Proceedings of the Iowa Academy of Science
Volume 51 | Annual Issue
Article 11

1944

Microclimatic Differences in Minimum Temperature and Variations in Frost Injury to Hillculture Plants

J. M. Aikman
Iowa Agricultural Experiment Station

G. L. Brackett
Iowa Agricultural Experiment Station

MICROCLIMATIC DIFFERENCES IN MINIMUM TEMPERATURE AND VARIATIONS IN FROST INJURY TO HILLCULTURE PLANTS[1]

J. M. AIKMAN AND G. L. BRACKETT

Quantitative investigations of climatic factors in the immediate habitat of both native and cultivated plants in the field and of the effect of these factors on the growth of the plants have proved that climatic factors may vary sufficiently within relatively narrow limits in space to produce significant variations in the development of plants. These contributions have had an important influence on the growth of the concept of microclimate and on the recent interest and research in this field. At present there is urgent need of information on the determination of the size of microclimatic areas and of the critical factors to be measured (2, 3, 6, 7, 10). These two questions must be considered on the basis of the magnitude of microclimatic differences and of the nature and degree of reaction of the plants to them. The microclimatic area considered needs be no smaller and the number of factors measured no greater than is necessary to determine definite relationships between differences in climatic factors and variations in plant response.

Of the climatic factors influencing the growth and yield of fruit trees and vines and other hillculture plants in southeastern Iowa, with the possible exception of exposure to excessive drying conditions on southwest facing slopes, the most important is low temperature. Modifications in low temperature and in dryness of the air caused by high temperature, low humidity and air movement have been of sufficient magnitude among several sites within the limits of the Hillculture farm at Floris, Iowa to affect significantly the establishment, growth and yield of plants (1, 2).

The importance of the selection of sites for orchards and vineyards on the basis of elevation and degree and aspect of slope is common knowledge. Grapes are usually planted on south or east facing slopes to insure sufficient exposure to the sun for proper ripening of the fruit. For stone fruits a north slope may prove advantageous because of the consequent delay in blooming and maturity. Most recommendations on fruit culture emphasize the importance of adequate cold air drainage (4, 5, 8, 9, 12).

On May 16, 1942 frost injury occurred on the lower portions of the south slopes of two of the five experimental vineyards at the Floris station which resulted in the loss of the 1942 grape crop. There was no frost injury to the grapes in the upper portions of these slopes or in any of the other vineyards. Since the grapes were located on plowed strips on the exact contour, the line of demarcation between injury to the new growth and absence of injury sufficient to destroy the crop was very narrow and distinct, following very closely the contour

[1]Journal Paper No. J-1211 of the Iowa Agricultural Experiment Station, Iowa. Project 582.

rows. The two areas injured by frost were one-fourth and one-half acre in size.

Temperature records from the soil-air thermographs maintained, in modified government shelters located at ground level, in different microclimatic areas on the farm showed the minimum air temperature on this date to be 31 degrees Fahrenheit at one of the stations, 30

Table 1. Minimum air temperature values from thermograph records at five stations on the Hillculture farm for the last two frost periods in the spring of 1942. Eleations are given in feet above the elevation of the lowest point on the farm (690 ft. approx. elev.)

1942	Station 1 Gentle south-east slope Elevation: 80	Station 2 Middle west slope Elevation: 55	Station 3 Southeast slope Elevation: 65	Station 4 Middle south slope Elevation: 45	Station 5 On flood-plain Elevation: 20
April 20.....	29° F.	27° F.	29° F.	28° F.	28° F.
May 16.....	31	29	30	30	30

degrees at three of the stations and 29 degrees at one of the stations (table 1). Station 4, where the reading was 30 degrees Fahrenheit, was located on the south slope in vineyard 1 near the upper limit of the smaller area of frost injury. The killing of the entire new growth of the vines, three to five inches in length, on May 16 constituted what seemed to be very severe injury in view of the slight reduction below freezing temperature recorded at the stations.

