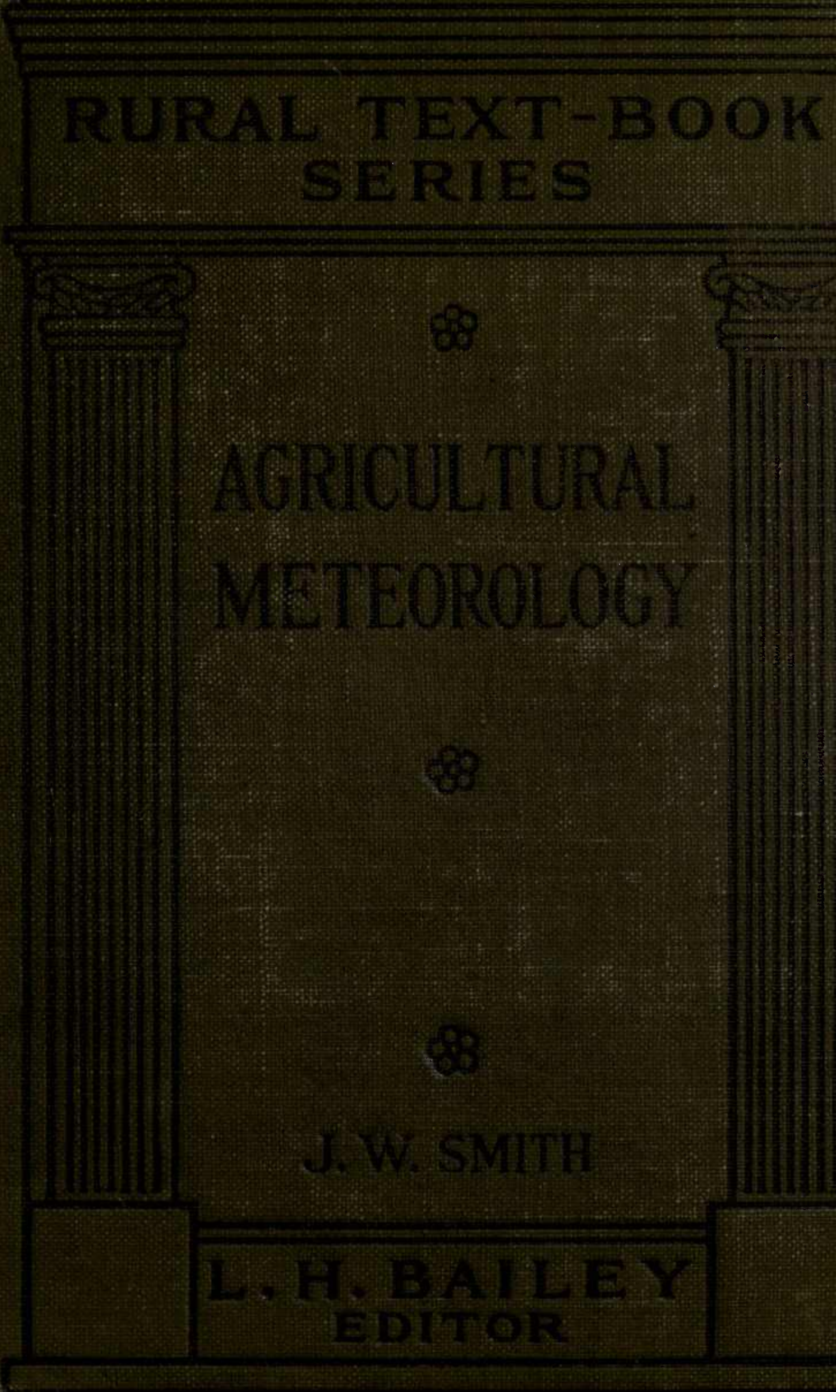
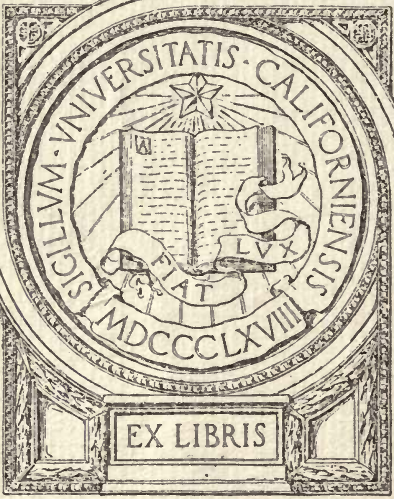


RURAL TEXT-BOOK
SERIES

AGRICULTURAL
METEOROLOGY

J. W. SMITH

L. H. BAILEY
EDITOR



AGRICULTURAL METEOROLOGY

The Rural Text-Book Series

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AGRICULTURAL METEOROLOGY

THE EFFECT OF WEATHER ON CROPS

BY
ohn
J. WARREN SMITH, B.S.M.S.
SPECIALIST IN WEATHER AND CROPS

New York
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1920

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PREFACE

This book is designed primarily for university and college students, but it is entirely practicable for agricultural high-schools, and for farmers' reading-courses. It will prove of interest to individuals who wish information regarding climate and crops, and the effect of the weather in varying the yield of crops.

The text is the outgrowth of over thirty years in climate and crop work in different sections of the United States, and fifteen years contemporary instruction in meteorology and agricultural meteorology at the Ohio State University.

The advanced students, especially, should use the available references at the close of each chapter. The instructor should extend the exercises and practicums, as the time available will admit. Original investigations of the effect of weather on the yield of crops can be made very readily by following the outlined procedure. Published climatic data may be found for individual states by writing the State Section Director, United States Weather Bureau, or the Chief of the Weather Bureau at Washington, D. C. Crop yield data can be obtained from the State Departments of Agriculture, or from the Bureau of Crop Estimates, Washington, D. C.

As this is the first text on the subject of agricultural meteorology that has ever been prepared, the author has had recourse to articles and papers by ecologists, botanists, plant physiologists and pathologists, entomologists, and the like. It has not been practicable to give the references in the text, but the literature at the close of each chapter indicates most of the articles that have been referred to. Charts that are not original or credited in the footnotes are from the publications indicated in the references at the close of each chapter.

We wish to give full credit to each author from whom information has been obtained. It is desired also to give due credit to various officials of the Weather Bureau whose papers and studies have been drawn on in the following pages.

Some of the data were from original studies made by the following-named students while taking the course in agricultural meteorology at the Ohio State University:

H. N. Bunnell.
Edward B. Scott.
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Washington, D. C.
May 1, 1920.

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AGRICULTURAL METEOROLOGY

AGRICULTURAL METEOROLOGY

CHAPTER I

INTRODUCTORY METEOROLOGY

Meteorology is a study of the phenomena of the atmosphere and includes what is known as weather and climate.

1. **Weather** is the condition of the atmosphere at a definite time. One may speak of the weather that prevailed last week or that is being experienced today. It includes all the phenomena of the air that surrounds us, such as pressure, temperature, moisture, wind, and the like.

2. **Climate** deals with the averages and the extremes of the weather that prevail at any place. Thus it will be seen that weather relates to time and climate to location.

THE ATMOSPHERE

3. **Composition.**—The air is composed of a mixture of a number of gases and vapors that differ widely from one another.

4. **Nitrogen,** which constitutes about 78 per cent of the volume of the atmosphere, is an inert gas; that is, it does not easily combine chemically with other elements, and by diluting the oxygen it diminishes the activity of combustion. In certain compounds it is an essential crop fertilizer.

5. **Oxygen** comprises about 21 per cent by volume of the atmosphere. It unites readily with many other elements and forms a large proportion of the waters of the ocean and of the superficial rocks of the earth's crust. It supports combustion and is necessary to animal and plant life.

6. **Carbon dioxide** is very essential to plant life, although it comprises only about 0.03 per cent of the air. Owing to its greater density, it may form such a large percentage of the air in wells, silos, and the like, as to cause death.

7. Water-vapor is of extreme importance but is the most variable component of the atmosphere. Its volume percentage varies with the temperature, hence while it averages 2.6 per cent at the equator it is only 0.2 per cent at 70° N. latitude, and decreases rapidly with elevation.

8. Other gases.—Argon comprises nearly 1 per cent of the atmosphere while other permanent gases are hydrogen, krypton, neon, helium, and xenon, although in very small quantities.

9. Height of the atmosphere.—One-half of the atmosphere is within 3.3 miles of the surface of the ocean; at an elevation of 6 miles it is not sufficient to support life; at 30 miles the pressure is only one six-thousandth that at sea level, while at 50 miles it is so thin as to be incapable of scattering perceptible amounts of sunlight. How far it extends above this is not known but observations of meteors show a sufficient gas, principally hydrogen, at elevations between 100 and 188 miles to retard their speed and render them luminous.

PRESSURE OF THE ATMOSPHERE

While the variations in the pressure of the atmosphere at any point on the surface of the earth are insufficient to be appreciable to the senses, yet the pressure or weight of the air is highly important. It forces water to rise in a pump when the pressure of the air therein has been diminished by means of a piston; its horizontal variations give rise to winds that in turn modify the temperature, moisture, and the like, and its accurate observation over wide areas enables the forecasters to predict the coming weather changes with considerable success.

10. Pressure varies with altitude.—The pressure of the atmosphere decreases with altitude at an approximate rate, through the first mile or so, of one inch on the barometer scale with each increase of 1000 feet in elevation. The exact rate of decrease, however, is less at increasing elevations because of the smaller amount of air above, and as it varies with the temperature, humidity, and so on, the rate of decrease is in accordance with a complex logarithmic law. A knowledge of the density of the air is of great practical importance in connection with the flight of projectiles, the study of atmospheric phenomena, and aeronautics.

The aviator is limited in the height to which he can fly by the decrease in density of the air and its effect on himself and the performance of his engines. Plant development is only slightly if at all affected by variations in pressure.

11. The barometer.—Atmospheric pressure is usually measured in terms of the linear height of the mercury column corrected for temperature, gravity, and the like, in a tube closed at the upper end, which is exhausted of air, and open at the bottom. The mercurial barometer in most common use is the Fortin type as indicated by Fig. 1. As the mercurial barometer is delicate and difficult to move without danger of breaking, the aneroid barometer is used for rough determinations of land elevations and the heights of balloons, kites, and aeroplanes. Fig. 2 shows a self-recording barometer or barograph operating on the principle of the aneroid barometer.

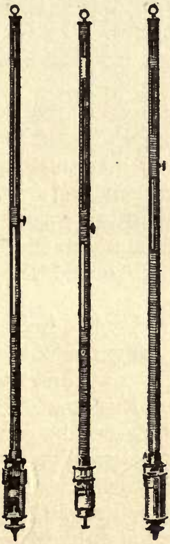

Fig. 1.—The mercurial barometer. This is the Fortin type, in most common use.

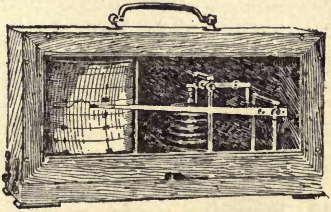

Fig. 2.—Self-recording barometer or barograph.

12. The barometer and weather forecasting.—While a knowledge of the barometric pressure in different places is the most important factor in weather forecasting, a single barometer, without a knowledge of surrounding conditions, is of little value in weather predictions, except possibly for a short time in advance and particularly when the pressure is changing rapidly. (See Chapter X.)

TEMPERATURE

The human system is more susceptible to changes in atmospheric temperature than to those of any other meteorological element. Plant development is also very responsive to temperature variations, as shown in Chapter V.

13. Source of heat.—The sun is the ruler of the temperature on the earth's surface as is well shown by the changes in temperature from equator to pole, from summer to winter, and from day to night. The radiant energy from the sun is termed insolation.

14. How the air is warmed.—The surface of the earth and the objects upon it are warmed by direct insolation in daytime while the layers of air in contact with the earth are warmed by conduction. Surface air thus warmed is then carried up by convection and in turn warms other masses by mixture and conduction. In addition to this, a considerable amount of the solar radiation is directly absorbed by the more humid portions of the atmosphere.

15. Radiation.—Clean dry air is warmed very little by insolation, which explains the well known warmth of direct sunshine on bright clear days, even while it may be cool in the shade. In hazy weather the sun does not seem so warm because some of its heat is absorbed and scattered by water-vapor, dust particles, and the like, which are present in the air. Some of the solar energy that reaches the surface of the earth is reflected while much more is absorbed and then reradiated. Water-vapor absorbs this long wave-length terrestrial radiation in much larger proportion than the short wave-length insolation.

16. How the air is cooled.—At night when insolation is absent, the surface of the earth and objects upon it cool rapidly through loss of heat by terrestrial radiation, and the layers of air in contact with the earth lose heat to it by conduction. As cool air is denser than warm, there is no convection; hence in still clear nights the air near the surface of the earth is considerably cooler than that immediately above. There is also some loss of heat by direct radiation from the air, especially when humid.

17. Inversion of temperature.—In the daytime the temperature of the air usually decreases from the surface of the earth upward for a mile or so, at an average rate of 2° to 3° (F) for each 1,000 feet in elevation. Under the conditions explained in the preceding paragraph, however, this is reversed, the temperature of the air then increasing from the surface of the ground upward for any distance from a few feet to several hundred, and sometimes several thousand. This is the condition called inversion of temperature, and explains the formation of frost in valleys when nearby hillsides may be free from damage.

18. Diurnal range in temperature.—The warmest part of the day occurs between 2 and 4 P. M. when the heating by insolation or incoming radiation from the sun is just balanced by that from outgoing terrestrial radiation and conduction. The lowest temperature is just before sunrise when insolation becomes equal to terrestrial radiation. Fig. 86 shows the diurnal march of temperature on days when under clear skies there are strong diurnal variations in temperature as well as on days when cloudy weather or an incoming cool wave prevents or entirely masks the usual diurnal temperature range.

19. Diurnal changes slight in cloudy weather.—When clouds prevail, a considerable part of the insolation is reflected from the upper surface of the clouds, and the temperature rises but little at the surface of the earth. Cloudy weather at night intercepts terrestrial radiation, and there is a comparatively slight fall in the temperature of the surface of the ground and consequently of the air in contact with it. Hence frosts are not expected during cloudy weather.

20. Diurnal temperature changes greatest over land.—Land surfaces warm up under insolation about four times as fast as water surfaces and also cool much more readily at night. Water surfaces reflect about 40 per cent of the insolation that reaches them while land surfaces reflect very little ; radiant energy penetrates many feet into the water and practically not at all into land; there is essentially no evaporation from dry land surfaces while a considerable part of the insolation absorbed by the surface of the water is used in evaporation and therefore becomes latent and does not raise its temperature; water that becomes heated may be moved horizontally or vertically by convection while there is no such movement in the land, and besides the specific heat of water is about five times that of dry soil. As a result, land areas and the air immediately above warm much faster than water areas under insolation, and also cool much faster at night.

21. Annual temperature ranges.—The interior of continents is also warmer in summer and colder in winter than coast districts unless the water surfaces are covered by ice. On the leaward side of oceans, such as the Pacific coast where the winds blow quite persistently from the west, the annual range in temperature is much less than in the interior of the country or on the Atlantic coast.

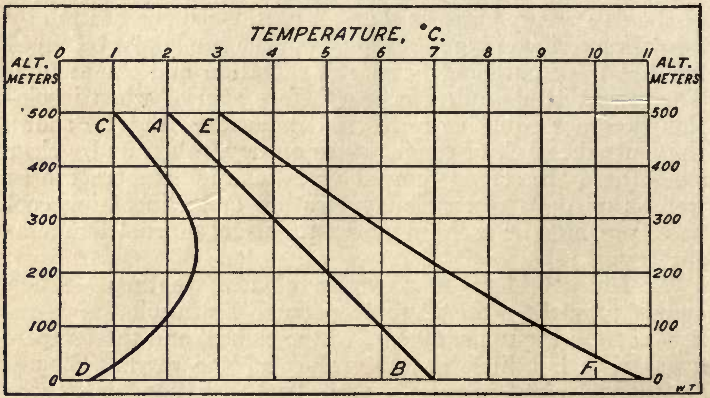

Fig. 3.—Examples of different states of air equilibrium: AB, adiabatic gradient for dry air (neutral equilibrium); CD, temperature inversion (stable equilibrium), and EF, superadiabatic gradient (unstable equilibrium).

22. Adiabatic change in temperature.—Ascending air expands and descending air is compressed because of the changing pressure (see paragraph 10). When air is compressed work is done on it and its temperature is raised, when it expands it does work and it is cooled. Whenever changes in pressure and volume of any gaseous matter occur without heat being added or subtracted from it, there will be a particular rate of change of the temperature, depending on the nature of the gas. The rate of change is then called the adiabatic rate. In the case of unsaturated air, the adiabatic rate of change of temperature amounts to 1.6° F. for each 300 feet variation in elevation, or, more accurately, 1° C., for each 103 meters. The line AB in Fig. 3 illustrates the adiabatic gradient for dry air.

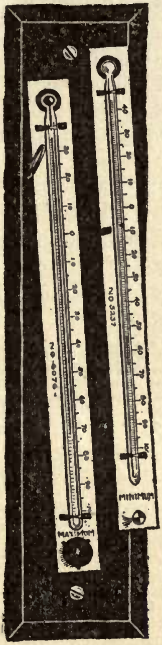

FIG. 4.—Maximum (lower) and minimum (upper) thermometers. Instead of being set as in this illustration the minimum thermometer must be set level and the maximum thermometer with the bulb end slightly elevated, as is shown in Fig. 5.

23. The average vertical temperature gradient or rate of temperature change upward does not differ much during summer from the adiabatic gradient but does considerably in winter. When the surface of the ground and the air near it are warmed by bright sunshine, the line EF represents the gradient. The line CD represents the temperature variation under

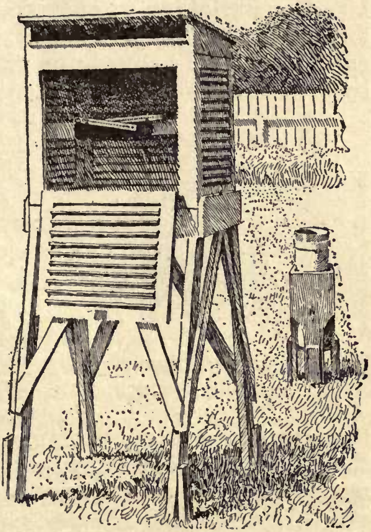

FIG. 5.—Thermometers properly mounted in a lattice-work shelter. The 8-inch rain-gage is shown set up in its shipping box at the right. (See Fig. 9.)

conditions of temperature inversion as explained in paragraph 17.

24. Recording the temperature.—The ordinary thermometer is well known. Fig. 4 illustrates the self-registering maximum and minimum thermometers and Fig. 5 these thermoneters mounted in the louevered shelter in most common use. Thermometers must be exposed in the shade and so as to have good air ventilation. Fig. 6 shows a good type of self recording thermometer, or thermograph.

25. Temperature records.—Maximum and minimum temperatures are important factors in crop development, as plants may be damaged by a few hours of excessive heat or killed by a brief period of freezing weather. The mean daily temperature is obtained approximately by adding the highest and lowest temperature values together and dividing by 2. Similarly the mean monthly temperature may be approximated by dividing the sum of the daily "means" by the number of days in the month.

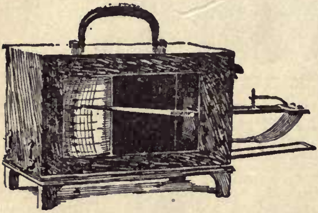

Fig. 6.—Richards thermograph, or self-recording thermometer.

26. Mean temperature and vegetation.—Mean monthly temperature figures are usually given in climatological tables, but weekly or ten-day means are of more value in studying the relation between temperature and plant growth. Mean maximum and mean minimum temperatures are often of more importance in vegetation than the mean daily temperatures because they represent more clearly the actual temperatures that plants experience.

PRECIPITATION

Dove has said: "The atmosphere is a vast still, of which the sun is the furnace, and the sea the boiler, while the cool air of the upper atmosphere and of the temperate zones plays the part of condenser, and we on a wet day catch some of the liquid which distils over."

27. Moisture in the atmosphere.—Water-vapor is one of the most important constituents of the atmosphere. It is essential to animal and vegetable life, and yet on a cold winter day it may not comprise more than .001 part of the atmosphere, and its maximum on a warm summer day near the seashore is never more than about .05 of the atmosphere.

