.0 (29)	6.7 (26)	5.2 (25)	8.1 (16)
Scottsbluff	5.0 (29)	5.6 (26)	5.4 (28)	8.4 (18)
Mitchell	7.4 (28)	8.2 (25)	7.5 (27)	10.6 (19)

[1] Mean A=all years included in computation.
[2] Mean B=years when last spring or first fall frost was advective excluded from computation.
[3] Number in parenthesis refers to years included in the mean.

frosts was determined. If last spring or first fall frost was due to radiation, the number of days until next frost of any type was counted. If last spring or first fall frost was of the advection type, a zero value was assigned. Results of the tabulation are shown in table 6. Numbers of intervening days were tested and found to be random. The hypothesis of normality was rejected at the 10 percent level of significance, however.

Extension of the spring growing season, possible with one night of frost protection, ranges from 5 to 9 days over all years averaged. Since radiation causes the greatest portion of last spring frosts, the average is not materially altered by exclusion of the zero years. A much larger proportion of first fall frosts is due to advection. A more realistic picture of the potential benefit to be gained from frost protection can be obtained by excluding the zero years from computation of the mean in fall. With zero years excluded, season extensibility ranges from 6 to 13 days.

5. DISCUSSION

Our data demonstrate the fact that across Nebraska in spring frost protection would permit from 12 to 20 days of earlier plantings, providing the soil temperatures are sufficiently high for initiation of crop growth. Mean dates of last advection frost occur in the area studied between April 7 and April 14. The 12 to 20 days of growing weather before the mean date of last 32° F. minimum temperatures can be important for the growing of certain specialized vegetable crops and can be critical for fruit development.

In fall, the mean date of first 32° F. minimum temperature-based frost occurs between September 27 and October 10. The mean interval between first radiation and first advection frost varies from 8 to 16 days. At this time of year, growing conditions are excellent for the maturation of many vegetable crops. Further, even a few days of extra operation made possible by frost protection, can be of great importance to the food processing industry.

It was found that the physiographic effect, with respect to upland and valley locations, was outweighed by other factors in determining the type and timing of frost. It is likely that the local terrain in the immediate vicinity of the station is more important than whether the station is in the valley proper or on the adjoining high ground.

6. CONCLUSIONS

Through careful analysis of historical synoptic sea level maps and 500-mb. charts it is possible, in most cases, to determine whether past occurrences of 32° F. or lower minimum temperatures were induced by radiation or advection.

The records of 10 Nebraska stations on an east-west line through and above the Platte Valley were studied in this way. No consistent differences are observed in percentage of last spring or first fall frosts due to advection or radiation across the State. However, mean dates of last spring advection-induced frosts differ by as much as 20 days at certain locations from the mean date based upon either last 32° F. minimum temperature or last radiation-induced frost. A similar situation exists in fall but here, because of the higher proportion of first frost events due to advection, the differences between means based upon either first 32° F. minimum or first radiation and means based upon first advection are not so great as in the spring.

Mean length of the potential growing season (defined as the number of days between last spring and first fall advection frost) is from 15 to 32 days longer than the 32° F. minimum-based definition of growing season.

The number of radiation frosts intervening between last spring or first fall radiation frost and their associated seasonal advection frost varies greatly from year to year. Generally mean numbers are greater in spring than in fall and greater in the western than in the eastern part of the State.

The mean number of days between the last two frost events in spring and first two in fall, when last spring and first fall frosts are radiation-induced, ranges from 4 to 10 according to season and location.

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Weather Note

AN UNUSUAL HAIL FORMATION

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1. DESCRIPTION OF HAILSTONES

Dr. Freier made photographs and a drawing of some unusual hailstones that fell on St. Paul., Minn., on Saturday afternoon, June 23, 1962. He brought them to me for a meteorological explanation of the phenomenon which, I am afraid, is beyond my capabilities. The structure of the stones is so symmetrical as well as unusual that it seemed worthwhile to record the phenomenon in the hope that this bit of order may eventually aid the understanding of the process of hail formation.

The hailstones arrived at the ground with the greatest dimensions about 1.5 in., but were disc shaped with a depth approximately ⅓ the lateral extent (fig. 1 is an idealized sketch of the configuration of the stones). The center of the hailstone appeared to be a normal milky rounded hailstone. Surrounding this cloudy center there was one or more unusually broad rings of clear ice [1] and surroundings these rings (or ring) was a rim of symmetrically arranged normal milky hailstones. Figures 2 and 3 are photographs of the hailstones at successive stages of melt. The rim of spherical hailstones is particularly clear in the melting stone shown by the arrow in figure 3.

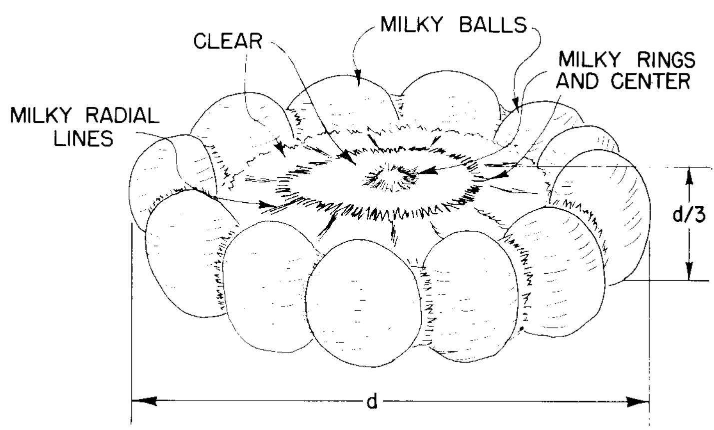

FIGURE 1.—Schematic sketch of hailstone structure.

[1] Clear ice presumably can form only from the freezing of supercooled raindrops from which the air has been removed from solution. Since such freezing is very inefficient, a clear layer 5 mm. thick must require an unusually long path in a cloud of supercooled drops.