Records of climatological data of the U. S. weather bureau show minimum temperature readings of 36 degrees Fahrenheit or above for stations in Davis and adjoining counties on May 16, 1942. These records show that the latest date of below freezing temperature for the general vicinity in the spring of 1942 was on April 20 at Fairfield when the minimum temperature was 30 degrees Fahrenheit. On that date the lowest reading recorded at the Floris station was 27 degrees (table 1), although the nearest Weather Bureau station at Bloomfield recorded a reading of 33 degrees.

The occurrence of definite frost injury in microclimatic areas much later in the spring and earlier in the fall than seemed possible from an examination of Weather Bureau records, has been noted many times by a number of investigators. This condition is possible because the weather stations are located in sites which will give a mean, overall climatological record in spite of variations within small areas. It would seem impossible as well as impracticable to have a *sufficient* number of climatological stations to give complete coverage to include variations among microclimatic areas.

Even in special studies of microclimatic areas, climatological determinations may not be adequate. There is little doubt but that the temperature records at the Floris Station for April and May, 1942 were inadequate to supply the necessary information to explain the extent and degree of frost injury in spite of the fact that recording thermographs were located at five selected sites within a 100-acre area. In order to supplement these thermograph data and to obtain a more nearly exact quantitative record of minimum temperature conditions in one critical microclimatic area during the growing season of 1943, minimum temperature readings were taken with minimum thermometers at three selected sites in and near the smaller area of 1942 frost injury.

The sites selected were at the top of the hill above vineyard 1, midway of vineyard 1 and on the narrow floodplain bordering a small stream at the bottom of the slope. The minimum thermometers were obtained from the U. S. Weather Bureau office at Des Moines, Iowa. They were checked against each other at intervals throughout the period of use. Care was taken that thermometers with broken columns were not used. The thermometers were attached by means of U. S. Government Weather Bureau mountings to short 2 x 4-inch sections which were nailed to posts at a height of three feet. The thermometers were not sheltered since the purpose of the readings was to determine the exact minimum temperature to which the plants were exposed usually at night. Tests at station 4 in vineyard 1 showed that minimum temperature readings from unsheltered thermometers varied from two degrees lower to about one-half degree higher than those from thermometers in a modified government type shelter. The only correction which must be made is in the event the lowest temperature occurs during daylight hours when radiation of the sun becomes a factor, which did not occur in this experiment. The readings were taken and recorded and the thermometers reset during the period of approximately highest temperature of the day. The Weather Bureau station readings included in the table for comparison were taken from the Weather Bureau records of climatological data. These minimum thermometers were enclosed in shelters of the U. S. Weather Bureau type.

Table 2 is a complete record of the minimum temperature data from the three stations in the vicinity of vineyard 1 and from two Weather Bureau stations: on the top of the hill, at the middle elevation of vineyard 1 near the upper limit of frost injury of 1942, on the narrow floodplain at the bottom of the slope, at the Weather Bureau station at Bloomfield 12 miles south and at the Weather Bureau station at Ottumwa 15 miles north of the station. The distance between the hilltop station and the station on the floodplain was approximately 600 yards. The mid-slope station was approximately 150 yards down the slope from the hilltop station. The difference in elevation, as shown in the table, between the upper and middle stations was approximately 65 feet and between the middle and lower stations was 35 feet.

The difference in minimum temperature between the hilltop station and the Bloomfield Weather Bureau station for the period was very slight in spite of the fact that there is a difference in elevation of approximately 25 feet and a distance of 12 miles between these two stations. The reason for the close agreement in these minimum tempera-