28. Depends on the temperature.—The temperature determines the amount of invisible moisture that can be present in the atmosphere as is shown by the following, giving the weight of water vapor in the atmosphere when completely saturated:

Temperature degrees F.	*Weight of a cubic foot of saturated vapor. Grains troy*
100	19.766
80	10.933
60	5.744
40	2.849
20	1.235
0	0.481
−10	0.285
−20	0.166
−40	0.050

This indicates that at a temperature of 40° it is not possible for the air to contain more than one-half as much water-vapor as it can at 60°. Almost one-half of the total water-vapor in the whole envelope of air that surrounds the earth is within one mile of the earth's surface, while one-half of the atmosphere is above three and one-third miles.

At a height of six miles above the surface of the earth, where the temperature is about 60° below zero, the total amount of water-vapor is only one ten-thousandth of the atmosphere.

29. Evaporation.—The process by which a liquid becomes a gas or vapor is termed evaporation. The rate of evaporation or the rapidity of the escape of the molecules from the water surface into the atmosphere in the form of vapor depends on the temperature, wind velocity, dryness of the air, and to a slight extent the pressure.

30. Humidity.—The amount of water-vapor present in the atmosphere is called the absolute humidity, and it may be expressed in the weight of the vapor in a unit volume, or in the expansive force that the vapor exerts termed vapor pressure. The absolute humidity usually varies with the temperature.

31. Relative humidity.—The absolute humidity divided by the saturation humidity at the same temperature is called the relative humidity. It is expressed in percentages. The diurnal relative humidity curve varies inversely as the temperature.

32. Saturation.—When the water-vapor present in the air is one-half as much as possible at the temperature, the relative humidity is said to be 50 per cent. When three-fourths, the relative humidity is 75 per cent. When the relative humidity is 100 per cent, the air is said to be completely saturated.

A room 20 x 20 feet and 10 feet high contains 4,000 cubic feet of air. If this air were completely saturated at a temperature of 80°, there would be 3 quarts of water in the atmosphere in an invisible form. If the temperature should be 60°, only 3 pints of water could be held in suspension in the atmosphere of the room. If the temperature of the air should be zero, it could contain less than 0.3 of a pint of water.

33. Dew-point.—The dew-point is the temperature of saturation for the moisture present. During the warmest part of the day, while the actual amount of moisture in the atmosphere is usually large, the amount is seldom sufficient for saturation, and the relative humidity is generally low. As the temperature falls in the late afternoon, the capacity for moisture decreases, hence the relative humidity increases. When saturation is reached, the temperature is at the dew-point. Any further cooling will cause part of the moisture to condense in the form of dew, fog, frost, or cloud. The difference between the temperature of the air and the dew-point temperature is called the complement or depression of the dew-point.

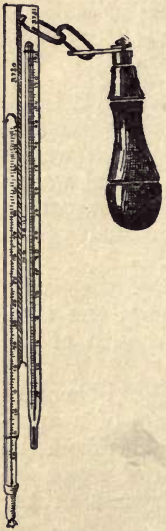

Fig. 7.—Sling-psychrometer.

34. Measuring the moisture in the atmosphere.—The sling-psychrometer or whirled psychrometer is used to determine the dry and wet bulb temperatures (see Fig. 7). From these data and simple hygrometric tables, the

absolute and relative humidity and dew-point temperature can easily be determined.

35. Condensation.—The natural processes of the condensation of the water-vapor in the atmosphere into visible form depend on a decrease in temperature. If the temperature of the air in a room is at 80° and if the space is completely saturated, about one-half of the moisture would be forced to condense if the temperature should be lowered to 60°. The condensation of the moisture would take place upon the clothing and other objects in the room which might be cold. The sweating of ice pitchers is a well known example of the condensation of moisture upon any object the temperature of which is below the dew-point.

36. How clouds are formed.—The temperature of the air is cooled sufficiently to cause the condensation of the surplus moisture into fog or cloud: (1) by expansional or dynamic cooling due usually to vertical convection; (2) by contact cooling; (3) by the mixture of masses of air of unequal temperatures; (4) by radiation.

37. Cloud types.—There are three main cloud types. (1) Cirrus, very high fibrous, white clouds that are composed of ice particles (see Plate I). (2) Stratus, a low, fog-like cloud of wide extent. From the top of high elevations these clouds have the appearance of valley fogs (Plate II). (3) Cumulus, a flat-bottomed cloud with rounded top (Plate III). The cumulus is a typical fair weather cloud, but will frequently grow into the cumulo-nimbus or thunder head, as shown by Plate IV. There are many combinations of these cloud types some of which are very beautiful. A nimbus is any cloud from which rain is falling. This is frequently classified as a fourth cloud type.

38. What makes it rain.—Rain is caused whenever a large mass of air is cooled below its dew-point or temperature of complete saturation. Clouds are formed just as soon as the dew-point is passed and condensation into visible drops begins to take place. If the cooling continues, large drops will be formed from the smaller cloud particles and these drops will fall to the earth as rain.

Vigorous cooling in masses of air of sufficient quantity to cause any considerable amount of precipitation is brought about only when the air is cooled by expansion. When a mass of air is carried to higher altitudes by any cause it expands, because there is less air above it and the presure on it is less and this act of expansion reduces its temperature. The rate at which it cools, before it reaches the temperature of complete saturation, is 1° F. for every 188 feet. After condensation begins, the rate of cooling is considerably less. If a current of air with a temperature of 80° and a relative humidity of 75 per cent is forced up to ten times 188 feet, or but little more than one-third of a mile, some of the moisture must be condensed into clouds and rain.

Ascending air is cooling and is then apt to be cloudy and rainy; descending currents of air are warming, the capacity for moisture is increasing instead of decreasing, and they are most likely to be accompanied by clear skies.

39. Rainfall increases with elevation on the windward side of mountains.—Currents of air blowing over a range of mountains are being cooled by expansion at the adiabatic rate, and the temperature is decreasing, hence there will be an increase in the rainfall up to a certain level, depending on the topography, and the like. The maximum level is about 5,000 feet in the western mountains, but it varies in different places. Precipitation decreases with higher elevations on the windward side, and then decreases with decreasing elevation on the leaward side, as the air there is being warmed by compression.


Fig. 8.—Self-recording, tipping bucket rain-gage.

40. Measuring rainfall.—Fig. 8 shows one type of self-recording rain-gage, while Fig. 9 illustrates the ordinary rain-gage with a cross-section to show the different parts. The receiver of the standard (United States) is 8 inches in diameter, while the area of the inner tube is one-tenth of that of the catching surface. The amount of fall is measured, on a scale of 1 to 10, with an ordinary rule. That is, 1 inch of water in the gage is 0.10 inches on the surface of the land, and so on. Amounts less than 0.01 inch (0.1 on the rule) are recorded as "T" (trace), an amount too small to be measured.

41. Rainfall data.—Rainfalls are tabulated by daily, monthly, seasonal, and annual amounts, and long-period averages of these. The National Weather and Crop Bulletin published by the Weather Bureau shows weekly rainfall charts or tables. From an agricultural point of view, all precipitation data should be tabulated and published in weekly or ten-day periods.

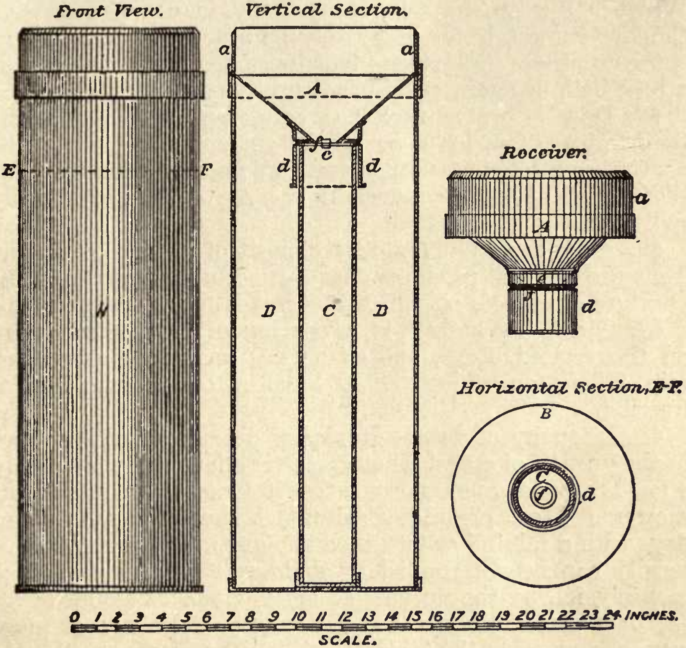

FIG. 9.—Standard 8-inch rain-gage, with vertical cross-section.

42. Snow is composed of tabular or columnar particles of ice formed in the free air at temperatures below freezing. All are hexagonal in form but of endless variety in detail. The amount of water from snow averages about 1 inch for every 10 inches of snow.

43. Sleet is composed of ice pellets, or frozen rain-drops (or largely melted snowflakes refrozen) due to the falling of precipitation through a cold layer of air near the surface of the earth. Sleet occurs only during cold weather.

44. Hail.—Lumps of ice more or less irregular in outline, generally consisting of concentric layers of clearish ice and compact snow, are designated as hail. As defined by the Weather Bureau, hail can occur only in connection with thunder-storms, hence will rarely be seen and then only in warm weather. Sometimes hailstones are found as large as a base-ball, or again of the size and shape of saucers.

45. Dew is water that has condensed on objects the temperature of which is below the current dew-point of the air that is in contact with them. The cooling necessary for the formation of dew is usually due to the loss of heat by radiation.

46. Frost is a light feathery deposit of ice caused by the same process that produces dew, but occuring when the temperature of objects on which it forms is below freezing.

47. Glaze (ice storm) is a coating of clear smooth ice on the ground, trees, and so on. It is usually caused by rain falling on objects that have a temperature below freezing.

48. Intensity of rain.—It makes considerable difference in the growth of crops, whether the rainfall is in the form of a few heavy downpours or whether it comes in frequent light showers. Most climatological tables show the number of days with a rainfall or 0.01 inch or more, and the rainfall intensity can be determined by dividing the total weekly or monthly fall by the number of rainy days. It would be an excellent plan if the number of days with 0.25 inch or more were also given in the tables.

49. Rain-making.—It has been held by many that it is possible to produce rain at will, and rain-making fakers have sometimes reaped rich harvests during periods of serious drought. It can be stated, however, that the processes of nature in producing rain are on far too large a scale to be duplicated in the slightest degree by man and that it is absolutely impossible for man to produce an appreciable rainfall in the open air over a considerable area. For example, the rainfall in Europe during the late war was only about normal notwithstanding the most terrific cannonading and bombing that the world ever saw.

50. Shooting hail-storms and tornados.—Some irrational speculations die hard and there are persons and communities in Europe and probably in this country that still believe it is possible to prevent hail and tornado damage by bombing the approaching storm cloud. Here again the forces of nature are too large to be dissipated by man-made efforts. Careful inquiries by capable men in France and elsewhere have failed to show any effect of hail firing whatever, but that the hail-storms continue to occur and that hail falls upon the "protected" and unprotected alike.

CIRCULATION OF THE ATMOSPHERE

If there is a difference in the temperature of the masses of air over two adjoining regions, there will be, through the action of gravity because of the resulting difference in pressure, a continuous overflow of air from the warmer to the colder region, and an underflow from the colder to the warmer.

51. What makes the wind blow.—Movements of the atmosphere, or winds, are due to differences in pressure, caused by difference in temperature and modified by the rotation of the earth.

52. Surface currents.—The large general movements of the atmosphere at the surface of the earth are: (1) The so-called doldrums or equatorial calms which surround the earth at the heat equator, where there are strong ascending currents; (2) the trade-winds which blow toward the warm equatorial belt, from a northeasterly direction in the northern hemisphere and a southeasterly direction in the southern hemisphere, from about latitude 30°; (3) the "horse latitudes", or areas of partial calms at about latitude 30°, where there is an apparently well-defined descending current; (4) the prevailing westerlies which occur in temperate latitudes north of about latitude 25° to 30° in the Northern, and south of about latitude 25° to 30° in the Southern Hemisphere.

53. General currents interrupted.—All these general currents are interrupted or confused by the differences in temperature which occur over large land and water areas; by seasonal variations in temperature; and by storms or other local disturbances.

54. Most important interruptions outside of the doldrums due to high and low pressure areas.—In temperate latitudes there is a constant succession of high and low pressure areas known, respectively, as anticyclones and cyclones which move in a west to east direction. As seen in Chapter X, the surface winds blow diagonally away from areas of high pressure and diagonally toward areas of low pressure.

55. Monsoon winds.—Another marked interruption of the general currents is due to the temperature contrast between large land and water areas. The land is warmer than the water in the summer and colder in winter, and as a result there is a movement of the air from the colder toward the warmer of the two adjacent areas. Monsoon winds are, therefore, seasonal winds.

56. Land and sea breezes.—Contrasted with the seasonal monsoons which prevail over large areas, there is a daily movement of the air over narrow areas along sea-coasts called land and sea breezes. The air along the coast flows toward the land in the daytime and toward the water at night. The sea breeze is felt for only a few miles, inland but it furnishes a pleasant relief from the heat where it does occur.

57. Mountain and valley winds.—In some mountain regions, there is a well-defined movement up the valleys in the daytime and an even more marked movement down the valleys at night.

58. Cold waves.—When a well-defined and energetic cyclonic area moves eastward across the central Mississippi Valley and the Great Lakes, strong southerly winds to the south and east of the center will cause unseasonably high temperatures, especially in winter time. With the shift of wind to west and northwest, as the center of disturbance moves eastward, the temperature falls rapidly. When the approaching high is large and well-defined, the northwest winds, often accompanied by snow squalls, are strong and the fall in temperature in twenty-four hours sometimes amounts to 40° or 50° or even more. These are the conditions which make up the well-known winter cold wave of the United States. After the windy front of the anticyclone has passed and the center lies over a district, the nighttime temperatures will be very low, especially in the valleys, under the influence of radiation and local surface "air drainage."

59. Tornadoes and waterspouts.—The tornado is the most diminutive and yet the most violent and destructive of all storms. It may be defined as a violent wind-storm accompanied by hail, thunder, and lightning, in which the air masses whirl with great velocity about a central core while the whole storm travels across the country in a narrow path at a considerable speed. When seen from a distance, the tornado has the appearance of a dense cloud mass, usually in violent agitation and with one or more pendant funnel-shaped clouds which may or may not reach the earth. Waterspouts are tornadoes that occur over bodies of water. The visible waterspout corresponds to the pendant cloud of the land tornado.

60. The tornado tube.—The tornado tube in its projection downward from the cloud mass is a simple vortex and obeys the laws of fluids in gyratory motion. A partial vacuum is produced at the center of the whirl, the low temperature which results generates the sheath of vapor that makes the tube visible and the wind about the vortex prostrates every obstacle. Neither the air pressure nor the wind velocity have ever been measured near the center of a tornado but from the force necessary to move certain objects it has been calculated that the wind must blow at the rate of well over 100 miles an hour and may reach a velocity of several hundred miles an hour.

61. Where tornadoes occur.—The region of greatest frequency of tornadoes is the central plains states and the Mississippi Valley, where they occur most often in April and May. They may occur in the Gulf states in the winter or early spring, and in the northern states in summer. The southern margin of a tornado is more dangerous than the northern, and as the width of the path of greatest destruction may not be more than a few yards or rods, a person can frequently find safety by running toward the northwest, if the tornado seems to be approaching directly.

62. Hurricanes.—Most of the cyclonic storms which gain such a velocity of gyration as to constitute hurricanes originate within the tropics. Those originating north of the equator move northwestward, many reaching latitude 20° or more and then recurving toward the northeast. Those of the Southern Hemisphere first move southwestward, and later, in many cases recurve towards the southeast. Hurricanes are the most destructive of all storms. They have all the characteristics of tornados but instead of being a few rods in width, their path of destruction may cover several hundred miles, and instead of their duration being less than one minute, as is the case with tornadoes, the terrific winds and rain accompanying them may last from twelve to twenty-four hours. Hurricanes seldom occur in the Northern Hemisphere except in the late summer or early autumn. Although there are an average of about ten annually that touch some portion of the Atlantic or Gulf coast, an average of less than one a year is severely destructive.

63. A severe hurricane.—The most intense hurricane of which there is record in the history of the coast of the Gulf of Mexico, and probably in the United States, moved into the lower Mississippi Valley on September 29, 1915. The pressure fell to 28.11 inches at New Orleans at 5.50 P. M., on the 29th. The wind reached a five-minute velocity of 86 miles an hour from the southeast at 5.10 P. M., on the 29th. The extreme velocity was 130 miles an hour. At Burrwood, Louisiana, 100 miles south of New Orleans, the velocity was the highest ever recorded on the Gulf Coast. At Burrwood, the extreme wind for one minute was 140 miles an hour, at 3.45 P. M., the maximum five-minute velocity was 124 miles an hour, and from 3.31 to 3.50 P. M., the average velocity was 116 miles an hour. From 3.00 to 4.00 P. M., the average velocity was 108 miles an hour; from 4.00 to 5.00 P. M., 106 miles an hour; and from 5.00 to 6.00 P. M., 96 miles an hour. The total loss of life in 300 miles of coast line was only 275. Twenty-three of these fatalities were known to be due to an absolute disregard of warnings at Rigolets. The property loss was probably more than $13,000,000. At Leeville, of the 100 houses in the village, only one was left standing.

64. Other winds.—Other winds of considerable interest in the United States are the "warm wave," the "blizzard," the "hot winds" of the Great Plains, and the "chinook."

65. Warm wave.—This is a moisture-laden wind that blows from the south into an advancing cyclonic or low pressure area. It is particularly well-marked in the winter time in the central and eastern states, when almost summer heat may be experienced. The Italian name "sirocco" is sometimes given this wind.

66. Blizzards.—The blizzard is characteristic of the Great Plains and is a very strong, cold wind accompanied by fine snow or ice particles. Its onset is sometimes accompanied by a drop in temperature of 30° to even 60° in a few hours. Blizzards frequently cause great loss of stock and sometimes of human lives.

67. Hot winds.—During long dry spells over the Great Plains, marked hot winds occur which cause great damage, particularly to corn. While they prevail, the transpiration is far greater than the moisture the roots can supply from soil that has already been depleted, and corn is frequently ruined over considerable areas. These winds sometimes occur at night and are so hot that persons are aroused with the belief that a fire is near.

68. Chinooks.—The chinook occurs mainly on the eastern side of the Rocky Mountains particularly in Montana and Wyoming, but may be felt in any mountain region. It is a hot dry wind which usually makes its appearance suddenly and may raise the temperature by 40° to 50° F. in a few minutes. Chinooks are locally known as "snow eaters" as the snow evaporates very rapidly and large areas previously snow-covered are made available for grazing. The name "chinook" is a local American term for a widespread type of wind to which the generic name "foehn" is applied by meteorologists. Its warmth is due to the dynamic heating of a mass of air that is rapidly descending from a considerable elevation.

69. Measuring the wind velocity.—Wind velocity is measured by means of a pressure-gage or most usually in the United States by a rotation anemometer as seen in Fig. 10. This will show by means of a dial the total wind movement for any short period of time, while by the use of a registering apparatus the time that it takes each mile of wind to pass the point is recorded. The "maximum" wind as reported by the Weather Bureau is the greatest number of miles recorded in five minutes of time. The extreme velocity is the quickest time for any single mile.

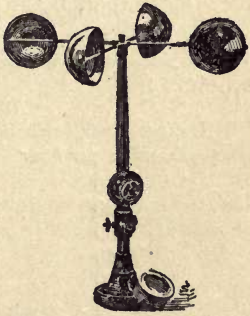

Fig. 10.—Robinson's anemometer. The cups rotate at a rate approximately one-third that of the wind.

The cups in the Robinson's anemometer are 4 inches in diameter while the supporting arms are 6.72 inches long. With these dimensions the cups move at approximately one-third the velocity of the wind. One mile of wind will cause 500 revolutions of the cups.

70. The pressure exerted by wind.—Within a range indicated approximately by velocities of 3 and 50 meters a second (6½ and 112 miles an hour), the pressure of the wind varies nearly as the square of the velocity. In any instance the actual pressure also depends on the character and dimensions of the surface and the density of the air which, in turn, is a function of the barometric pressure and the temperature of the air. At sea-level, under ordinary conditions, wind-pressures may be determined with fair accuracy by the formula,—

$$P = 0.0735\ SV^2$$

in which P is the pressure in kilograms to the square meter of surface exposed normal to the wind, S the surface in square meters, V the velocity in meters a second, and 0.0735 a factor determined by experiment.

The following indicates the pressure corresponding to the velocity of the wind as recorded by the Weather Bureau anemometers :

Indicated wind velocity in miles per hour	*Wind pressure; pounds per square foot*
10	0.369
20	1.27
30	2.64
40	4.44
50	6.66
60	9.22
70	12.2
80	15.5
90	19.2

71. Estimating wind velocity.—When no instruments are available for measuring the wind velocity, as is generally the case at sea, it may be estimated approximately by means of the following scale, which is the Beaufort or standard scale in most common use :

Beaufort number	*Explanatory titles*	*Miles per hour*	*Apparent effect*
0	Calm	Less than 1	Calm, smoke rises vertically.
1	Light air	1 to 3	Direction of wind shown by smoke drift, but not by wind vanes.
2	Slight breeze	4 to 7	Wind felt on face; leaves rustle; ordinary vane moved by wind.
3	Gentle breeze	8 to 12	Leaves and small twigs in constant motion; wind extends light flag.
4	Moderate breeze	13 to 18	Raises dust and loose paper; small branches are moved.
5	Fresh breeze	19 to 24	Small trees in leaf begin to sway; crested wavelets form on inland waters.
6	Strong breeze	25 to 31	Large branches in motion; whistling heard in telegraph wires; umbrellas used with difficulty.
7	High wind	32 to 38	Whole trees in motion; inconvenience felt when walking against wind.
8	Gale	39 to 46	Breaks twigs off trees; generally impedes progress.
9	Strong gale	47 to 54	Slight structural damage occurs (chimney pots and slate removed).
10	Whole gale	55 to 63	Seldom experienced inland; trees uprooted; considerable structural damage occurs.
11	Storm	64 to 75	Very rarely experienced, accompanied by widespread damage.
12	Hurricane	Above 75	

LABORATORY EXERCISES

1. Paragraph 6. By expelling the breath into a tall drinking glass and then inserting a lighted match, the effect of the excess of carbon dioxide and the lack of oxygen will be seen. One should never go into an old well or deep cistern or a partially filled silo without first lowering a candle or lantern into it. If the light is extinguished, there is a dangerous excess of carbon dioxide.

2. Paragraph 10. Determine the variation in pressure at different elevations by means of an aneroid barometer. A delicately adjusted

instrument will show a difference in pressure between the floor and the top of an ordinary table.

3. Paragraph 15. Expose one thermometer to direct sunshine, and another near the first, but shaded from the sun.
4. Paragraph 17. Obtain temperature at different elevations on clear still nights.
5. Paragraph 18. Study the records from a thermograph in clear weather as compared with cloudy weather. (par. 19)
6. Paragraph 24. Observations should be made with thermometers properly exposed.
7. Paragraph 34. Determine absolute and relative humidity and dew-point with a sling psychrometer.
8. Paragraph 37. The main cloud types should be learned.
9. Paragraph 71. Practise estimating the wind velocity wherever anemometer records are available to verify the estimates.

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CHAPTER II

AGRICULTURAL METEOROLOGY

Agricultural meteorology may be defined as "meteorology in its relation to agriculture." It considers the vegetation and animal life of the globe, the distribution of food and other crops, and farm operations as affected by climate. It shows the effect of weather on the growth and yield of crops. It treats of the influence of climate and weather on insect activities, the development of plant diseases, and the protection of crops, animal life, and buildings from damaging meteorological phenomena.

72. Conditions for plant growth.—There is an optimum combination of temperature, moisture, and sunshine in which plants make their best growth, and under which the largest yields will be obtained. Food is available to the roots of plants only in a soluble form; it is carried into the plants and converted into vegetable tissue under the influence of solar energy expressed in heat units or calories.

73. Factors must be in correct proportion.—If there is not enough moisture to furnish sufficient soluble plant-food, part of the solar energy is wasted, while on the other hand if there is more food brought to the roots than the solar energy can utilize, the food material is wasted. In the arid districts too little food is available, under natural conditions, for the solar energy, but when, through irrigation, a large amount of food is made available, large crop yields result. Moisture is the controlling factor in these regions. In the highest latitudes, there is generally an excess of moisture and a deficiency of heat. These are the conditions that prevail in much of northern Europe, Alaska, and some high mountain regions. Here the crop yields are largely a question of temperature variations.

74. Requirements vary.—Different plants require unlike proportions of moisture, heat, and sunshine, and most plants require varying amounts for best growth at different stages of development. A few plants require hot arid climates while others reach their best development only in cold moist regions.

75. Critical periods of growth.—Many plants have a certain (frequently short) period during growth when there must be a well-defined combination of certain weather factors to produce large crop yields ; others have the ability to stand nearly dormant when unfavorable conditions prevail, but will revive and make an excellent growth when the weather factors are in correct proportion.

76. To determine critical period.—There are three well-defined methods for determining the most critical period of growth of farm crops and the weather factor having the greatest influence in varying the yield: (1) Laboratory experiments; (2) field observations; (3) correlations of weather with past records of crop yields.

77. Laboratory experiments.—One method is to carry out laboratory experiments in which the various factors can be under control. The moisture, temperature, and sunshine are the most important meteorological factors, and by keeping two of these constant and varying the other, its influence can be determined. Or one can be kept constant and the other two varied. Some work of this kind has been done, but the experiments that may and should be made are sufficient to engage the attention of many men. It requires special apparatus and close attention and should be attempted only by trained plant physiologists, or ecologists.

78. Field observations.—With the most carefully arranged details, the conditions that surround plants in the field can hardly be duplicated in the laboratory tests. Hence it is desirable that detailed records be made of all the meteorological factors and the growth and yield of various crops at many different places and covering a period of many years.

79. Observations in Russia.—Russia was the pioneer in the organization of a group of agricultural-meteorological and horticultural-meteorological stations to determine quantitatively the relation of different climatic factors to crop production. The Russian Bureau of Agricultural Meteorology was authorized in 1894 and observations were begun in 1896. In

1912 Russia had observations under way at eighty-one different experiment stations where meteorological records were being kept as near as possible to the test plats.

80. Records in Canada.—Similar records were begun in Canada in 1915 at fourteen different experiment farms where particular attention was given to spring wheat. Some results have been published, but the records should cover several years to make the correlations conclusive.

81. Records in the United States.—A division of Agricultural Meteorology was organized in the United States Weather Bureau early in 1916, and one of the first important things done was to start plans for the inauguration of agricultural meteorological stations at each of the main agricultural experiments stations in each state. The war emergency made it necessary to hold these plans in abeyance, however. It is believed by the chief of this Division that this is one of the most important steps that can be taken in the interest of agriculture in this or any other country. The climate of the United States is so varied, the crops are so diversified and the yield so variable, that a careful record of all the weather factors and the consequent development of the crop plants must be made for several years to determine the critical periods of growth.

82. Value of records.—If it is found, for example, that a light rainfall in May means a small hay crop, other forage crops can be planted. If it has been learned that the crop of winter grains will be reduced by certain weather during the winter, the spring grain area can be increased if these weather conditions prevail. When the water requirements of various crops are determined for different stages of growth, water can be more economically handled in the arid and semi-arid regions of the West. The climate of a district will be more carefully studied and crops planted that are best adapted to the prevailing climate, or where the season is long enough, seeding will be done at such a time as will bring the critical period of growth when the weather factor most affecting it will be nearest its optimum for that crop. There are innumerable ways in which this knowledge can be applied. Much has already been done by experiment stations in this direction but the work lacks the system and correlation that would be obtained under definite direction.

83. Correlation of weather with past records of crop yields.—While records and results are being accumulated by laboratory experiments and field observations, much valuable knowledge can be obtained by a mathematical correlation of accumulated climatic data with records of crop yields during past years. The manner of making these correlations will be explained in Chapter IV and some of the results already obtained will be shown in Chapters VII to IX.

84. Not a new science.—While the term "agricultural meteorology" is new, the importance of studying the relation of weather to crops has been recognized and referred to by agriculturists and meteorologists for many years. Measurements of rainfall were made in Palestine in the first century of the Christian era, and there was a network of rainfall stations in the important rice-growing districts of Korea as early as the middle of the fifteenth century. As this crop needs a large amount of moisture during its growth, it is only reasonable to suppose that the farmers of Korea made a practical use of their knowledge of the distribution of moisture in connection with the growth of this important food crop.

LABORATORY EXERCISES

1. Paragraph 77. Carry out some laboratory experiments as indicated in paragraph 77. Consult the plant physiologist.

2. Paragraph 78. All students should keep a detailed record of weather effects. In the summer select some particular plant or field, or some fruit-tree, and record its growth and condition in connection with the weather condition prevailing. Determine the moisture-content of the soil at frequent intervals (consult the agronomist); record the temperature of the soil each day.

In winter keep a record of the snowfall and the depth of snow covering and its effect on grain and grass fields.

Record the effect of temperature and sunshine on fruit-buds; note any swelling and subsequent temperature damage.

Record the effect of variations in sunshine on greenhouse plants. It has been found that head lettuce that is raised in such large quantities in greenhouses about Boston cannot be successfully grown in the vicinity of Cleveland, Ohio. Why? Is it because of less winter sunshine at the latter place?

Record the effect of temperature on the amount of food consumed by stock.

Plate II.—Avection fog, with alto-stratus clouds above. When the fog has lifted somewhat, it has the appearance of the stratus cloud from below.

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CHAPTER III

AGRICULTURAL CLIMATOLOGY

That branch of agricultural meteorology which deals with the relation of climate to vegetation and farm operations is called "agricultural climatology." The climate largely determines the vegetation natural to a region, the kind of crops that can be grown profitably and, therefore, the types of farming, and in a general way the characteristics of the people who live in any region.

85. Climate and man.—It has been stated that the native of the tropics, where nature is lavish and provides food ready for use by simply gathering it, where only slight protection is needed from rain and wild beasts, and where custom expects the simplest as well as a very slight amount of clothing, has, by building a simple hut and planting a few bread-fruit trees, made as full a provision for his family as the man in the upper temperate region by building a warm house and carrying on the cultivation of large crop areas. In each case the necessities of life are provided.

86. In the arctic, where agriculture is not possible, the food of man is fish and meat. His houses are made of driftwood and ice and snow, while clothing is from skins. His wants are few and these regions are inhabited by a happy and improvident people.

87. In the temperate zone.—The most highly developed people are in the temperate zone. In the tropics life is too easy and in the arctic too hard, and in each case the wants are few and there are found the people least developed mentally and physically. In the temperate regions where man must work through the growing season to provide food for the winter, where there is a constant struggle to keep the fields free from weeds and the encroaching native vegetation, are the most inventive and best developed people in every way.

88. Native vegetation a key to field crops.—A study of the native vegetation will frequently enable one to determine what crops can be grown most profitably, and it is the problem of the plant ecologist to establish these relations. In some sections of the Rocky Mountain region, the "grass-steppe," the "sage-brush steppe," the "pinyon pine juniper," the "yellow pine," the "lodge-pole pine," and the "Engelmann spruce-balsam" represent zones of increasing rainfall but decreasing temperature, respectively, and show well defined agricultural possibilities. In the grass-steppe, the temperature is high enough for field crops, but the rainfall is insufficient. In the Engelmann spruce-balsam fir forest zone, on the other hand, the annual rainfall may run as high as on the best agricultural lands in the East, but the temperature is too low and the growing season too short for crops, although summer grazing is excellent in the open parks. Between these extremes and corresponding to the respective zones, are: (a) excellent farming and orchard lands; (b) small grains, potatoes, garden crops, and orchards; (c) oats, barley, potatoes, alfalfa, and hardy garden crops; and (d) grazing only.

89. Importance of temperature.—While the lack of moisture is the limiting factor in successful agriculture in many sections, the temperature is the most important factor in defining the large areas of certain crop distribution or plant varieties. In the north temperate zone it is the winter temperature that limits the northern distribution of crops, and the summer temperature that restricts them at the southern edge.

90. Seasonal development of crops.—The seasonal development of all vegetation is determined by the climate of the particular region. Hopkins has determined that, other things being equal, the variation in the time of occurrence of a given periodical event in life activity under the influence of climate, obeys a well defined law.

91. Bioclimatic law of latitude, longitude, and altitude.—Hopkins has given the above designation to the law that shows the variation in climate and through that the development of plants and of insect activities. He states that in temperate North America this variation is at the general average rate of four days to each degree of latitude, each 5 degrees of longitude, and each 400 feet of altitude. The phenological dates are later northward, eastward, and upward in the spring and early summer, and the reverse in the late summer and fall.

92. Local influences.—Departures from this general law are the result of local factors. Accelerating influences are sunshine, dryness, prevailing warm winds, southern slopes, broad valleys, sandy soils, absence of large bodies of water, and the like. The retarding influences are the opposite conditions. Southern or northern slopes may vary this rule from one to four days, while coastal influences may amount to ten to fourteen days.

93. Practical application of law.—After determining the climate at a few well located places, and the average influence of this climate in developing vegetation, the climate and plant development at other places where records are not available can be determined by the bioclimatic law. The proper date for seeding winter wheat in order to escape hessian fly damage, for example, can be determined; the limiting zone of natural forest cover can be ascertained; the optimum locality for growing certain crops found in new regions; the proper dates for planting crops with the average time from seeding to harvesting, together with the possible number of days between frosts; the probable date of harvesting crops; the probable time of occurrence of insect pests; the proper time for spraying found; the northern and southern limit for certain crops established, and in general as an aid in solving some of the problems constantly coming before the farmer everywhere.

94. An aid in farm management.—In old settled regions, the best crops to grow as well as the best methods of handling the crops have become well established by the "survival of the fittest." In newer districts, the bioclimatic law, using the settled regions as a base, will aid in all kinds of farm operations, and in determining the best crops to plant.

95. Natural vegetation an aid in determining best dates for farm operations.—Properly recorded and correctly interpreted periodical events in natural vegetation serve as excellent keys for proper farm operations because these events are the result of all the climatic and other factors making up the environment. Some examples of commonly recognized events in the advance of the season are the following: the opinion of the Indians that the proper corn planting time is when the white oak or maple leaves are the size of squirrel ears; the saying in the Rocky Mountain region that sheep shearing should not be done until the "spring sown grain begins to carpet the fields in green," or "the wool goes off as the fruit blossoms come on"; calling the *Amelanchier canadensis*, or "lance-wood" bush the "shad-bush," because when it came into bloom it was recognized along the Atlantic Coast that it was time to fish for shad. The ornamental shrubs are more or less constant in this response to the advance of the season and serve as very good guides.

96. Phenological records desirable.—Every person interested in agriculture should keep detailed records of the seasonal events of a few native trees, the dates of planting of various crops, whether this planting was at the proper season to produce quick germination, rapid growth, and seasonal maturing, and above all a record of the prevailing weather and its effects.

97. Records from simple meteorological instruments valuable.—A properly located rain-gage, and a set of maximum and minimum thermometers exposed in an inexpensive shelter, will give records of very great value in handling farm work and in studying the effect of the weather on the condition of different soils and the growth and yield of various crops. The expense is small and the time necessary for the records very little, while the results are very illuminating. But with or without instruments, a daily journal of the weather will be of untold interest and value as one year follows another with its problems and queries as to reasons for crop failure or success, insect activities, results of spraying, and the like.

LABORATORY EXERCISES

1. Paragraph 88. Make maps of climate and zones of vegetation. Different varieties of forests, different field, garden, and fruit crops.
2. Paragraph 89. Chart seasonal temperatures and crop distribution.
3. Paragraph 91. Verify the bioclimatic law by charting known distribution of well defined vegetation.

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CHAPTER IV

CORRELATION

This chapter will explain briefly some of the simpler methods for finding the relation between definite weather conditions and the yield of crops. The advanced student who wishes to take up the matter in a more mathematical way should consult text-books on harmonics and the theory of statistics, and the references at the end of the chapter.

98. A common method.—Figs. 11, 41, 42, illustrate the common method of showing the relation between two or more factors. A horizontal line through the center of the chart is considered the normal for all the factors, while figures at the side indicate values above or below this normal. The years are given at the top of the page.

Each curve is drawn independently of the others by placing a dot under each year opposite the side figures that show the value of the particular factor for that year. The dots are then connected by proper lines.

In Fig. 11, the solid line, A, shows the departure of the potato yield from the normal from year to year in Ohio. The broken line, B, indicates the departure of the total average rainfall of Ohio for June and July of each year from the normal. The dotted line, C, shows the departure of the average temperature from the normal for the same months.

99. Relation of lines.—It is customary to say that when two curves run together, that is, when one runs above the normal line and the other does the same, and when one goes below the normal line, the other usually follows, or when they run in opposite directions, they show a correlation between the factors, positive in the first case and negative in the second. On this chart, therefore, inasmuch as the lines A and B, representing respectively potato yield and rainfall, appear to follow each other in a general way, it may be assumed that there is some relation between the rainfall of June and July and the yield of potatoes. On the other hand, a careful inspection of curves A and C indicates an opposite bending of the lines, and hence there must be a negative correlation. The difficulty with this method of correlation, however, is that while with two curves only a very general comparison can be made, with three or more curves there seems to be only a confusion of lines.

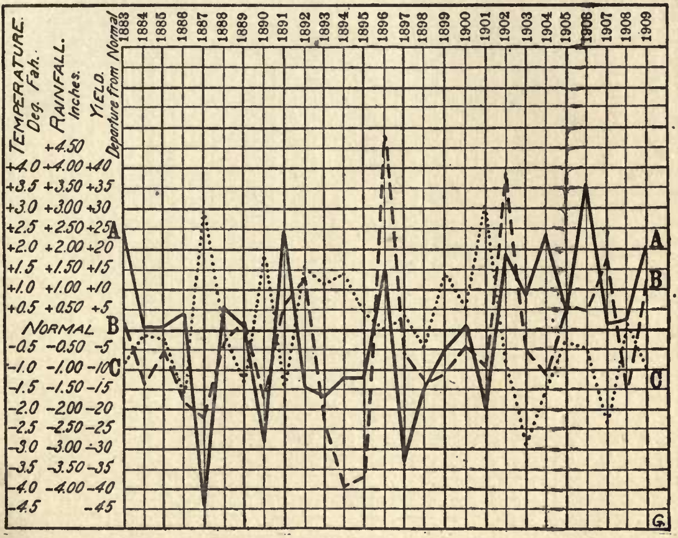

FIG. 11.—Relation of weather to the yield of potatoes in Ohio, 1883–1909.

While this method can be used to show roughly the relation between two factors, it is not recommended for careful work, and not at all when three factors are involved, because of the confusion of lines.

100. A better method.—If three curves are to be used, it is far better to arrange the years so that one of the factors will have an increasing or decreasing value, as in Fig. 12. In this chart the years are arranged so that the curve showing the yield of potatoes runs from the highest yield regularly to the lowest. Then, by drawing the other curves for the years as shown at the top, broad general correlations can be shown. It will be found better in practice, however, to put only two curves on the same diagram.

Examination of the curves on this chart indicates a slight general relation between the yield and rainfall, and a strong opposite relation between the yield and temperature. When the yield is above the normal, the temperature is nearly always below normal, and when the yield is low the temperature is generally high.

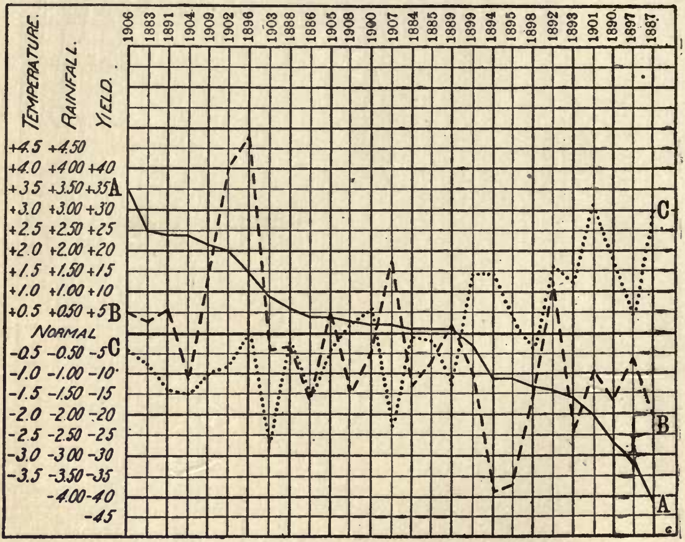

FIG. 12.—Relation of rainfall and temperature to the yield of potatoes in Ohio, 1883–1909.

101. Proper way to find the relation between two variables.—In all attempts to ascertain the relation between two variables, such as rainfall or temperature and crop yield, three steps are necessary: (1) Plot the data as in Figs. 13 to 17; (2) proceed to find the equation of the data on the chart by the method of least squares and trace the calculated straight line or curve of nearest fit; (3) if it is found that the relation between the two variables can be represented by a straight line quite as well as by a curve, the correlation coefficient may be calculated. In this case it is not necessary to make the calculation under No. 2.