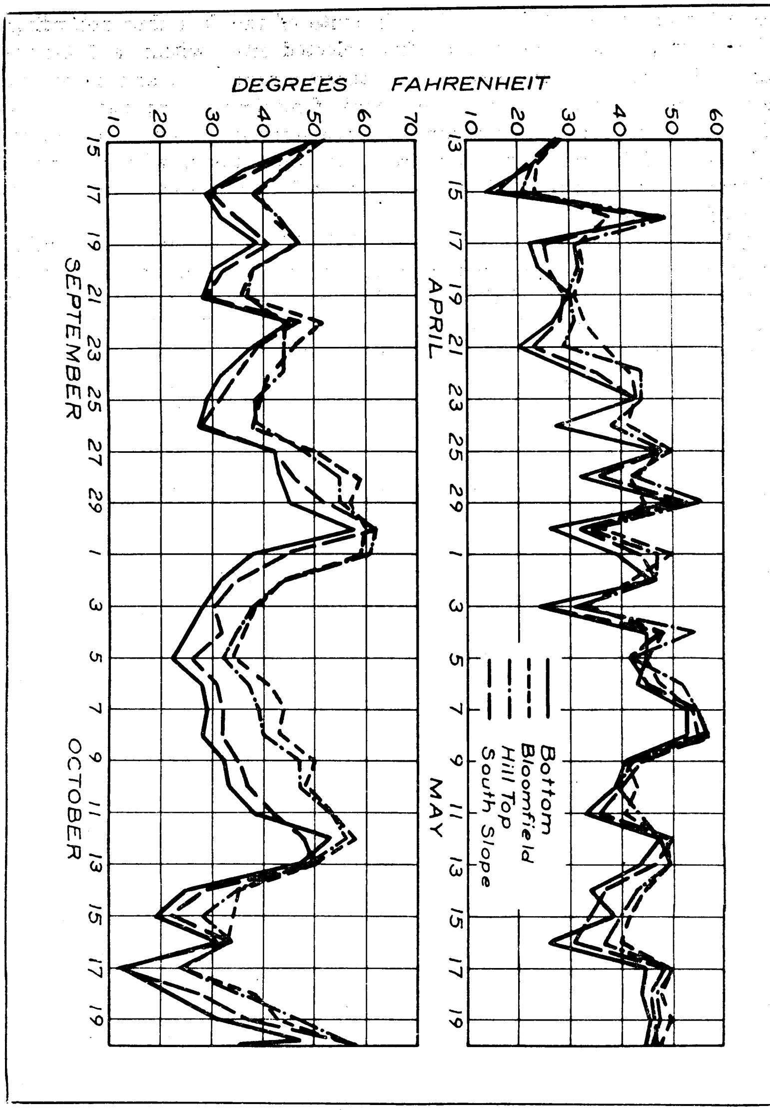

Figure 1. Comparison of minimum temperature readings at three stations on a given slope and at the nearest Weather Bureau station (Bloomfield) for critical frost periods during the growing season of 1943.

ture readings would seem to be the fact that each station is on the upland at the highest point of the vicinity. The greatest modifications in temperature were among the three stations on the farm probably because cold air drainage is poor at the mid-slope and floodplain stations. Inadequate cold air drainage at the mid-slope station may be attributed to the fact that a stand of native timber is located not far below it on the slope and at the floodplain station to the fact that it is at the bottom of the slope.

The data in table 2 show that the last frost in the spring of 1943 at Bloomfield occurred on April 19, at Ottumwa on April 21 and at the hilltop station on May 1. At the hilltop station the first time in the fall that the minimum temperature dropped to 32 degrees was October 5 but no frost was apparent. On October 15 the first frost in the fall occurred at the hilltop station and at Ottumwa but the minimum temperature did not fall below freezing at Bloomfield till October 17 when the minimum temperature was 25 degrees or below at all three of the stations.

Table 2. Comparison of minimum temperature readings in degrees F. at three stations on a south slope and at the two nearest Weather Bureau stations (Ottumwa and Bloomfield) for critical frost periods during the growing season of 1943.