102. The dot chart the first step.—In all attempts to ascertain the relation between two variables, it is practically indispensable to make the easily-constructed dot chart, as shown in Figs. 13–17. The data for Fig. 13 were taken from Table 1 showing the average July rainfall and average corn yield in Ohio from 1854 to 1913.

TABLE 1.—AVERAGE JULY RAINFALL AND THE YIELD OF CORN IN OHIO, 1854 TO 1913

Year	*Rainfall, inches*	*Yield, bushels*	*Year*	*Rainfall, inches*	*Yield, bushels*
1854	2.6	26.0	1884	3.8	33.3
1855	5.8	39.7	1885	3.2	36.8
1856	2.6	27.7	1886	2.9	33.5
1857	4.9	36.6	1887	2.2	30.5
1858	4.7	27.7	1888	4.4	38.9
1859	1.6	29.5	1889	4.2	32.3
1860	5.8	38.2	1890	2.0	24.6
1861	3.3	33.5	1891	3.8	35.6
1862	3.6	30.0	1892	3.8	33.3
1863	2.6	27.0	1893	2.5	29.1
1864	2.1	27.0	1894	1.6	32.6
1865	5.7	35.0	1895	2.0	33.7
1868	5.1	36.5	1896	8.1	41.7
1867	3.2	29.8	1897	4.6	34.3
1868	2.7	34.4	1898	4.0	37.4
1869	4.8	28.4	1899	4.2	38.1
1870	4.7	37.5	1900	4.6	42.6
1871	3.7	36.7	1901	2.7	30.0
1872	6.7	40.9	1902	4.7	38.8
1873	6.2	35.1	1903	3.7	31.5
1874	3.8	39.2	1904	4.1	32.8
1875	6.9	34.2	1905	3.9	37.9
1876	6.4	36.9	1906	5.1	42.2
1877	3.7	32.5	1907	5.4	34.8
1878	5.4	37.8	1908	4.1	36.1
1879	4.2	34.3	1909	3.8	38.7
1880	4.2	38.9	1910	3.2	36.6
1881	3.6	31.0	1911	2.4	38.6
1882	3.2	34.0	1912	5.7	42.8
1883	4.2	24.2	1913	5.2	37.8

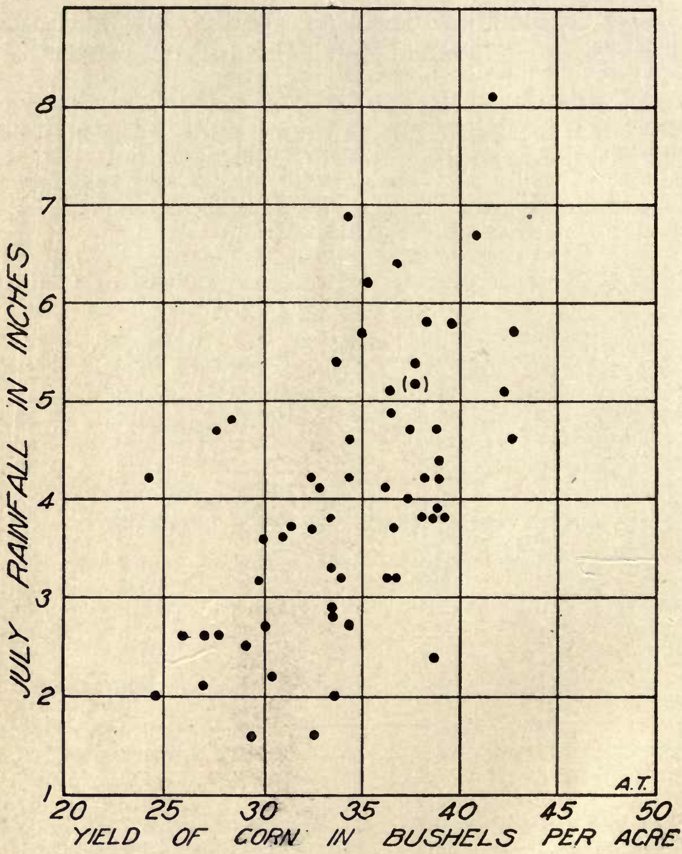

FIG. 13.—Dot chart showing the relation between the July rainfall and the yield of corn, Ohio, 1854–1913.

103. How dot chart is made.—A dot is placed on the chart for each year so that its location agrees with the rainfall value and the yield figures for that year. For example, on Fig. 13, in 1913, the rainfall averaged 5.2 inches, while the yield of corn was 37.8 bushels to the acre, hence the dot (inclosed in brackets) was located to agree with these values.

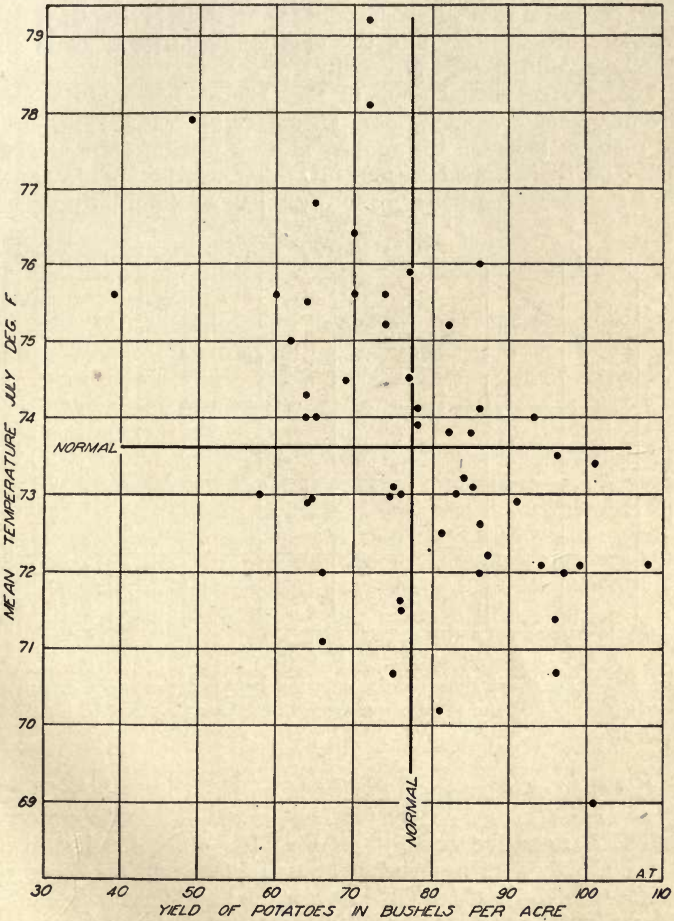

FIG. 14.—Dot chart showing the relation between the mean temperature in July and the yield of potatoes, Ohio, 1860–1914.

104. Potato yield and temperature.—Figs. 14 and 15 were prepared in a similar manner from data giving the mean temperature for July and the yield of potatoes in Ohio and Portage County, respectively.

105. No relation shown in Fig. 15.—When the dots are promiscuously scattered over the chart, as in Fig. 15, there is no relation between the factors and no further time need be spent on their consideration. In other words, Fig. 15 shows that the mean temperature for July has no dominating effect on the yield of potatoes in Portage County, Ohio. (See Chapters VII, VIII, and IX for further discussion of this matter.)

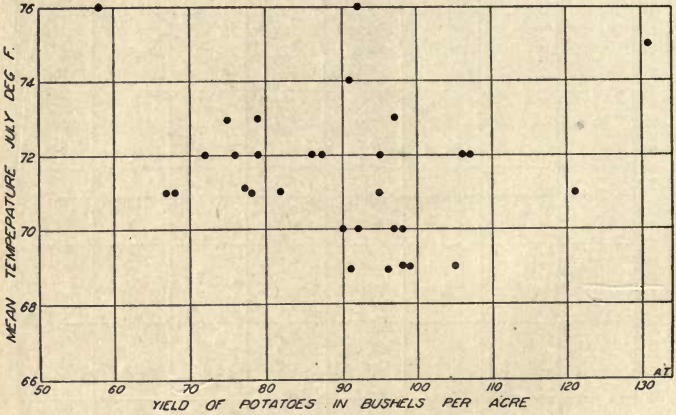

FIG. 15.—Dot chart showing the relation between the mean temperature in July and the yield of potatoes in Portage County, Ohio, 1884–1913.

106. A negative relation in Fig. 14.—Fig. 14, however, shows clearly that in general a warm July is unfavorable for potatoes in the state of Ohio as a whole, and that a cool July is usually followed by a yield of potatoes above the normal. The lines in the center of the chart indicate normal temperature and yield values.

107. Fig. 13 indicates a positive relation.—When the dots are grouped as in Fig. 13, a positive relation is indicated. In this particular case, the chart shows that the heavier the rainfall in July in Ohio, the greater the corn yield will be, in general. Both figures will be discussed further in Chapter VIII.

108. When mathematical correlations should be made.—The dots in Figs. 13, 14 and 15 indicate not only that there is a relation between the two factors, but that this relation can be represented by a straight line. When the dots show a definite linear relation or a relation that can be represented by a curve, then the best fitting line or curve should be determined. This is step No. 2, under paragraph 101, and gives the definite relation between the two variables. The formula can be used in calculating one from the other, such as yield from rainfall.

109. To determine the straight line of nearest fit.—The calculation of the straight line of nearest fit by the method of least squares will be illustrated by a method recently evolved by the author for predicting minimum temperatures on nights when radiation conditions prevail. The dot chart in Fig. 16 shows for San Diego, California, the relation between the depression of the dew-point temperature from the air temperature in the late afternoon, and the variation of the minimum temperature during the following night from the evening dew-point, as indicated by the figures and legend on the chart. The line A, B, was calculated by the method of least squares, as shown by the following.

110. Equation for a straight line.—The equation for determining the straight line of nearest fit, such as A, B, in Fig. 16, is $y=a+bR$. In this case R is the depression of the evening dew-point (*i. e.*, the number of degrees that the dew-point is below the dry bulb or current temperature at the evening observation); y is the variation of the minimum temperature during the coming night from the evening dew-point, or the value that is desired in predicting the minimum temperature. The values a and b are unknown factors that are determined by Table 2 and the calculation following.

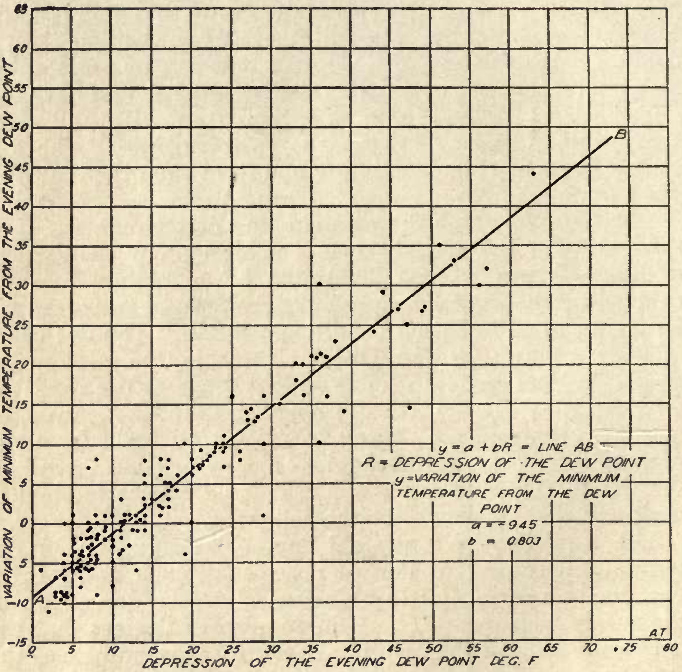

Fig. 16.—Dot chart showing the relation between the variation of the dew-point from the current temperature (the depression of the dew-point) at the evening observation, and the variation of the minimum temperature from the evening dew-point. San Diego, California, radiation nights in November from 1897–1916.

Table 2.—Relation Between the Depression of the Dew-point in the late Afternoon, and the Variation of the Minimum Temperature During the Night from the Evening Dew-point. San Diego, Cal., 20 Novembers to 1916

(1)

R	*y*	R^2	*Ry*
79	+64	6241	+5056
63	+44	3969	+2772
44	+29	1936	+1276
53	+33	2809	+1749
57	+32	3249	+1824
56	+30	3136	+1680
51	+35	2601	+1785
49	+27	2401	+1323
39	+14	1521	+ 546
46	+27	2116	+1242
36	+10	1296	+ 360
27	+14	729	+ 378
44	+27	1936	+1188
36	+21	1296	+ 756
27	+14	729	+ 378
35	+21	1225	+ 735
33	+18	1089	+ 594
24	+ 9	576	+ 216
47	+25	2209	+1175
36	+21	1296	+ 756
33	+20	1089	+ 660
34	+20	1156	+ 680
24	+11	576	+ 264
21	+ 7	441	+ 147
43	+24	1849	+1032
37	+21	1369	+ 777
29	+16	841	+ 464
28	+13	784	+ 364
26	+ 9	676	+ 234
24	+ 7	576	+ 168
16	+ 2	256	+ 32

(2)

R	*y*	R^2	*Ry*
23	+ 9	529	+ 207
17	+ 5	289	+ 85
36	+30	1296	+1080
25	+16	625	+ 400
16	+ 6	256	+ 96
13	— 1	169	— 13
8	+ 8	64	+ 64
23	+ 9	529	+ 207
22	+ 8	484	+ 176
14	+ 5	196	+ 70
28	+13	784	+ 364
16	+ 1	256	+ 16
14	0	196	0
8	— 2	64	— 16
38	+23	1444	+ 874
27	+13	729	+ 351
22	+ 8	484	+ 176
14	+ 8	196	+ 112
11	+ 3	121	+ 33
37	+16	1369	+ 592
34	+16	1156	+ 544
24	+10	576	+ 240
14	+ 3	196	+ 42
11	— 1	121	— 11
31	+15	961	+ 465
29	+10	841	+ 290
29	+ 1	841	+ 29
20	+ 8	400	+ 160
20	0	400	0
13	+ 1	169	+ 13
26	+ 8	676	+ 208

(3) San Diego, Cal., *continued.*

R	*y*	R^2	*Ry*
24	+ 9	576	+216
20	+ 6	400	+120
11	— 4	121	— 44
21	+ 9	441	+189
20	+ 7	400	+140
17	+ 5	289	+ 85
11	0	121	0
17	+ 8	289	+136
13	— 6	169	— 78
12	+ 1	144	+ 12
21	+ 7	441	+147
14	— 1	196	— 14
14	+ 6	196	+ 84
11	0	121	0
10	— 2	100	— 20
23	+10	529	+230
18	+ 6	324	+108
14	+ 2	196	+ 28
13	0	169	0
11	+ 8	121	+ 88
9	— 2	81	— 18
9	+ 1	81	+ 9
7	— 6	49	— 42
19	+10	361	+190
13	— 1	169	— 13
7	+ 7	49	+ 49
5	0	25	0
5	— 4	25	— 20
4	— 9	16	— 36
17	+ 3	289	+ 51
17	+ 7	289	+119
10	— 3	100	— 30
7	— 5	49	— 35
6	— 6	36	— 36
17	+ 2	289	+ 34
11	— 2	121	— 22
7	— 5	49	— 35
7	— 1	49	— 7
7	0	49	0

(4)

R	*y*	R^2	*Ry*
7	— 3	49	—21
7	— 6	49	—42
7	— 4	49	—28
5	— 9	25	—45
1	— 6	1	— 6
18	+ 4	324	+72
16	+ 2	256	+32
14	+ 1	196	+14
10	+ 1	100	+10
8	— 4	64	—32
8	— 5	64	—40
7	— 6	49	—42
5	— 4	25	—20
4	— 9	16	—36
4	— 9	16	—36
17	+ 4	289	+68
12	— 3	144	—36
9	— 1	81	— 9
8	0	64	0
7	— 4	49	—28
5	— 3	25	—15
19	— 4	361	—76
10	— 5	100	—50
8	+ 1	64	+ 8
7	— 2	49	—14
4	—10	16	—40
3	— 9	9	—27
2	—11	4	—22
15	+ 3	225	+45
11	— 4	121	—44
8	— 9	64	—72
7	— 3	49	—21
7	— 1	49	— 7
6	— 6	36	—36
6	— 8	36	—48
6	— 4	36	—24
5	— 3	25	—15
5	— 5	25	—25
13	0	169	0

(5) SAN DIEGO, CAL., *continued.*

R	y	R^2	Ry
12	+1	144	+12
8	−2	64	−16
10	−8	100	−80
8	−5	64	−40
6	−6	36	−36
4	−6	16	−24
5	−6	25	−30
4	−8	16	−32
4	−4	16	−16
9	−1	81	− 9
6	−2	36	−12
6	−4	36	−24
3	−9	9	−27
6	−7	36	−42
4	−9	16	−36
5	−2	25	−10
5	+1	25	+ 5
4	−7	16	−28
3	−9	9	−27
4	−5	16	−20
3	−7	9	−21
4	0	16	0

Sums $2803 = \Sigma R$ $+ 720 = \Sigma y$ $80{,}093 = \Sigma R^2$ $+ 37{,}829 = \Sigma Ry$.
(162 items = n)
R = Depression of the dew-point.
y = Variation of the minimum from the evening dew-point.

111. To determine values of a and b.—The values of the unknown quantities a and b in the equation $y = a + bR$, are determined by the following equation and calculation:

$$(1)\quad b = \frac{n(\Sigma Ry) - (\Sigma R)(\Sigma y)}{n(\Sigma R^2) - (\Sigma R)^2}.$$

Inserting the values at the foot of the table we have,

$$(2)\quad b = \frac{162(37829) - (2803)(720)}{162(80093) - (2803)^2} = 0.803$$

$$(3)\quad a = \frac{\Sigma y - b(\Sigma R)}{n}$$

Inserting the values in the table, and the value of b, we get,

$$(4)\ a = \frac{720 - 0.803\ (2803)}{162} = -9.4494.$$

112. To locate line AB.—After finding the values of a and b, it becomes a simple matter to insert them in the equation $y = a + bR$, and compute y. For example, if the dew-point at the evening observation is 30° below the current temperature, the equation becomes

$$y = -9.5 + 0.803 \times 30 = 14.6$$

A mark is then placed on the 30 perpendicular line opposite the value of 14.6 at the left. One other point is located in the same manner and the straight line AB is drawn. This is the method which should be followed on all dot charts where an inspection shows that the relation is linear.

113. When a curve fits the data best.—After the dot chart has been made, if an inspection shows that a curve will fit the data better than a straight line, as in Fig. 17, the problem is to find some form of curve that will represent the arrangement of dots with satisfactory accuracy. If the curvature is not great and there are points of inflection, the parabola or possibly the hyperbola may be the simplest forms to try. In this case the deviation from a straight line is not great and is fairly regular, hence it seems probable that the data may be represented by some portion of some parabola which is perhaps the simplest type of curve likely to be suitable.

114. Evaluation of the coefficients.—Having chosen the type of curve, the next problem is to evalulate the unknown coefficients. It is a well known principle in algebra that the values of unknown terms in equations can be calculated only when there are just as many independent simultaneous equations between the quantities as there are unknown terms to be found.

115. Least square method.—The least square method is simply a mathematical scheme by which a large number of observations may be combined in a manner which will give the required or so-called "normal" equations and at the same time according to a principle which will give the best fit. Whether the type chosen be a straight line, parabola, or other curve, the least square solution gives at once the particular line of that type which fits best, but whether some other type of line will fit still better can be found only by trial, that curve being the best for which the standard deviation is a minimum.

116. The equation for a parabola.—The equation of a parabola may be written $y = a + bx + cx^2$, in which the coefficients a, b, and c are commonly designated as constants whose values are either known beforehand or must be determined in order that the curve may fit some particular case. The quantities x and y may have almost any value in pairs and are called variables. For some arrangements of data the equation might need to be written

$$x = a + by + cy^2$$

but the same result would be gained simply by transposing the scheme of plotting the data. Inasmuch as the last letters of the alphabet are commonly used to designate unknown quantities, the first equation is changed to read

$$v = x + by + cz$$

in which x, y, and z are the coefficients to be determined; b is the evening relative humidity; c the square of the relative humidity and v the variation of the minimum temperature of the following morning from the evening dew-point, or the value desired in making a forecast of the minimum temperature on radiation nights.