Date	Otwa.	Blmd.	Hill-top	Mid-slope	Bot-tom	Date	Otwa.	Blmd.	Hill-top	Mid-slope	Bot-tom
	*649	825	800	735	700						
Apr.						Sept.					
13	31	29	29	28	....	15	53	50	52	51	51
14	25	24	23	22	23	16	43	45	45	39	37
15	22	23	21	15	14	17	37	39	38	30	29
16	48	38	49	48	49	18	40	42	43	35	32
17	32	32	31	25	22	19	47	47	47	41	39
18	36	33	32	26	24	20	38	38	38	32	30
19	31	31	30	29	30	21	37	36	37	29	28
20	31	33	31	28	27	22	52	52	44	47	45
21	29	37	29	23	20	23	43	46	44	39	38
22	45	42	44	35	32	24	40	41	44	35	32
23	47	43	44	43	43	25	40	39	38	31	29
24	37	41	38	29	27	26	37	38	39	28	27
25	53	50	48	49	48	27	51	50	48	42	42
26	45	42	43	36	32	28	51	59	55	46	43
27	54	45	56	53	51	29	53	57	55	52	45
28	37	36	34	32	26	30	62	60	62	62	58
29	50	50	47	44	39	Oct.					
30	48	42	47	47	46	1	59	59	61	45	38
May						2	45	44	44	35	32
1	36	33	31	25	23	3	37	39	38	30	28
2	52	48	55	48	45	4	35	36	35	32	25
3	45	45	42	42	45	5	34	34	32	26	22
4	51	48	52	45	43	6	37	41	37	31	28
5	57	54	55	55	53	7	40	44	39	32	29
6	57	55	57	57	53	8	38	43	40	32	28
7	43	41	42	44	41	9	43	50	47	35	32
8	41	43	39	40	39	10	43	48	47	37	33
9	43	41	43	36	33	11	48	53	53	42	38
10	50	49	48	50	48	12	59	58	56	48	53
11	50	50	50	47	44	13	51	50	49	50	47
12	44	45	43	37	34	14	35	35	35	29	25
13	44	42	40	41	39	15	30	34	28	22	19
14	38	40	37	31	26	16	36	33	34	34	31
15	51	50	50	49	45	17	23	25	24	11	12
16	48	48	47	46	44	18	32	38	36	27	22
17	49	50	48	47	46	19	47	43	47	37	31
18	48	48	46	47	45	20	56	56	58	56	47

*Approximate elevation in feet above sea level.

In contrast to the data from the hilltop and two Weather Bureau stations, the last frost in the spring at the mid-slope and at the bottom of the slope was on May 14 and the first frost in the fall was on September. 17. On the basis of minimum temperature readings of 32° Fahrenheit or below the frost-free season in 1943 was 181 days at Bloomfield, 177 at Ottumwa, 158 at the hilltop station and 126 at the mid-slope and bottom stations. In 1942 the frost-free season at both Ottumwa and Bloomfield was 166 days and on the floodplain at the farm was 128 days. Based on an approximate 40-year average, the longest frost-free season in Iowa was 182 days at Keokuk in the southeastern corner of the state and the shortest was 132 days at Sibley near the northwestern corner of the state (11).

The modifications in minimum temperature among the stations on the farm and the Bloomfield station are shown graphically in figure 1. This figure shows that at almost weekly intervals during the critical spring and fall periods of 1943 freezing temperature occurred at the two lower stations while the minimum temperature was above or only slightly below freezing at the hilltop station and the two Weather Bureau stations. The comparative duration of the periods of low temperature, which is a very important factor in plant response, is also easily discernable from the graph of figure 1.

Evaluation of the areas of the farm on the basis of temperature data at several stations and of frost injury to plants and a computation from the contour map of the farm of the total low-elevation acreage, indicate that approximately 30 acres of the 187-acre farm should be placed in the same class with the mid-slope and bottom stations in having almost weekly intervals of freezing temperature during the critical fall and spring periods of 1943. The low temperature intervals were not so frequent nor so evenly spaced in 1942 but they were at least as severe as in 1943. Although the size of this critical frost area is larger in proportion to the size of the farm than the average because of extremely steep slopes and lack of clearing, it would seem advisable to give more attention than has previously been considered necessary to delimiting the critical frost areas of most farms.

Frost injury to the grapes and grafted black walnuts in the critical frost areas of the Hillculture farm was extremely severe on May 16, 1942. There was minor injury to other plants but there was a good crop of plums on all slopes and of peaches on a northeast slope. Peaches on a south slope bore no fruit. The new growth on the grapes (three to five inches in length) in these critical areas was killed as was the new growth (four to six inches) on the grafted black walnuts planted in individual basins on a protected southwest slope of approximately the same elevation as the portions of the vineyards where the grapes were injured. The native wooded area to the southwest of this walnut basin slope, which protects the trees from drying winds in the summer, was probably the critical factor in preventing cold air drainage from the slope.