117. Star point method for calculating the parabolic curve.—The use of the least square method is generally tedious and laborious, especially when large quantities of data must be treated and when three or more unknowns are to be found, although it must be employed in many cases. On the other hand, the present and many other similar problems may be solved much more expeditiously and without sacrifice of useful accuracy by what Charles F. Marvin, Chief of the Weather Bureau, has called the "star point method" in order clearly to differentiate it from the least square method.

118. Star point method applied to other problems.—It may be applied to the solution of any problem and supplies the required number of "star" equations simply by the judicious selection, on the graph, of the required number of "star" points, one for each unknown to be evalulated. (See

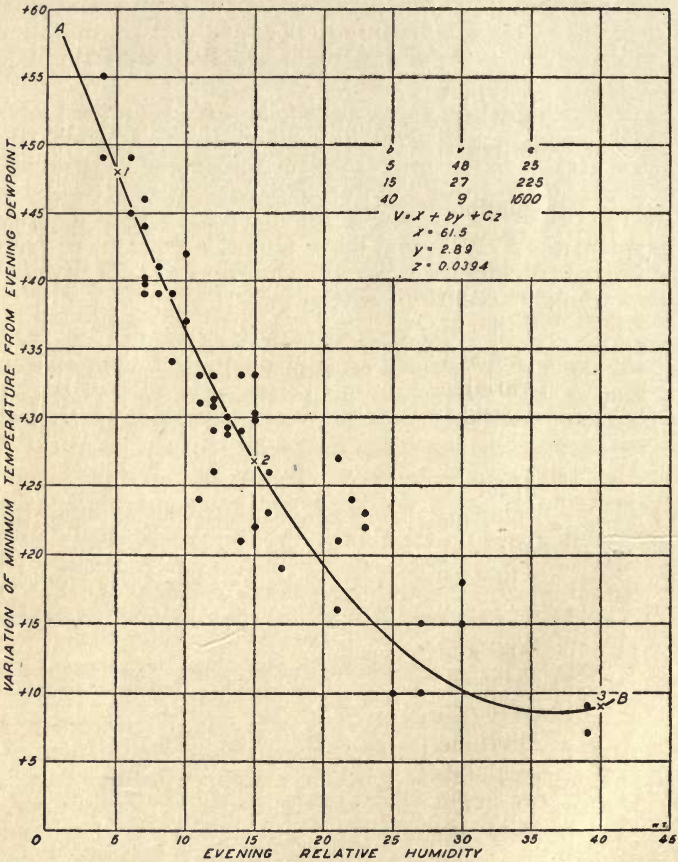

FIG. 17.—Dot chart showing the relation between the evening relative humidity and the variation of the minimum temperature from the evening dew-point, El Paso, Texas, radiation nights in 1918.

1, 2, and 3, Fig. 17.) This method simply substitutes intelligent selection of the star points for the tedious least square process of forming normal equations, with the further convenience that in general the numerical factors are small numbers, thereby simplifying the solution of the equations.

119. Accuracy necessary.—It seems proper to add a word of advice to beginners in regard to securing accuracy in arithmetical computations. In problems of the kind under consideration, it is generally necessary to carry four, or possibly five, significant figures throughout the original computations, inasmuch as this makes the derived results sufficiently accurate to show serious disagreement if errors of arithmetic are made in the process. At the end of the operation, unnecessary significant figures may be dropped by the usual rules. The effect of this may, however, appear by seeming to shift the calculated curve so as not to pass exactly through the original star points, as should otherwise be the case.

120. Calculating the parabolic curve.—The process for calculating the parabolic curve by the star point method is given somewhat in detail for the benefit of the student who may not have access to the more complete text-books. After the selection of the relative humidity values to be used in these equations, the exact locations of the points, 1, 2, and 3 can be determined by inspection or by calculation from the position of the surrounding dots. On this figure, point 1 was placed at a relative humidity of 5 per cent with the variation of the minimum temperature from the dew-point 48°. At the star point 2, the relative humidity is 15 per cent and the variation 27°; at point 3 the relative humidity was 40 per cent and the variation 9°.

121. Normal equations.—With these data, the normal equations are written as follows:

Normal Equations

b	v	c
5	48	25
15	27	225
40	9	1600

In these b is the relative humidity; c the square of the relative humidity, and v the variation of the minimum temperature from the dew-point.

From this table the three equations for solving the unknown factors x, y, and z are written

$$
\begin{aligned}
&(1)\ x + b_1y + c_1z = v_1\\
&(2)\ x + b_2y + c_2z = v_2\\
&(3)\ x + b_3y + c_3z = v_3
\end{aligned}
$$

The coefficients b_1, b_2, and b_3 represent the three values of b in this table, viz: 5, 15, and 40; the values of c_1 and v_1 and so on, are the corresponding values of these factors.

122. Solving for unknown quantities.—The values of x, y, and z will be determined by the usual algebraic methods of solving for unknown quantities. This may be done by indicating the work algebraically and solving for each value, or preferably by what may be termed the direct solution method.

123. Solving by direct solution.—Usually the value of z can be determined by substituting the known values of b, v, and c in the normal equations and then solving. In this case equations (1), (2), and (3) become

$$
\begin{aligned}
&(1)\ x + 5y + 25z = 48\\
&(2)\ x + 15y + 225z = 27\\
&(3)\ x + 40y + 1600z = 9
\end{aligned}
$$

Subtracting equation (2) from equation (1), we get

$$(4)\ -10y - 200z = 21.$$

Subtracting (3) from (2), we have

$$(5)\ -25y - 1375z = 18.$$

Obtain like coefficients for y by multiplying equation (4) by 5 and equation (5) by 2 when we get, respectively,

$$
\begin{aligned}
&(6)\ -50y - 1000z = 105, \text{ and}\\
&(7)\ -50y - 2750z = 36.
\end{aligned}
$$

Subtracting equation (7) from equation (6), we have,

$$
\begin{aligned}
&(8)\ 1750z = 69, \text{ or}\\
&z = 0.03943.
\end{aligned}
$$

124. To determine the value of y and x.—The next step will be to substitute the value of z in equation (4) or (5), and solve for y. The work will be checked by solving for y in both equations and this should be done. Substituting the value of z in equation (4) we get

$$
\begin{aligned}
&(9)\ -10y - (200 \times 0.03943) = 21\\
&y = -2.8886.
\end{aligned}
$$

Substituting z in equation (5), it becomes

$$(10)\ -25y - (1375 \times 0.03943) = 18$$

$$y = -2.88865.$$

These values of y must agree closely if the arithmetic is correct. Substituting the values of y and z in equations (1), (2), and (3) we get the following

$$(11)\ x + (5 \times -2.8886) + (25 \times 0.03943) = 48$$

$$(12)\ x + (15 \times -2.8886) + (225 \times 0.03943) = 27$$

$$(13)\ x + (40 \times -2.8886) + (1600 \times 0.03943) = 9$$

Carrying out the calculation we have for each equation, respectively,

$$x = 61.45725$$

$$x = 61.45725$$

$x = 61.456$, or an average of

61.457 for the value of x.

125. Checking the work.—In general, it would be best to check the accuracy of all the arithmetic in the computation of coefficients. This is done by substituting the values of x, y, and z in equations (1), (2) and (3) which should give exactly the absolute terms, in this case 48, 27, and 9. Very slight errors will result from dropping digits in the values of x, y, and z but appreciable discrepancies indicate arithmetical errors.

126. The hygrometric equation for El Paso, Texas.—By using these values: $x = 61.46$; $y = -2.889$; and $z = 0.0394$ for the unknown quantities in the equation, $v = x + by + cz$, the probable variation of the minimum temperature from the evening dew-point (v) can be determined on radiation nights with a fair degree of accuracy at El Paso. The parabolic curve will be placed on diagram 17 by utilizing the points already selected and calculating others by this equation. For a relative humidity of 10 per cent, for example, by inserting the known values of b and c, and the above determined values for x, y, and z, in the equation

$$v = x + by + cz,$$

it becomes

$$(14)\ v = 61.46 + (10 \times -2.89) + (100 \times 0.0394).$$

Carrying out the calculation, we get,

$$v = 36.5°.$$

By the same method the value of v for other relative humidity figures is calculated, and then the line AB drawn.

If the line, as calculated, runs too high or too low, it will be evident that the points for making the three normal equations were not correctly located, when new points must be taken and the work repeated.

If trials fail to give a satisfactory parabolic curve, it will be evident that the line of satisfactory fit is not a parabola, but some other curve. Just as the trial of a parabolic curve to fit the data shows a closer agreement than a straight line gives, so the trial of some other curve than the parabola might show by the magnitude of the sum of the squares of the residuals which of the two or many curves tried will give the best fit, that best fit being shown by the minimum sum of the squares.

127. Practical application of the formula.—Having satisfied oneself that a particular formula is a dependable aid in the work in hand, the use of the equation in practical work is effected most expeditiously by computing a table or preparing charts giving the necessary values either of *v* for a series of values b, or providing a larger table or chart giving directly the values of v based on the known relations between b and v.

In the following tabulation the variation of the minimum temperature from the evening dew-point (v) for certain relative humidities (b) at the evening observation at El Paso, Texas, are tabulated. This is from the equation $v = x + by + cz$ when the values of the unknowns, determined from the above calculations are,

$$x = 61.457;\ y = 2.889;\ z = 0.03943.$$

b	*c*	*by*	*cz*	*v*
5	25	— 14.445	0.986	48.00
6	36	— 17.334	1.3184	45.44
7	49	— 20.223	1.9306	43.16
8	64	— 23.112	2.5216	40.87
9	81	— 26.001	3.1914	38.65
10	100	— 28.89	3.943	36.51
20	400	— 57.78	15.767	19.44
30	900	— 86.67	35.487	10.27
40	1600	—115.56	63.088	8.99
50	2500	—144.45	98.575	15.58

128. Other curves.—If neither the straight line nor the parabolic curve fits the data, other curves may be calculated. The hyperbola, for example, involves four unknown quantities and requires four normal equations. After these have been stated, the solving of the unknown quantities proceeds in a similar manner. A text on curve fitting should be consulted in these operations.

129. The correlation coefficient.—When the dot chart shows a linear relation between the two variables, and it is not desired to determine this relation in the definite manner that is possible by the calculation indicated in step No. 2, the index of the extent to which a relation can be represented by a straight line can be determined by finding the correlation coefficient, step No. 3. (See paragraph 101).

130. Definition and explanation.—The correlation coefficient may be defined as the mean product of deviations of corresponding variates from their mean values in units of the standard deviation.

The correlation coefficient is a measure of the resemblance of two sets of observations or the measure of the dependence of one phenomenon on another when this dependence is linear.

The theory of the correlation coefficient assumes that a series of observations can be represented by a straight line, and the correlation coefficient expresses the degree of exactness, on a basis of 0 to +1 or 0 to −1 with which the observations fall on that line. The determination of the coefficient, further, gives an idea of what the equation of the straight line may be.

131. Most commonly used in showing relation between weather and crop yield.—The calculation of the correlation coefficient in studying the influence of certain weather factors in varying the yield of crops was first applied by G. Udny Yule and R. Hooker in Europe, S. M. Jacob of Calcutta, and independently in this country by the author. It has since come to be the method most commonly used by students of weather and crops everywhere. Too much weight should not be given to the results of this method, however, unless the dot chart shows a well defined linear relation. The dot chart should, therefore, always be made before the correlation coefficient is calculated.

132. How to calculate the correlation coefficient.—The method of determining the correlation coefficient is illustrated in Table 3, and the discussion following.

TABLE 3. CORRELATION OF JULY RAINFALL AND THE YIELD OF CORN, IN OHIO, 1854 TO 1913

Year	*July rainfall*			*Corn yield*			
1	2	3	4	5	6	7	8
	Amount	*Departure*	*Square of departure*	*Amount*	*Departure*	*Square of departure*	3 x 6
	Inches	*Inches*		*Bushels*	*Bushels*		
1854	2.6	−1.5	2.25	26.0	−7	49	+10.5
1855	5.8	+1.7	2.89	39.7	+7	49	+11.9
1856	2.6	−1.5	2.25	27.7	−5	25	+ 7.5
1857	4.9	+0.8	.64	36.6	+4	16	+ 3.2
1858	4.7	+0.6	.36	27.7	−5	25	− 3.0
1859	1.6	−2.5	6.25	29.5	−3	9	+ 7.5
1860	5.8	+1.7	2.89	38.2	+5	25	+ 8.5
1861	3.3	−0.8	.64	33.5	+0.4	..	− 0.3
1862	3.6	−0.5	.25	30.0	−3	9	+ 1.5
1863	2.6	−1.5	2.25	27.0	−6	36	+ 9.0
1864	2.1	−2.0	4.00	27.0	−6	36	+12.0
1865	5.7	+1.6	2.56	35.0	+2	4	+ 3.2
1866	5.1	+1.0	1.00	36.5	+4	16	+ 4.0
1867	3.2	−0.9	.81	29.8	−3	9	+ 2.7
1868	2.7	−1.4	1.96	34.4	+2	4	− 2.8
1869	4.8	+0.7	.49	28.4	−4	16	− 2.8
1870	4.7	+0.6	.36	37.5	+5	25	+ 3.0
1871	3.7	−0.4	.16	36.7	+4	16	− 1.6
1872	6.7	+2.6	6.76	40.9	+8	64	+20.8
1873	6.2	+2.1	4.41	35.1	+2	4	+ 4.2
1874	3.8	−0.1	.01	39.2	+6	36	− 0.6
1875	6.9	+3.0	9.00	34.2	+1	1	+ 3.0
1876	6.4	+2.5	6.25	36.9	+3	9	+ 7.5
1877	3.7	−0.2	.04	32.5	−1	1	+ 0.2
1878	5.4	+1.5	2.25	37.8	+4	16	+ 6.0
1879	4.2	+0.3	.09	34.3	+1	1	+ 0.3
1880	4.2	+0.3	.09	38.9	+5	25	+ 1.5
1881	3.6	−0.3	.09	31.0	−4	16	+ 1.2
1882	3.2	−0.7	.49	34.0	+0.5	..	− 0.4
1883	4.2	+0.3	.09	24.2	−9	81	− 2.7

TABLE 3. CORRELATION OF JULY RAINFALL AND THE YIELD OF CORN, IN OHIO, 1854 TO 1913—*Continued*

Year	*July rainfall*			*Corn yield*			
1	2	3	4	5	6	7	8
	Amount	*Departure*	*Square of departure*	*Amount*	*Departure*	*Square of departure*	3 x 6
	Inches	*Inches*		*Bushels*	*Bushels*		
1884	3.8	−0.1	.01	33.3	−0.2	..	......
1885	3.2	−0.7	.49	36.8	+3	9	−2.1
1886	2.9	−1.0	1.00	33.5	−0.03	..	......
1887	2.2	−1.7	2.89	30.5	−3	9	+ 5.1
1888	4.4	+0.5	.25	38.9	+5	25	+ 2.5
1889	4.2	+0.3	.09	32.3	−1	1	− 0.3
1890	2.0	−1.9	3.61	24.6	−9	81	+17.1
1891	3.8	−0.1	.01	35.6	+2	4	− 0.1
1892	3.8	−0.1	.01	33.3	−0.2	..	......
1893	2.5	−1.4	1.96	29.1	−4	16	+ 5.6
1894	1.6	−2.6	6.76	32.6	−4	16	+10.4
1895	2.0	−2.2	4.84	33.7	−3	9	+ 6.6
1896	8.1	+3.9	15.21	41.7	+5	25	+19.5
1897	4.6	+0.4	.16	34.3	−3	9	− 1.2
1898	4.0	−0.2	.04	37.4	+0.4	..	− 0.1
1899	4.2	+0.01	.001	38.1	+1	1	......
1900	4.6	+0.4	.16	42.6	+6	36	+ 2.4
1901	2.7	−1.5	2.25	30.0	−7	49	+10.5
1902	4.7	+0.5	.25	38.8	+2	4	+ 1.0
1903	3.7	−0.5	.25	31.5	−6	36	+ 3.0
1904	4.1	−0.1	.01	32.8	−4	16	+ 0.4
1905	3.9	−0.3	.09	37.9	+1	1	− 0.3
1906	5.1	+0.9	.81	42.2	+5	25	+ 4.5
1907	5.4	+1.2	1.44	34.8	−2	4	− 2.4
1908	4.1	−0.1	.01	36.1	−1	1	+ 0.1
1909	3.8	−0.4	.16	38.7	+2	4	− 0.8
1910	3.2	−1.0	1.00	36.6	−0.4	..	+ 0.4
1911	2.4	−1.8	3.24	38.6	+2	4	− 3.6
1912	5.7	+1.5	2.25	42.8	+6	36	+ 9.0
1913	5.2	+1.0	1.00	37.8	+1	1	+ 1.0
Sum			111.83			1,045	+203.2

133. Explanation of table.—Eight columns are used in the table. Column 1 indicates the items, which in this case are the years from 1854 to 1913, inclusive, a period of sixty years.

Column 2 gives the average rainfall for the state of Ohio for the month of July for each of these years. Column 3 shows the departure of the rainfall for each year, from the average or normal for the month. In column 4 these departures from the normal have simply been squared.

In column 5 there has been entered the average yield of corn for the state of Ohio for each year, in bushels to the acre. Column 6 gives the difference between the yield for each year and the normal or average for a long period.

134. Average corn yield.—The average yield of corn for Ohio for the sixty years is 34.5 bushels an acre. A careful inspection of the yield figures, however, will show a gradual increase in the yield during much of the time, and instead of taking the difference between the yield for each year and the average for the whole period, it seemed best to use the mean for each twenty years in determining the departure figures for column 6. The average yield of corn for the period from 1854 to 1873 was 32.9 bushels to the acre; from 1874 to 1893, 33.5 bushels to the acre; and from 1894 to 1913, 37 bushels to the acre. Inasmuch as a mean yield was determined for each twenty years in showing the departure from the normal, the rainfall departures in column 3 were obtained for the same years in the same manner. It will be noticed also that the yield figures are given to tenths while the departure figures are to the nearest whole number.

The figures in column 7 are the square of the departure figures in column 6 and correspond with column 4. In column 8 there is given the product of the two departure columns 3 and 6. Care must be taken in this column to place the proper sign before the figures, remembering that in multiplying like signs produce "plus" and unlike signs "minus" values. The next step in the calculation is to obtain the sums of columns 4 and 7, multiply them and obtain the square root of the product. The sum of column 4 is 111.83 and of column 7, 1,045. The product of these factors is 116,862.35 and the square root of this product is 341.8.

The next step is to obtain the algebraic sum of the values in column 8. This is +203.2 and this must be divided by 341.8, the square root of the product of the sums of columns

4 and 7. This gives a quotient of +0.59 which is called the "correlation coefficient" or r.

135. Value of correlation coefficient.—In this method of correlation, if there is an exact relation between the two factors under discussion, the correlation coefficient will be either +1 or −1. That is to say, if every time the rainfall was increased a certain amount the corn yield was increased in exactly the same ratio, then the correlation coefficient would be exactly +1. And on the other hand if every time the rainfall was increased a certain definite amount the corn yield would be decreased in an exact ratio, the correlation coefficient would be exactly −1.

So in this correlation, the nearer the correlation coefficient, r, approaches 1 the closer the relation, and the nearer it approaches 0 the less the relation. Some writers believe that the relation or influence of one factor on another is well established if the correlation coefficient is three times the probable error, while others think that it should be six times the probable error. It probably is safest to assume that there may be some relation if the correlation coefficient is three times the probable error and the relation is established beyond question if it is more than six times the probable error.

When the correlation coefficient is six times the probable error, the chance that there is a relation between the two factors is something like 15,000 to 1, and when it is two times the probable error it is about 7 to 1.

136. The probable error.—The probable error is found by the following equation in which r is the correlation coefficient and n the number of years under consideration:

$$0.674\,\frac{1 - r^2}{\sqrt{n}}$$

Substituting the values obtained in Table 3, we have the equation:

$$0.674\,\frac{1 - (0.59)^2}{\sqrt{60}}$$

which equals ± 0.057 which is only one-tenth of the correlation coefficient. This shows without question a very high correlation between the July rainfall and the yield of corn in Ohio covering a sixty-year record.

137. Partial or net correlation.—When it is desired to determine the influence of each factor where two or more are involved, partial or net correlations can be made. A case in point would be the weight that should be given to both temperature and rainfall for any month on the yield of corn.