Frost injury to the grapes and walnuts in the critical frost areas was slight on May 14, 1943. The new growth, of approximately two inches, was injured but recovered. There was very little apparent reduction in fruit yield of the plants. In general, however, the 1943 season was not as favorable for fruit production as was the 1942 season. There was a failure of apples, plums and peaches in the entire region. One important factor in the failure of the plum crop on the farm was the almost total lack of pollination of bees becaus eof the wet, cold spring. Although pollenizer plums are distributed throughout the experimental plum orchards, the Minnesota plum varieties seem to require pollinating activity of bees for the best setting of fruit.

In attempting to explain the difference in frost injury in the same frost areas in 1942 and 1943 the chief factors to be considered seem to be the difference in depression in temperature and the duration of the depression, and the difference in the development of the plants when the frost occurred. Since readings from unprotected minimum thermometers were not taken in 1942, no exact comparison can be made with the values in table 2. However from a comparison of thermograph records for the two periods, one of which was taken each year from the station in vineyard 1, it has been determined that the reduction in temperature in the frost areas was only one degree less in 1943 than in 1942. The duration of the period of temperature reduction at or below 32 degrees Fahrenheit, as shown on the thermograph records, was approximately the same: four hours.

The difference in the development of the plants when frost occurred is indicated by the difference in development of new growth: in 1942, three to five inches in the grape, four to six inches in the walnuts; in 1943, two inches in both the grape and the walnut. Although morphological studies of the new growth were not made, it was evident that development of the flowers was further advanced on May 16, 1942 than on May 14, 1943. Since new growth in 1942 was at least double that in 1943, we may assume that the plants were physiologically more active when frost occurred in 1942 than in 1943.

The cause of the difference in development and the degree of difference is indicated by an examination of the temperature conditions from thermograph records for a period of one month proceeding the last frost period. In 1942, growth was initiated by a warm period beginning on April 13. In spite of the fact that there was one freezing temperature of 29 degrees Fahrenheit on April 19, there was no time during this 33-day period when the average daily temperature fell below a plant zero of 40 degrees. Temperature conditions were favorable for growth during the entire period. In 1943 growth was initiated 10 days later than in 1942 because there was only one night during this 10-day period when frost did not occur. When growth was initiated on April 23, 1943, temperature conditions were not favorable for rapid growth. From April 23 to May 16 the average temperature was approximately 52 compared to 60 in 1942.

Preceding the last frost on May 16, 1942 there was a growth period of 33 days with a total of 930 effective heat units (above a plant zero of 40° Fahrenheit) compared to a growth period of 21 days with a total of slightly less than 600 effective heat units proceeding the last frost on May 14, 1943. As was anticipated the ratio between the total effective heat units in the two seasons was not as high as the ratio between total new growth although probably the chief factor causing the difference in growth was temperature since the soil moisture supply was adequate. This apparent discrepency may be attributed to the fact that it has been determined experimentally that in general the rate of plant growth is approximately doubled for every increase of 18° Fahrenheit in temperature, till the most favorable temperature for the given plant is reached.

Since time is an important factor in the morphological and physiological changes which occur following the initiation of growth in woody deciduous plants in the spring, the increase in the length of growing time by 10 days at the beginning and two days at the close of the 1942 pre-frost period was doubtless a contributing factor in advancing the stage of development of the plants in 1942 which made them very susceptible to frost injury. However this was probably not as important a factor as the forcing effect of high temperature in 1942 compared to the hardening effect of low temperature and retarded development in 1943.

The preceding data on variations in temperature between the two seasons indicate that seasonal variations and their effect on plant growth must be considered in a study of microclimates. It is a well known fact that depressions in temperature, of a few degrees, caused by inadequate cold air drainage do not cause injurious effects every season. In sites where the depression in temperature may be six or eight degrees or more below the temperature of the upland, however, danger of frost injury is always a possibility.

The ranking of the sites on a farm on the basis of adequacy of cold air drainage, length of growing season and other temperature values, may easily be done with the use of three or four minimum thermometers. In measuring cold air drainage, the readings should be taken after the cold air has moved in and cold air drainage down the slope is well established.