In this case there are the three variables, precipitation, temperature, and yield, to consider. By representing these by p, t, and y respectively and writing r_{py}, r_{ty}, and r_{pt}, to represent respectively the correlation coefficients between precipitation and yield, temperature and yield, and precipitation and temperature, the equations may be written as follows:

$$(1)\quad r_{py.t} = \frac{r_{py} - r_{pt}\, r_{ty}}{\sqrt{(1 - r_{pt}^2)\,(1 - r_{ty}^2)}}$$

$$(2)\quad r_{ty.p} = \frac{r_{ty} - r_{pt}\, r_{py}}{\sqrt{(1 - r_{pt}^2)\,(1 - r_{py}^2)}}$$

By inserting the various correlation coefficients in these equations and making the calculation, there will be in equation 1, the influence of the rainfall on the yield of corn after eliminating the influence of the temperature and in equation 2 the influence of the temperature after eliminating the effect of the rainfall. The influence of other factors such as sunshine may be obtained in a similar manner.

138. A graphic illustration of the influence of two factors on a third.—Figs. 35, 36, 43, 48, 58, and 59 show a graphic method of determining in a general way the combined effect of temperature and rainfall on the yield of crops.

LABORATORY EXERCISES

1. Paragraph 98. Obtain rainfall, temperature, and crop yield data and prepare curves showing relation between two factors.

2. Paragraph 102. Make dot charts on cross-section or squared paper, from the climatic and yield data. Place the yield figures on the axis of abscissas, or horizontal axis, and the temperature or rainfall figures on the axis of ordinates.

3. Paragraph 108. Calculate the straight line of nearest fit for the dot charts made.

4. Paragraph 113. Calculate the parabola of nearest fit for the dot charts made.

5. Paragraph 129. Calculate the correlation coefficient for the data which have a linear relation as shown by the dot charts made.

6. Paragraph 136. Calculate the probable error of the correlation coefficient determined.

7. Paragraph 137. Calculate the partial or net correlation for any equation where three factors are involved. For example, temperature and rainfall and the yield of a crop.

8. When three factors are involved, chart the figures showing the departures of the temperature and the departures of the rainfall from the normal on cross-section paper as in the figures indicated. The location of each "point" is fixed by giving its distance from the vertical and horizontal axes. The distance from the vertical axis is called the abscissa, and the distance from the horizontal axis is called the ordinate, of the point. The horixontal axis is commonly called the X-axis, or the axis of x; and the vertical axis the Y-axis, or the axis of y. The abscissa and the ordinates are then called respectively the x and y coördinates.

The two axes divide the plane into four parts, called quadrants.

In working the above it is well to consult one of the text-books on the method of least squares.

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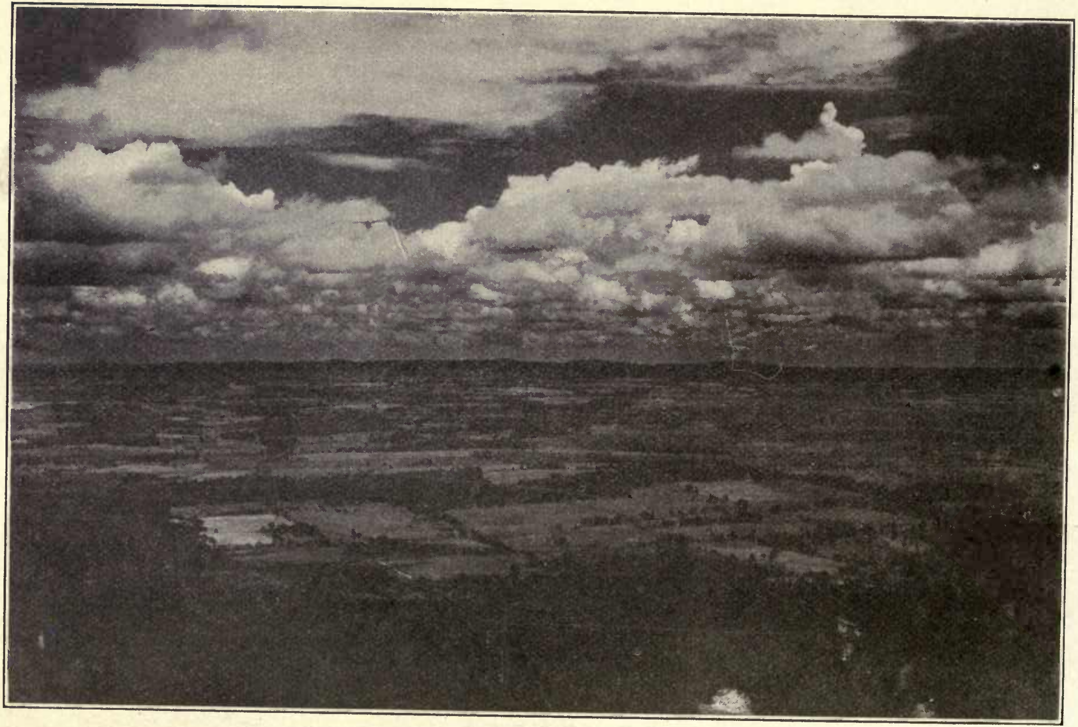

Plate III.—Cumulus clouds.

CHAPTER V

CLIMATE AND CROPS

Climate has been defined as "mean weather." Climate is the sum total of the meteorological phenomena that characterize the average condition of the atmosphere at any place on the earth's surface.

139. Solar or mathematical climate has to do with the amount of energy received from the sun at the surface of the earth. The solar climate of a place, then, depends on its latitude and the conditions of the atmosphere.

140. Physical or natural climate is the solar climate as modified by the surface features of the earth. The chief causes of this modification or interference with the solar climatic zones are : (1) Irregular distribution of the land and water over the earth's surface; (2) atmospheric and oceanic currents; (3) difference in altitude of the land above sea-level.

141. Three classes of climate.—Climate then depends on: (1) latitude; (2) location with reference to land and water; (3) elevation. There are three main classes of climate found on the surface of the earth: (1) continental; (2) marine or oceanic; and (3) mountain.

142. Continental and marine climates.—The surface of the land warms up more rapidly under the influence of sunshine than the surface of the water, and the land loses heat more rapidly at nighttime by radiation than the water. Hence, diurnal changes in temperature are much more rapid in continental climates in the interior of the country than near the coast. Generally the temperature changes are greater between summer and winter; so that the common feature of a continental climate in all latitudes is a large range in temperature. Other things being equal, the range is greater the higher the latitude. Over continents the highest temperature comes about one month after the date of the sun's maximum altitude. In marine climates the warmest month is August, two months after the sun has reached its highest point.

Over continents the minimum temperature is one month or less later than the time when the sun is farthest south, while in a marine climate the lowest temperature does not occur until two or even three months after the sun is the lowest. A marine climate has a cold spring and warm autumn, April and May being colder than September and October. The conditions are reversed on the continent, where the spring is warm and the autumn cold; April is warmer than October as a rule.

143. Mountain climate.—Mountain systems exert a profound influence on climate, not only in the immediate neighborhood, but also far to the leeward with respect to the prevailing winds. In general the characteristics which distinguish between the climate of mountains and the surrounding lowlands are: (1) lower temperatures in both winter and summer; (2) a drier atmosphere; (3) a greater rainfall and snowfall on the slopes exposed to the moisture-laden winds; (4) higher wind velocities; and (5) greater intensity of the direct solar rays.

An interesting and peculiar climatic condition of mountains is the low night temperatures in the valleys as compared with the surrounding hillsides, and the early frosting of all crops in the valleys. In the Alps this fact is recognized and farm-houses and villages are often built on the hillsides instead of in the valleys. During the calm clear spells of late autumn, the traveler stopping at one of these houses on the steep hillside may there breathe the air that has the mildness of summer; he may see the green fields still decked with autumn flowers, and may watch the sheep grazing in the fields, while down below in the valley the ground is already frozen hard, the trees are leafless, and all activities of plant life have long since ceased.

144. Verdant zones or thermal belts.—In North Carolina there are rather poorly defined zones along the mountain side called thermal belts where the damage by frost is practically nil, while above and below this belt crops may be killed. A careful investigation by the Weather Bureau and the State Department of Horticulture shows, however, that this frost-free zone is variable and fluctuates up and down the mountain side with different seasons.

145. Climatic zones.—For more than two thousand years geographers have recognized three climatic divisions, torrid, temperate, and frigid. These are purely astronomical and are really zones of sunshine. In the tropics the sun reaches the zenith twice each year and the day is never less than ten and one-half hours long. In the frigid or polar zone, the sun is below the horizon for twenty-four hours at least once in winter, and above once in summer. The temperate zone is between the two extremes. At no point can the sun be in the zenith, nor, except on the polar circle, is there anywhere a twenty-four hour day or night. Early writers taught that both the torrid and frigid zones were uninhabitable.

146. Relative areas and limits.—Taking the area of a hemisphere as unity, the relative areas of these zones are: tropical, 0.40; temperate, 0.52; and polar, 0.08. Inasmuch as temperature determines habitability, the limits of plant growth, and the general conditions of human life, one important division of climate has been made in limiting the temperate zone within certain well-fixed limits of temperature, these limits having well-marked relations to organic life. Two critical daily mean temperatures, 68° and 50°, and the duration of these periods for one, four, and twelve months are the factors of this classification. A normal duration of 50° for less than a month fixes very well the polar limit of trees and the limits of agriculture. Near this line are found the last group of trees in the tundras. A temperature of 50° for four months marks the limit of oaks and closely coincides with that of wheat cultivation. North of the tree limit, agriculture ceases and man's food is to be sought very largely from the sea. With approach to this line, the period of plant growth is shortened more and more, agricultural operations become restricted, and occupations of other kinds are taken up.

From this classification we have: (1) tropical belts with all months hot, that is, the temperature averaging over 68°; (2) temperate belt with the mean temperature of four of the twelve months averaging between 50° and 68°; (3) polar belts, that is, with all months cold, or with the average temperature for the warmest month 50° or lower.

147. The main factors in climate.—The main meteorological factors in determining climate are temperature, moisture, sunshine, and wind.

TEMPERATURE

148. Importance.—The temperature is the most important factor in determining the flora and the general zones of vegetation and the location of the most important food plants. Experiments indicate that the higher forms of plants cannot grow where the temperature remains continuously below 32° or above 122°, while most food plants can thrive only within much narrower ranges. Wheat and corn are grown within a belt where the mean annual temperature is between 39° and 68°; oats and barley, 28° to 68°; rice, 68° to 86°: and potatoes 35° to 61°.

149. Temperature effects.—High and low temperatures affect crops in various ways, but the principal ones are by preventing germination, checking growth, killing all or part of the vegetative parts, injuring the blossoms, or damaging the maturing products. Most plants make growth only during the portion of the year when the temperature remains within certain limits, maturing, dying, or becoming dormant when the temperature falls too low or rises too high.

150. Temperature and plant distribution.—So far as the controlling influence of temperature is concerned, plants spread readily to the east and west, less readily to south and least easily to north.

151. Affects various plants differently.—Most annuals grow continuously during a certain period of the year and either die or mature when it becomes too cold or too warm. A few become dormant when unfavorable temperatures obtain, resuming and finishing growth when more favorable temperatures prevail.

152. Periods of growth.—For the sake of convenience, the months when the mean daily temperature is between 49° and 72° are considered periods of growth for most crops. When the average temperature is above 72° and there is plenty of moisture, tropical and subtropical plants continue growth or fruits will ripen. When moisture is lacking, however, this becomes a period of summer rest.

153. Periods of rest.—In most sections of the United

States, there are periods during the year, varying in length in different localities, with temperature too low for active plant growth; these are known as rest-periods. When the temperature in its annual march rises to the vegetative or active value, growth, in general, begins. The rate is slow at first, but it is accelerated with the rise in temperature, provided sufficient soil-moisture is present, until the optimum is reached, after which growth is slowly retarded until the winter rest-period is again entered. The rest, vegetative, and optimum temperature values differ for different plants and localities, but, in general, cultivated plants remain more or less dormant in temperate climates as long as the mean temperature remains below 49°.

154. Length of rest period.—Fig. 18 shows the general rest-periods for most plants in different sections of the country, as determined by the average time in months between the first month in autumn and the last in spring, inclusive, with a mean temperature below 49°. The vegetative period is represented by the months of the year other than those shown for the several areas on the chart.

In portions of the northeastern states, in the western Upper Lake region, most of Wisconsin and Minnesota, and also in the Dakotas, Montana, and the central and northern portions of the Rocky Mountain region, the rest-period extends from October to April, or is of seven months' duration. Immediately to the southward of this area, there is a belt of limited width in which the mean temperature does not fall below 49° until November, but remains below that value in spring for the month of April, thus covering a period of six months. Throughout a wide belt, extending from Kansas and Nebraska eastward to the middle Atlantic coast and reaching as far south as the northern portions of North Carolina, Tennessee, Arkansas, and Oklahoma, the rest-period extends from November to March, five months. From this area it decreases southward to the central portion of the Gulf states where only one month, January, has a mean temperature below 49°; while along the Gulf coast, including the whole of Florida, a mean monthly temperature of 49°, or higher, is found in every month.

Owing to the diversity of topography from the Rocky Mountains westward, very little detail has been attempted in

FIG. 18.—Chart showing the average time, in months, in which plant life in general, remains more or less dormant. It is based on the average period between the first month in the fall and the last in spring, with a mean temperature below 49° (F).

drawing the chart, and consequently the areas shown for these regions are broadly generalized. However, the dormant period is mostly from six to seven months in length, except in part of the Pacific Coast states and in the lower Colorado River Valley where in some areas the monthly means do not fall below 49°.

155. Effective temperatures.—There is a certain definite temperature below which a plant will make no growth. This temperature, which may be called the "zero of vital temperature" varies with different species and may vary with varieties of the same species. It varies also with different functions of the same plant. The difference between this "zero" and the prevailing temperature is termed the "effective temperature." If the zero temperature is 46°, and the prevailing is 48°, the effective temperature is 2°. There is also a certain temperature above which there will be no growth.

156. Temperature and carnations.—It is stated that the temperature in greenhouses during the growth of carnations should be kept as near as possible at 50° to 53° at night, and between 60° and 62° during the day. Some growers advocate even slightly lower temperatures for best results. Because the air temperatures frequently run higher than this, it is not practicable to raise carnations commercially in the extreme South.

157. "Zero" of vital temperature point 6° C. (42.8° F.).—The actual temperature at which a plant begins to carry on its functions varies with different species and the climate to which it has been subjected. Some species of the lower forms of plants will grow at freezing or slightly below, while date-palms, for example, make little or no growth below 64°. It is believed, however, that 6° (C.) or 42.8° (F.) marks the temperature below which most field and garden crop plants will make little if any development. Hence, the "zero" of vital temperature may safely be taken as 43° F. in whole numbers.

158. A new "zero" suggested.—Kincer has recently suggested that the zero of vital temperature for the spring seeded crops should be the mean daily temperature at the average date of the beginning of planting. It has been found that these temperatures for some of the important crops are as follows:

Spring wheat,	37° to 40°
Oats,	43°
Potatoes,	45°
Corn,	55°
Cotton,	60° to 62°

The normal or seasonal rise in temperature in the spring is quite regular, and reaches the points indicated above on later dates at higher latitudes. The average date of the beginning of planting progresses also toward the north (in the north-temperate zone), and the average date of seeding agrees with the temperatures indicated above in different latitudes.

159. Total effective temperatures.—For many years an effort has been made to determine the total of the effective heat necessary for any definite phenological period in crop development. There has been a difference of opinion as to the temperature from which the calculations should be made; whether this temperature should be that recorded in the sun or in the shade; whether it should be the daily mean temperature or the maximum temperature; whether it should be calculated from the date of seeding or from the date that the plant appears above the ground, or in the case of winter grains whether it should be from January 1 or some date in the spring; in the case of fruits, from some definite date of the preceding year or at the opening of spring, and after these points have been determined to the personal satisfaction of the investigator, how the effective temperature should be calculated.

The best zero point of growth seems to be 43° and all daily mean temperatures above this point, with the thermometers exposed in the standard shelter, may be considered as effective temperatures.

160. Summation processes.—Three methods have been used to determine the effect of temperature above the zero values on plant growth. The "remainder" process, the "exponential system," and the "physiological summation indices."

161. The remainder indices.—By this process, which has been used most frequently, all mean daily temperatures above the zero temperature are added together. For example, if the mean daily temperature between certain phenological events, such as the date of planting corn and the date when it comes into blossom, is 65°, the zero temperature of 43° is subtracted from 65° and the remainder multiplied by the total number of days between the two dates. Or the difference between 43° and the mean temperature is determined for each day between the two events and these remainders added together. Other influences being similar, it is argued that the sum of these daily differences would be the same for different seasons for the same variety of plants. Elaborate studies have been made in Europe and the results seem to bear out the theory in a general way. The total of these differences has been much the same in the same latitudes and with equal elevation. With higher altitudes or higher latitudes, the total heat units, as these sums are designated, necessary from planting to ripening for any crop become less. This is due partly at least to longer hours of daylight, shorter growing season, and plant characteristics.

162. Exponential indices.—These are based on the fact that the plant growth ratio follows the chemical principle of van't Hoff and Arrhenius which states that the chemical reaction velocities about double with each increase in temperature of 18° (F.). With this law it is considered that the rate of growth will be twice as great with a mean daily temperature at 79° as at 61°, and four times as great at 97° as at 61°, other conditions being the same.

163. Physiological summation indices.—These indices were derived by Livingston from a study by Lehenbauer of the relation of temperature to the rate of elongation in seedling maize shoots. These data showed that the average hourly rate of elongation of the maize shoots exposed to maintained temperatures for twelve hours was 0.09 mm. for 12° (C.); 1.11 mm. for 32° (C.), and 0.06 mm. for 43° (C.). Maize seedlings about 10 to 12 centimeters high were used in this test, which had been sprouted practically in darkness and with approximately constant temperatures. The seed was uniform and of good quality, and so-called "sports" were eliminated before the actual temperature influence test was begun. The plants were then exposed in a chamber with moderate air circulation with an air humidity of approximately 95 per cent, and with light conditions fluctuating between very weak, diffuse daylight and darkness. The increments of elongation were measured at three-hour intervals for the low and the high temperatures and at longer intervals for the remainder, the periods of exposure being from three to twenty-one or more hours to maintained temperatures of 12° (C.) to 43° (C.).

Graphs made from these detailed studies showed clearly the existence of the minimum, optimum, and maximum temperatures for this kind of growth and that the optimum temperature varies with the period of exposure for which the average hourly growth-rate was determined. For a three-hour period, the optimum temperature was 9° (C.), for a six-hour period it was 30° (C.), for nine-hour, twelve-hour, and twenty-one-hour periods, it was 32° (C.) or 48.2°, 86°, and 89.6° (F.), respectively.

The definite results of these studies are given as follows by Livingston:

> 1. The somewhat widely accepted idea that the curve of growth in relation to temperature shows two optima is not at all substantiated in this work with the shoots of maize seedlings grown in water culture, practically in darkness, and with relative air humidity of 95 per cent.
> 2. The optimum temperature for growth of shoots of maize seedlings in water culture, for a 12-hour period, is shown to be 32° (C.).
> 3. The optimum temperature for growth, under these conditions is found to change as the length of the period of exposure is altered.
> 4. At high temperatures (31° C. and above), for shoots of maize seedlings under these experimental conditions the initial growth-rate is not maintained, there being a marked falling off in this rate during prolonged periods of exposure.
> 5. This decrease in the growth rate with prolonged periods at high temperatures makes it necessary to consider the length of the periods for which average growth rates are obtained, in defining the optimum for growth of these shoots. Indeed, it appears that the term "optimum temperature" for growth, in this case at least, is quite without meaning unless the length of the period of exposure is definitely stated.
> 6. The fall in growth rate here brought out is similar to the decrease in rate of certain other physiological processes under the influence of high temperatures during prolonged periods.
> 7. At temperatures near the minimum (12°–14° C.) for the growth of shoots of maize seedlings under the conditions here employed, no decrease in the growth rate is shown, even with rather prolonged periods of exposure.
> 8. The growth rate at medium temperatures accords with the van't Hoff law, showing a doubling of the rate for each rise of 8° or 10° (C.).

Great care was taken in all this study, and as laboratory test and as a basis for ecological investigations the information obtained is of marked value. It must be borne in mind, however, that the plants were practically in darkness during the entire period of experimentation, and that the study was made in only one phase of the development of one plant, and care should be taken in applying the results obtained to a study of the plants under natural conditions.