Many of the most severe storms in winter which cause freezing damage move in so rapidly that damage to orchards and other woody plantations is at least as severe on the upland as on the lower slopes or bottoms. The storm of November 11, 1940 which caused the destruction of so many orchards in the middle west was in this class as was also the storm of September 28, 1942 which caused extremely severe damage to grafted nut trees and other trees throughout Iowa. In the former storm the variation in temperature among the four weather stations on the farm was only 3 degrees Fahrenheit but the lowest temperature was at the stations of highest elevation. In the latter storm, the temperature among all of the stations did not vary one degree.

Table 3. Comparison of minimum temperature in degrees F. during winter storm periods at three elevations on a south slope and at the two nearest Weather Bureau stations. 1943-1944.

Date	Ottumwa	Bloomfield	Hilltop	Mid-slope	Bottom of slope
Dec. 16.....	— 7	—9 (Dec. 15)	—10	—13	—16
Dec. 23.....	— 3	— 3	— 5	— 9	—10
Jan. 8.....	— 3	— 6	— 5	— 7	—10
Jan. 13.....	— 2	6	— 3	— 8	—10
Feb. 12.....	—12	—15	—15	—18	—22
Feb. 18.....	— 4	— 5	— 6	— 9	—17

Minimum temperature readings were continued at the same stations during the winter of 1943-1944, at weekly intervals, in order to learn something of the nature and degree of microclimatic temperature variations in winter storms on the farm. The coldest day of each week was determined by comparison with the thermograph records from the weather stations located on the farm. In table 3 are listed a few selected readings to show some of the widest variations among the stations compared to Weather Bureau records.

Assuming that the differences between the readings at the Weather Bureau stations and the hilltop station are attributable to the unsheltered thermometer at the hilltop station, the temperature depression at the other two farm stations may be great enough to endanger some plants that are adapted to the temperature conditions of the hilltop station. Allowing for the unsheltered thermometers, both the lower stations had lower minimum temperature than any Weather Bureau station in Iowa on December 16 and the bottom station was lowest on January 13. These data seem to indicate that evaluation of sites on a winter temperature basis for fruit trees, vines and other woodly plants by means of minimum temperature readings would be advisable in order to prevent possible winter-killing. It would also seem desirable to designate elevation of the site in making recommendations on the adaptation of plants to different regions or zones.

Botany and Plant Pathology Section,
Iowa Agricultural Experiment Station and
Soil Conservation Service, U. S. D. A.

Literature Cited

1. Aikman, J. M. 1941. The effect of aspect of slope on climatic factors. Iowa State Coll. Jour. Sci. 15:161-167.
2. Aikman, J. M., and Ivan L. Boyd. 1941. Adaptation studies of plants for soil conservation purposes in southern Iowa. Proc. Iowa Acad. Sci. 48:117-121.
3. Bair, Roy A. 1942. Climatological measurements for use in the prediction of maize yield. Ecol. 23:79-88.

4. Barnett, R. J. 1940. Growing an orchard in Kansas. Kans. Agr. Exp. Sta. Bull. 290.
5. Batchelor, L. D., and F. L. West. 1915. Variation in minimum temperature due to the topography of a mountain valley in its relation to fruit growing. Utah Agr. Exp. Sta. Bull. 141.
6. Geiger, Rudolf. 1930. Microklima und Pflanzenklima. Verlag Gebrüder Bornträger, Berlin.
7. Hildreth, A. C., J. R. Magness, and John W. Mitchell. 1941. Effects of climatic factors on growing plants. U. S. Dept. Agr. Yearbook: 292-307.
8. Kinman, C. F., and J. R. Magness. 1940. Pear growing in the Pacific coast states. U. S. Dept. Agr. Farm. Bull. 1739.
9. Magness, J. R., and H. P. Traub. 1941. Climatic adaptation of fruit and nut crops. U. S. Dept. Agr. Yearbook: 400-420.
10. Potzger, J. E. 1939. Microclimate and a notable case of its influence on a ridge in central Indiana. Ecol. 20:29-37.
11. Reed, Charles D. 1941. Climate of Iowa. U. S. Dept. Agr. Yearbook: 862-872.
12. Sandstrom, E. P., F. M. Green, and L. R. Bryant. 1940. Orchard management in Colorado. Colo. Agr. Exp. Sta. Bull. 458.