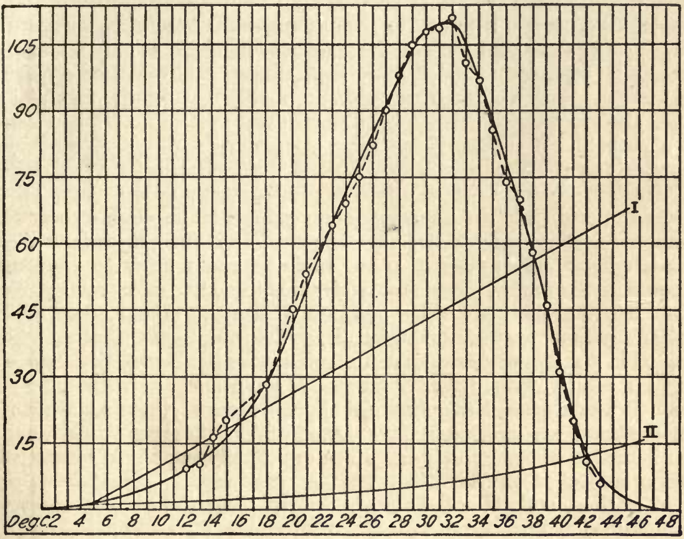

FIG. 19.—Graphs showing increase in value of index of temperature efficiency for plant growth (ordinates) with rise in temperature itself (abscissas), for the three systems of indices. Graph I represents the remainder system, Graph II the exponential one. The broken line is Lehenbauer's graph of the relation of temperature to the rate of elongation of the shoots of maize seedlings. The smoothed graph corresponding to the latter represents the physiological system of indices. All graphs pass through unity at 4.5° C. (F.).

Fig. 19 is from Livingston and the following is quoted to explain the graphs:

> As is shown by Fig. 19 the rate of increase in index value with rise of temperature, between the minimum and optimum for growth is much more rapid in the case of the physiological series than in that of either

of the other series. The range of temperature thus indicated (from 2° C. or 35.6° F. to about 32° C. or 89.6° F.) is the range usually encountered in nature during the frostless season, at least in temperate climates, and most of the plant growth of the world is probably accomplished with temperatures lying within this range. Practically, this very rapid rise in the index values constitutes the most important difference between the physiological series and the other two. While it is quite apparent that the system of physiological indices here described is far superior, in several respects, to the other systems heretofore suggested, it is equally clear that these indices are to be regarded as only a first approximation and that much more physiological study will be required before they may be taken as generally applicable. In the first place, they are based upon tests of only a single plant species, maize, and there are probably other plants (perhaps even other varieties of the same species) for which they are not even approximately true. Second, these indices are derived from the growth of seedlings, and no doubt other phases of growth in the same plant may exhibit other relations between temperature and the rate of shoot elongation, and, third, these indices refer to rates of shoot elongation and there are many other processes involved in plant growth, which may require other indices for their proper interpretation in terms of temperature efficiency. Fourth, they apply strictly only under the moisture, light, and chemical conditions that prevailed in Lehenbauer's experiments; with more light or with a different light mixture, with different humidity conditions, or with different moisture or chemical surroundings about the roots, these same plants in the same seedling phase, may exhibit very different values of the temperature efficiency indices. Fifth and finally, plants in nature are never subject to any temperature maintained for any considerable period of time, and these indices are derived from 12-hour exposures to maintained temperatures.

Figs. 20, 21, and 22, show Livingston's climatic zonation for the United States by the remainder, exponential, and physiological indices, respectively.

164. Both temperature and moisture.—Livingston has carried these applications still further in a paper suggesting a method by which the moisture and temperature conditions of any locality for any period, as they affect plants, may be expressed as a single numerical value, the index of moisture-temperature efficiency for plant growth. This index is the product of three factors: The index of rainfall, the reciprocal of the index of atmospheric evaporation, and the physiological index of temperature efficiency.

The writer states that the index of moisture-temperature efficiency as above described may be represented by the formula

$$I_{mt} = I_t - \frac{I_p}{I_e}$$

where "I" denotes the efficiency index for the time period considered and the subscript letters denote the respective environmental conditions for which the various indices stand.

I_{mt} is the moisture-temperature index with which we are mainly concerned. I_t is the index of temperature efficiency,

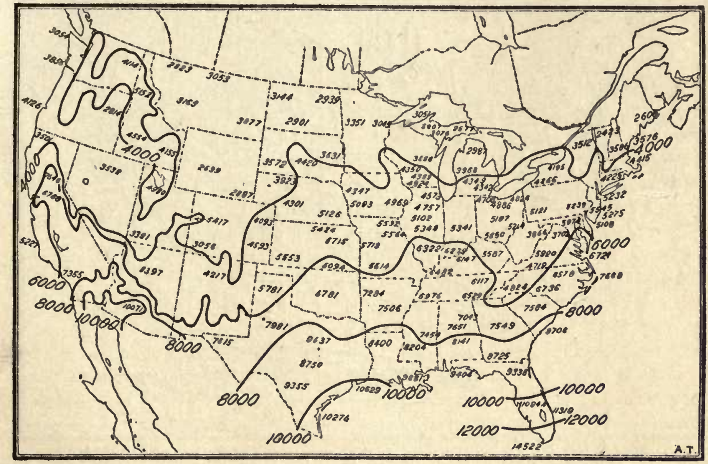

Fig. 20.—Chart of the United States showing climatic zonation according to remainder summation indices of temperature efficiency for plant growth, for the period of the average frostless season.

derived by means of the physiological system. I_p is the index of precipitation intensity and represents simply the summation of the rainfall for the period. I_e is the index of the atmospheric evaporation, also a simple summation for the period.

165. Weakness of summation plan.—Seeley has shown that neither of these systems agree with the actual temperatures recorded during the different growing seasons, and that the effective temperatures for different years may vary as much as 50 per cent. He found that Livingston's method gave the closest comparison during the early stages of corn growth if the daily maximum temperatures are used instead of the means.

166. Plant temperatures.—Seeley suggests that the temperature of the plant should be considered in calculating effective temperatures instead of that of the air. He carried on a series of observations at Lansing, Michigan, during the growing season in 1915 and 1916 in which thrice daily records

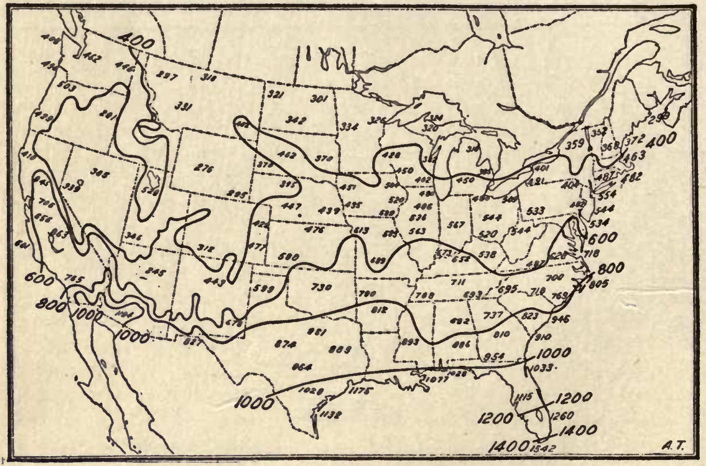

FIG. 21.—Chart of the United States showing climatic zonation according to exponential summation indices of temperature efficiency for plant growth, for the period of the average frostless season.

were kept of the soil, plant, and air temperatures and the rate of growth of plants part of the time.

167. Temperatures of leaves higher in sunshine than air temperatures.—Seeley found that when the sun was shining the leaf temperature was always higher than the air temperature, this difference being as great as 20° to even 36° on especially clear and still days. In 304 observations made at midday, the plant thermometer was lower than the air temperature only forty-one times and these days were invariably dark and cloudy, frequently with rain falling.

168. Leaves cooler at night.—In the early morning, the temperature of the leaves was about 3° to 4° cooler than the air temperature and the plants lost their heat more rapidly than the air, in the early evening. At 7 P. M., the leaves were sometimes 9° or 10° cooler than the air.

169. Effect of cloudiness on plant temperature.—Seeley tabulated a total of over 300 days and found that the plant temperatures averaged 15° higher than the air temperatures in full sunshine, in partial sunshine 10°, and in cloudy weather nearly 1°. From these averages he deduced the following formula for finding the effective temperature from air temperature: $T=t+15C+10P$, in which T is the sum of effective temperatures for plant growth, t is equal to $m-42x$, m being the sum of all maximum temperatures above 42° during the period in question; x the number of such days; C, the number of clear days, and P, the number of partly cloudy days during the period.

FIG. 22.—Chart of the United States showing climatic zonation according to physiological summation indices of temperature efficiency for plant growth, for the period of the average frostless season. The numbers on the isoclimatic lines each represent thousands. Broken lines denote a very high degree of uncertainty.

170. Difficulty of comparing plant temperatures.—The difference in the temperature of plants in direct sunshine and in shade, and the action of the pigments in varying the temperature of different colored leaves and plants in sunshine, is shown in a recent article by the French naturalist J. Dufrénoy, of the Biological Station at Arachon, in the Revue Generale de Sciences.

He explains the formation of the pigments in plants, and the increase or decrease of pigmentation in varying heat, moisture, and sunshine values, then shows the effect of these different pigments in the absorption of solar energy.

The following is quoted from a review of this article in the "Scientific American Supplement" for February 15, 1919:

> The solar energy absorbed by the pigments is largely converted into heat. In January at Arachon, on a fine day, the temperature of the plants exposed to the sun exceeds that of the air by from 6° to 8° C., at noon, and by from 12° to 15° C. at 3 P. M.; the amount of this rise in temperature varies according to the color and to the intensity of the pigmentation, so that a difference of more than one degree C. may exist between the yellow and the green leaves of the variegated foliage of a spindle tree, or even between the two borders of a single variegated leaf. Experiments made in January at Arachon gave the following results:
>
> In a variegated leaf of the *Iris pallida* the green portion showed a rise in temperature of 9.8° C. over that of the air against a rise of only 8.5° C. in the yellow portion. Similar observations were made with the red and green leaves of an arbutus, the time being 10 A. M., and the temperature of the air 10° C.; in this case the red leaf showed a rise of 7.5° C., and the green leaf a rise of only 7° C.
>
> In November, tests were made at 2 P. M., with red and white arbutus berries, the temperature of the latter being 29.5° C., and that of the red, one degree higher. Finally, experiments were made with grapes of various colors placed in sunshine and in shade. The temperature of the red grapes in the sun was 37° C., and 10° C. less in the shade; that of white, green, and amber colored grapes was 34° C. in the sun, and 26° C. in the shade.
>
> A second experiment showed that grapes with a dull surface had a temperature of 35.5° C. in the sun, whereas that of those with a bright surface was 34.8° C. A highly interesting fact is that every rise of 10° C. in the temperature of the organs exposed to sunlight doubles or even trebles the rapidity of the reactions observed—for example, the intensity of respiration is greatly enhanced, more carbon dioxide being liberated. In fruits exposed to sunlight the plant acids contained are reduced, and the ripening is correspondingly hastened.

Plate IV.—Cumulo-nimbus cloud. Rain can be s ng from this cloud.

These experiments illustrate the difficulty in making comparable records of the temperature of plants in sunshine as conducted by different investigators or by the same man at different times.

171. Leaf temperature fluctuation rapid.—The use of a very sensitive electrical apparatus for measuring the surface temperature of leaves shows a very rapid fluctuation of a leaf growing in the open. If a moderately strong wind is blowing, the temperature may fluctuate as much as 5° C. in thirty seconds.

172. Value of temperature summation figures.—Botanists have been able to make little practical use of the large amount of effective temperature summation data that has been compiled, due partly to the difficulty of comparing different observations. While all of the methods proved, as well as the factors presented by various investigators to explain the modification of physiological constants, applicable in certain circumstances, they are all subject to some exceptions.

173. Solution possible.—The actual determination of some of the physiological constants is possible; in other cases certain definite factors can be found which will be of service within certain limits. The problem is to devise some method for calculating the heat requirements of various crops during different periods of development.

174. Lissner's law.—Lissner developed a theory or law which is useful in determining a constant for several localities in different latitudes. His law may be stated briefly as follows: In two different localities the sums of the effective daily temperatures for the same phase of vegetation are proportional to the annual sum total of all effective temperatures for the respective localities. It is a well known fact that plants of the same species develop under a considerably smaller sum of heat in northern than in southern districts. The Burbank plum, for example, blossoms in the middle of March in the southern part of the United States and the middle of May in the northern portion, while the total effective heat received is considerably less in the northern latitude.

175. Lissner's aliquot.—Lissner's conclusion was that this is due to a matter of adaptation to climatic environment. That as plants at the southern latitude are subject to a much greater sum total of temperature for the entire year, they simply lengthen all the phases of development in the South. Thus the blossoming phase of the Burbank plum, as an illustration, depends on a constant aliquot, instead of depending on a constant temperature sum.

To compute the aliquot, the sum of the effective temperatures for a certain phase of development is divided by the sum of the effective temperatures for the entire year. The determination of the aliquot is illustrated in the following for the Burbank plum:

Place	*Sum of temperatures above 32° from Jan. 1 to blossoming*	*From Jan. 1 to Dec. 31*	*Aliquot*
Stillwater, Okla.	967	7409	.130
Parry, N. J.	909	7044	.129
State College, Pa.	725	5578	.129
Burlington, Vt.	577	5292	.109

Except at Burlington the proportion is practically the same.

176. Optimum conditions.—It is found that for each phase of plant development there is a definite optimum of temperature, moisture, and light, at which the growth and development goes on with greatest vigor. When either one of these factors varies, the effect of the others is changed and the development slows down so that the absolute amount of heat necessary to complete a definite phase of growth varies one year with another, due to the variation of other conditions.

177. Time factor.—Another factor of importance is the length of time that the plant is subjected to different temperatures. All these conditions can be controlled in a laboratory experiment, but are constantly varying in natural growth.

SOIL TEMPERATURE

The temperature of the soil affects the germination and growth of plants and the development of some plant diseases to a marked degree. The temperature of the surface soil varies with covering, physical structure, moisture-content, inclination, slope, latitude, color, cloudiness, season, temperature of the air above, and the like, and efforts to relate soil temperature with plant development must take all these things into account.

178. Most favorable temperature.—It has been found that, with other conditions favorable, staple crops will grow when the temperature of the soil is as low as 40° and as high as 120°. The most favorable temperature for growth is between 65° and 70°. The warmer the soil in the spring, the more rapid the germination and growth. Soil bacteria do not become active until the temperature of the soil reaches 45° to 50° F.

179. Source of heat.—The sun is the chief source of heat in raising the temperature of the soil, although a slight amount of heat is received from the interior of the earth.

180. Loss of heat.—The heat that is accumulated in the surface of the earth by absorption of solar energy, is lost by radiation through the air to space, conduction to the air above, and conduction to lower layers of soil.

181. Diurnal changes in temperature.—The diurnal changes in temperature of the soil usually extend to a depth of only about 2 to 3 feet, and these changes occur in the form of waves. The surface soil loses heat by radiation very rapidly during the nighttime and reaches its lowest temperature just about sunrise. At this time the lowest temperature is at the surface and the temperature increases with depth although losing heat by conduction upward. As soon as the surface of the soil begins to absorb solar energy, its temperature rises, and in turn begins to warm the next lower layers of soil by conduction. This wave of higher temperature follows the wave of falling temperature, both decreasing in range as they travel downward.

As late afternoon approaches again and the surface loses heat by conduction and radiation more rapidly than it gains by absorption, it begins to cool and a second wave of falling temperature follows the daytime warmer wave.

182. The lag in temperature fluctuation.—The lag of the maximum and minimum epochs or waves is proportional to the depth. The maximum temperature at the surface of the ground is about the middle of the afternoon on an average. At a depth of 3 to 6 inches, the maximum occurs in the evening, and at about 1 foot not until the next morning. Below this depth the change is slight, but where it does occur, it is not until the next day, when a second wave of higher temperature is starting from the surface.

183. Annual ranges.—The annual change in temperature in the soil is limited to the surface 30 to 40 feet. These changes are propagated downward by successive waves in the same general way as the diurnal changes. For each step downward of 4 feet, the occurrence of the epoch of extreme temperature is retarded on an average of twenty-one days. The lowest temperature at the lowest depths occurs the following summer, and the highest the following winter. At a depth of 30 to 40 feet, the temperature is at all times about the same as the mean annual air temperature.

184. Soil cover.—While there is very little difference in temperature between cultivated and uncultivated soils, there is a marked difference between a bare soil and one covered by vegetation. In a four-year study in Michigan it was found that the bare ground warms up more quickly in the spring and remains at a higher temperature than that covered by sod through the summer. In the fall the bare ground loses its heat more rapidly and remains colder during the winter.

185. Snow cover.—A thick snow cover is a most efficient agent for keeping the soil warm in the winter and preventing it from attaining extreme low temperatures during severe cold weather.

186. Desirability of soil temperature records.—The importance of a systematic soil temperature survey is well recognized. The Ecological Society of America recommends the use of soil thermographs, carefully calibrated and with the bulb at a uniform depth of 3 inches in level or nearly level ground where it is not subject to inundation or saturation. The location of the instrument should be where no shade falls on the soil at any time and under a light cover of weeds or short grass. Temperatures at depth of 1, 5, 12, and 24 inches should be recorded also if practicable.

PRECIPITATION

After temperature the next most important climatic factor is the moisture, either as water-vapor or as water in the form of rain, snow, and the like. The rainfall determines the productiveness of a country. In places where the temperature and sunshine are generally sufficient, the development

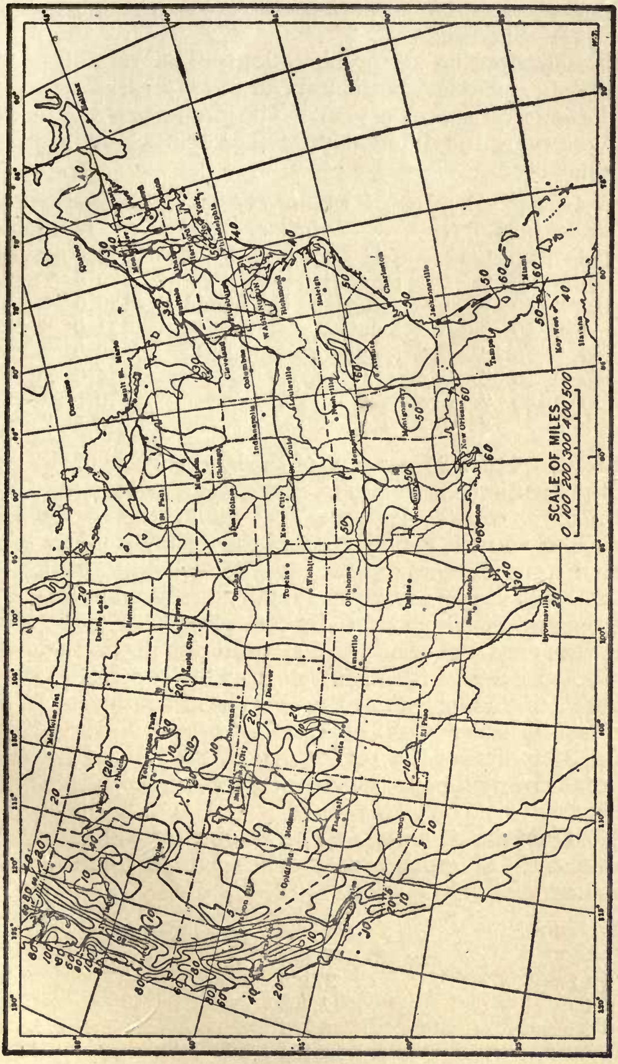

FIG. 23.—Annual precipitation in the United States.

of the plants and more especially the crop yields depend most largely on the rainfall.

187. Distribution of precipitation.—The rainfall of the whole globe, including both land and water areas, is estimated to be about 60 inches a year. The proportion of the land areas receiving the different rainfall amounts is indicated by the following:

Annual precipitation	*Character of climate*	*Proportion of land receiving*
Less than 10 inches	arid	25.0 per cent
From 10 to 20 "	semi-arid	30.0 " "
" 20 " 40 "	sub-humid and humid	20.0 " "
" 40 " 60 "	humid	11.0 " "
" 60 " 80 "	"	9.0 " "
" 80 " 120 "	"	4.0 " "
" 120 " 160 "	"	0.5 " "
Above 160 "	"	0.5 " "

This shows that 55 per cent of the land surface of the globe receives less than 20 inches of rain a year, while only 25 per cent receives over 40 inches. The significance of this must be realized when it is remembered that it takes about 2 tons of water to produce an ordinary loaf of bread, and that 5-acre feet of water are necessary to support one human life.

188. Precipitation in the United States.—Fig. 23 shows the average annual precipitation (rain and melted snow) in the United States. The greatest amount is received on the North Pacific coast, while the least is in southwestern Arizona, southeastern California, and western Nevada.

Fig. 24 indicates the percentage of the annual precipitation that occurs during the growing season, April to September, inclusive.

189. Quantity of water.—The amount of water that falls on each acre of ground when rain occurs is shown by the following:

Depth of rain in inches	*Gallons per acre*	*Tons per acre (2,000 lbs.)*
0.01	271.5	1.1
0.05	1,358	5.6
0.25	6,789	28.0
1.00	27,154	113.0
5.00	135,772	565.0

FIG. 24.—Percentage of annual precipitation occurring between April 1 and September 30.

190. Drought.—A drought may be defined as a condition under which plants fail to develop and mature properly because of an insufficient supply of moisture. Just what deficiency of rainfall or how long a period without rainfall or with an amount insufficient to cause an appreciable increase in soil-moisture will cause a damaging drought, cannot well be stated. It will depend on the season of the year, the prevailing temperature, wind, and sunshine, the kind of plants, their critical period of growth, soil texture, moisture in the soil at the beginning of the period of deficient rainfall, and other factors.

In Russia a drought has been defined, for convenience, as a period of ten days with a total rainfall not to exceed 5 mm. (0.20 inch). One definition used in the United States is a period of thirty days or more in which the precipitation does not amount to 0.25 inch in any twenty-four hours. These definitions are purely arbitrary, however, and would not apply at all in some places or at all seasons.

In some parts of the country, a drought may result when there are several successive five-day periods with the evaporation from a free water surface in excess of the rainfall.

191. Rainfall and plant growth.—There was a time when water was thought to be the real food of plants, but with experiments it became obvious that the influence of rainfall on plant growth is exerted in replenishing the moisture in the soil. Someone has likened the soil to a gigantic reservoir which is replenished at more or less infrequent intervals and which is drained by underground seepage, surface evaporation, and by transpiration of plants.

A plentiful water supply as a rule favors the development of the vegetative organs, while the scarcity of water brings about their reduction. On the contrary, the production of the sexual organs is usually favored by a lack of water and impeded by an excess. The amount of moisture in the soil affects the activity of soil bacteria.

192. Soil-moisture.—The direct source of the water supply of plants is moisture in the soil. Probably no other factor so often limits crop production as does soil-moisture, as it is the means by which the food in the soil is made available to the plant. There is no direct relation between the percentage of water present in the soil and the amount that is available for plant use. A sandy soil with 15 per cent of moisture may be near saturation and have a large amount of available water, while a stiff clay with 15 per cent of moisture may have so little available water that all plants will wilt in it.

193. Wilting coefficient.—The wilting coefficient of a soil, as defined by Briggs and Shantz, is the moisture-content of the soil (expressed as a percentage of the dry weight) at a time when the leaves of the plant growing in that soil first undergo a permanent reduction in their moisture-content as a result of a deficiency in the soil-moisture supply.

The water-content of a soil which is available for growth is the difference between the actual moisture-content and the wilting coefficient. There is a wide difference in the wilting coefficient of different soils, as fine soils are much more retentive of moisture than coarse, while the wilting coefficient for any soil is practically the same for all crops.

194. Transpiration is the term used to express the loss of water from the surface of the aërial parts of plants. It is often called "evaporation," but is not exactly the same thing, even though the rate of each is affected by similar weather conditions. Kiesselbach has found that the amount of water transpired from a given leaf-area of corn (based on expanse of leaf and not on both surfaces) is approximately one-third as great as the evaporation from a free water surface of the same area.

The maximum transpiration is at the warmest part of the day. On days of extreme temperature there may be an atmospheric demand of ten pounds of water from a single corn plant during twenty-four hours. The greater part of this need is for a period of about seven hours in the hottest part of the day; such days are very critical if there is not moisture enough in the soil to supply the demand. Corn curls and wilts when the transpiration exceeds the absorption through the roots. The plant itself apparently has power to influence the rate of transpiration, but outside of the plant influence, transpiration increases with increase of temperature and wind velocity and decreasing relative humidity.

195. Evaporation.—The loss of soil-moisture by evaporation is an important factor especially in dry regions. The amount of water evaporated from a free water surface in different parts of the country is shown in the following tables:

AVERAGE WARM-SEASON EVAPORATION

Table 4.—Summary of Measurements, in Inches, made by the Office of Biophysical Investigations, United States Department of Agriculture

Station	*Number of years in record*	*April*	*May*	*June*	*July*	*August*	*September*	*Average total, April to Sept.*
Yuma, Ariz.	9	7.76	9.54	10.58	10.21	9.61	7.43	55.13
Biggs, Cal.	4	4.47	6.25	8.64	9.60	8.15	6.38	43.49
Akron, Colo.	10	4.96	6.40	7.88	9.09	7.87	6.48	42.68
Aberdeen, Idaho	6	4.61	6.07	8.46	9.65	7.70	5.58	42.07
Colby, Kans.	4	4.35	5.90	7.48	8.69	7.47	6.02	39.91
Garden City, Kans.	10	6.50	8.58	9.89	10.91	9.51	7.46	52.85
Hays, Kans.	11	6.16	7.04	8.42	9.97	9.29	7.02	47.90
Crowley, La.	7	4.85	5.69	6.18	5.72	5.36	4.54	32.34
Havre, Mont.	2	3.28	5.51	5.55	7.98	6.40	3.88	32.60
Huntley, Mont.	7	3.24	4.56	5.89	7.55	6.67	4.32	32.23
Moccasin, Mont.	9	3.83	4.93	5.56	6.78	7.06	4.62	32.78
Mitchell, Nebr.	7	4.83	6.16	7.43	7.97	6.80	5.26	38.45
North Platte, Nebr.	11	5.68	6.55	8.14	9.11	8.06	6.11	43.65
Fallon, Nev.	10	6.21	8.09	9.92	10.78	9.74	6.58	51.32
Tucumcari, N. Mex.	6	7.23	9.72	10.89	10.84	9.26	7.44	55.38
Dickinson, N. Dak.	10	4.04	4.64	6.25	6.80	5.98	4.08	31.79
Edgeley, N. Dak.	11	3.60	4.71	5.30	6.40	5.53	4.02	29.56
Hettinger, N. Dak.	7	4.16	4.93	6.40	7.45	5.91	3.92	32.77
Mandan, N. Dak.	5	3.78	5.15	6.06	7.37	6.45	4.49	33.30
Williston, N. Dak.	8	4.31	5.52	6.39	7.08	6.05	3.76	33.11
Lawton, Okla.	3	6.60	6.65	8.48	8.97	8.20	6.66	45.56
Woodward, Okla.	4	6.38	7.51	9.43	10.84	8.54	6.82	49.52
Burns, Oreg.	4	3.84	5.76	7.29	9.27	8.49	5.68	40.33
Hermiston, Oreg.	6	4.03	5.48	7.47	8.47	6.82	4.38	36.65
Moro, Oreg.	7	4.54	6.27	8.01	9.35	8.54	4.28	40.99
Ardmore, S. Dak.	5	3.81	5.24	7.21	8.71	7.56	6.06	38.59
Newell, S. Dak.	10	4.23	5.57	6.99	8.43	6.93	4.85	37.00
Amarillo, Tex.	11	7.03	8.79	10.17	10.38	9.11	7.23	52.71
Big Springs, Tex.	3	7.40	10.03	12.72	11.65	9.88	7.32	59.00
Chillicothe, Tex.	5	6.48	7.90	8.98	10.14	9.11	6.30	48.91
Dalhart, Tex.	10	7.49	9.52	10.56	10.61	9.63	7.58	55.39
San Antonio, Tex.	11	5.70	6.69	8.69	9.61	9.01	6.35	46.05
Nephi, Utah,	10	4.56	6.16	8.78	9.52	9.23	6.36	44.61
Archer, Wyo.	5	3.65	5.06	7.17	7.95	6.88	5.63	36.34
Sheridan, Wyo.	1	3.14	4.91	5.82	9.81	7.85	5.14	36.67

TABLE 5.—SUMMARY OF EVAPORATION MEASUREMENTS, IN INCHES, MADE BY THE WEATHER BUREAU

Station	*No. of years*	*April*	*May*	*June*	*July*	*Aug.*	*Sept.*	*Total April to Sept.*
Silverhill, Ala.	1	4.50	5.75	6.90	5.33	....	4.45	....
Mesa, Arizona	2	7.58	9.20	10.48	9.98	8.58	6.70	52.52
Roosevelt, Arizona	3	8.05	10.93	14.00	12.81	11.29	9.82	66.90
Willcox, Arizona	2	10.82	11.80	11.87	10.96	9.43	9.53	64.41
Yuma, Arizona	2	8.04	9.32	9.80	10.55	10.74	7.89	56.34
Oakdale, Cal.	1	6.21	9.07	14.23	13.94	12.67	5.65	61.77
Tahoe, Cal.	3	2.42	3.16	4.38	5.62	6.00	4.89	26.47
American University, Dist. of Columbia	3	4.64	6.06	6.23	6.50	5.82	4.22	33.47
Lawrence, Kansas	3	5.25	7.08	8.99	10.47	9.52	5.44	46.75
Columbia, Missouri	3	4.40	5.97	7.55	9.51	7.68	5.14	40.23
Bozeman, Montana	3	2.10	5.12	7.46	8.52	7.44	4.16	34.80
Valver, Montana	3	3.54	6.16	8.65	6.51	7.52	3.94	36.32
Lincoln, Nebraska	2	5.76	7.44	9.92	10.32	9.54	6.44	49.42
Elephant Butte Dam, New Mexico	3	12.12	14.89	15.47	12.87	10.99	9.43	75.77
Santa Fe, New Mex.	3	6.68	8.71	11.28	9.15	8.05	6.98	50.85
Albany (near), N. Y.	2	1.70	4.86	4.74	5.60	5.88	3.40	26.18
Wooster, Ohio	3	3.35	4.88	5.34	6.04	5.99	3.78	29.38
Rapid City, S. D.	3	2.99	5.20	6.55	8.19	7.16	5.15	35.24
Hills Ranch, Texas	3	6.74	7.52	9.36	10.04	9.58	7.60	50.84
Laredo, Texas	2	9.25	10.17	11.10	12.91	12.22	8.76	64.41
Provo, Utah	1	4.18	5.86	7.20	6.81	6.32	4.34	34.71
Walla Walla, Wash.	3	4.46	6.48	7.10	8.23	7.62	4.37	38.26

196. Evaporation and rainfall.—At the Desert Laboratory in Arizona, the evaporation is 9.3 times the rainfall, while in most sections of the arid West, the evaporation from a water-surface is greater than the rainfall. Evaporation determines the efficiency of rainfall in a great measure, particularly when the annual rainfall is below 25 or 30 inches. A district of rather heavy rainfall, but with high evaporation, may not be any better for crops than one with much less rainfall if the evaporation is low.

197. Rainfall efficiency.—A rainfall of 21 inches in the Texas Panhandle is no better for crops than 15 inches in the upper Great Plains because the evaporation in Texas is nearly double that in North Dakota. The line of 20-inch annual rainfall passes through the Red River Valley of the North, where it is ample for the large grain crops in most years, while in Texas it passes through a region that is necessarily devoted to grazing or to drought-resistant crops. The seasonal distribution of rain is an important factor also in these two districts.

198. Evaporation from the soil.—The rate of evaporation from a wet soil surface is about the same as from the surface of water in a tank. The evaporation from the surface of the soil with the water level maintained 6 inches below the surface was found in Wyoming to be 95 per cent of that from a water surface; with the water level at 12 inches, 70 per cent; 18 inches, 45 per cent; at 22 inches, 35 per cent. By stirring the ground once a week to the depth of 2 inches, the evaporation was retarded about 19 per cent when the water level was 22 inches below the surface; when the stirred surface was 4 inches deep it was retarded 23 per cent; and when 6 inches deep, 45 per cent.

199. Water requirement of plants.—It is not often that a crop has during its entire life just the quantity of water that best serves its needs, although there is no such thing as a definite water requirement which is constant for any one kind of plant. A plant requires different amounts at separate periods of growth and under varying conditions of temperature, wind, and sunshine. Investigators have disagreed on the water requirement, due in a large degree to different environment and methods of operation.

Plants require several hundred pounds of water in order to make a growth of one pound. This means that each day a growing plant such as wheat and corn requires several times its own weight of water. Water enters the root-hairs and passes up the stem to the leaves where it is evaporated, or transpired through little openings called stomata. If for any reason water cannot be supplied from the soil through the roots, the water in the plant evaporates until the plant becomes so dry it dies.

200. Water requirement at different periods of growth.—The grain crops require less water in the early part of the growth than during the period when the heads and kernels are forming. In a ten-day period of maximum transpiration, the annual crops lose about one-fourth of the water lost during the season. The transpiration of annual crops rises to a maximum a little beyond the middle of the growth period and then decreases until harvest.

201. Relative water requirements of plants.—Briggs and Shantz carried out extensive experiments on the relative water requirements of plants at Akron, Colorado, the results of which are given in the following table. The figures show the ratio of the weight of water absorbed by the plants during growth to the weight of dry matter produced, exclusive of the roots.

PRECIPITATION

TABLE 6.—SUMMARY OF WATER-REQUIREMENT DETERMINATIONS AT AKRON, COLORADO, IN 1911, 1912, AND 1913, BASED ON PRODUCTION OF DRY MATTER

Plant	*Botanical name*	*Number of observations*	*Water requirement*	
		Years	*Of species or variety*	*Mean of genus*
Grain Crops				
Proso:				
Voronezh, C. I. 16	Panicum miliaceum	1	268 ± 1	
Tambov, S. D. 366	"	1	270 ± 1	293
Black Voronezh, S. D. 334	"	1	341 ±10	
Millet:				
Kursk, S. P. I. 30029	Chætochloa italica	1	261 ±15	
Kursk, S. P. I. 34771	"	2	265 ± 3	
Kursk, S. P. I. 22420	"	1	287 ± 2	310
German, S. P. I. 26845	"	2	293 ± 9	
Turkestan, S. P. I. 20694	"	1	444 ± 9	
Sorghum:				
Kafir, Dwarf Blackhull, C. I. 340	Holcus (Andropogon) Sorghum	1	285 ± 3	

TABLE 6.—SUMMARY OF WATER-REQUIREMENT DETERMINATIONS AT AKRON, COLORADO, IN 1911, 1912, AND 1913, BASED ON PRODUCTION OF DRY MATTER—*Continued*

Plant	*Botanical name*	*Number of observations*	*Water requirement*	
		Years	*Of species or variety*	*Mean of genus*
Grain Crops				
Sorghum:—*Continued*				
Kaoliang, Brown, S. P. I. 24993	Holcus Sorghum	2	296 ± 2	
Kafir, White, C. I. 370	“	1	297 ± 4	
Red Amber, S. P. I. 17563	“	3	301 ± 2	
Kafir, Early Blackhull, C. I. 472	“	1	302 ±13	
Minnesota Amber, A. D. I. 341–13	“	2	305 ± 2	322
Kafir, Blackhull, S. P. I. 24975	“	2	308 ± 4	
Milo, White, C. I. 365	“	1	317 ± 3	
Kafir X Durra, C. I. 198–15–3	“	1	321 ± 5	
Feterita, C. I. 182	“	1	323 ± 4	
Milo, S. P. I. 24960	“	1	324 ± 4	
Durra, White, S. P. I. 24997	“	1	327 ± 2	
Milo, Dwarf, S. P. I. 24970	“	2	344 ± 3	
Sudan Grass, S. P. I. 25071	“	1	467 ± 9	
Corn:				
Esperanza	Zea Mays	2	315 ± 3	
X Esperanza	“	1	325 ± 2	
Indian Flint	“	1	342 ± 5	
China White X Hopi	“	1	345 ± 3	
Hopi	“	2	361 ± 6	368
China White X Laguna	“	1	376 ± 5	
Northwestern Dent	“	3	377 ± 7	
Laguna	“	1	384 ± 8	
Bloody Butcher	“	1	405 ± 7	

TABLE 6.—SUMMARY OF WATER-REQUIREMENT DETERMINATIONS AT AKRON, COLORADO, IN 1911, 1912, AND 1913, BASED ON PRODUCTION OF DRY MATTER—*Continued*

Plant	*Botanical name*	*Number of observations*	*Water requirement*	
		Years	*Of species or variety*	*Mean of genus*
Grain Crops				
Corn:—*Continued*				
Iowa Silvermine	Zea Mays	2	407 ± 5	
China White	"	2	413 ± 5	
Wheat:				
Turkey, C. I. 1571	Triticum æstivum	1	473 ± 8	513
Kharkov, C. I. 1583	"	1	475 ± 8	
Kubanka, C. I. 1440	Triticum-durum	3	492 ± 4	
Galgalos, C. I. 2398	Triticum æstivum	1	496 ± 4	
Emmer, C. I. 2951	Triticum dicoccum	2	545 ± 7	
Spring Ghirka, C. I. 1517	Triticum æstivum	2	550 ± 3	
Marvel Bluestem, C. I. 3082	"	2	559 ± 4	
Barley:				
Hannchen, C. I. 531	Hordeum distichon	2	502 ± 4	534
Beardless, C. I. 716	Hordeum vulgare	2	534 ± 7	
Beldi, C. I. 190	"	2	542 ± 3	
White Hullless, C. I. 595	"	2	556 ± 2	
Buckwheat:	Fagopyrum esculentum	1	578 ±13	578
Oats:				
Canadian, C. I. 444	Avena sativa	2	559 ± 8	597
Swedish select, C. I. 134	"	3	594 ± 4	
Burt, C. I. 293	"	3	613 ± 3	
Sixty-day, C. I. 165	"	2	622 ± 9	

TABLE 6.—SUMMARY OF WATER-REQUIREMENT DETERMINATIONS AT AKRON, COLORADO, IN 1911, 1912, AND 1913, BASED ON PRODUCTION OF DRY MATTER—*Continued*

Plant	*Botanical name*	*Number of observations*	*Water requirement*	
		Years	*Of species or variety*	*Mean of genus*
Grain Crops				
Rye, spring, C. I. 73	Secale cereale	2	685 ± 7	685
Rice, Honduras, C. I. 1643	Oryza sativa	2	710 ±15	710
Flax, North Dakota, No. 155	Linum usitatissimum	1	905 ±25	905
Other crops				
Beet, sugar:				
Morrison-grown Kleinwanzleben	Beta vulgaris	2	397 ± 6	397
Potato:				
Irish Cobbler	Solanum tuberosum	2	554 ± 9	636
McCormick	"	1	717 ±11	
Cotton, Triumph	Gossypium hirsutum	2	646 ±11	646
Legumes:				
Alfalfa, Peruvian S. P. I., 30203	Medicago sativa	1	651 ±12	831
Alfalfa, Grimm, A. D. I. E23-20-52	"	2	844 ± 8	
Alfalfa, yellow-flowered	Medicago falcata	1	865 ±18	
Alfalfa, Grimm, S. P. I. 25695	Medicago sativa	2	963 ± 9	

This table shows that the grain crops can be grouped into two sections. Those of low water requirements are proso, millet, sorghum, and corn, and those of high water requirements are wheat, barley, oats, rye, and flax.

Those crops of low water requirement are the late maturing ones which make their best growth during the hottest and driest portion of the summer, while those of high water requirement mature during midsummer and make their best growth in the earlier, cooler part of the year.

Representing the water requirement of proso as 1, the water requirement of the grain crops is as follows: Millet, 1.06; sorghum, 1.10; corn, 1.26; wheat, 1.76; barley, 1.83; buckwheat, 1.98; oats, 2.04; rye, 2.34; rice, 2.42; and flax, 3.38. In other words, flax requires more than three times as much water and rice more than twice as much water as proso and millet in producing a pound of dry matter.

Representing the water requirement of the sugar-beet as 1, the values for the "other crops," exclusive of the legumes, are as follows: Cabbage, 1.36; Irish Cobbler potato, 1.39; watermelon, 1.51; cantaloupe, 1.57; turnip, 1.60; cotton, 1.63; cucumber, 1.80; wheat-grass, 1.85; rape, 1.87; squash, 1.89; pumpkin, 2.10; and brome-grass, 2.56.

202. Farming in the semi-arid regions.—It is customary to give the greatest attention to the total annual rainfall in considering the desirability of a region for dry-farming, although the amount of rain that falls during the growing season and the character of the fall is of equal importance. The amount that may be lost by run-off with heavy local showers, the evaporation, altitude, length of the growing season, the wind, and the like, must all be carefully considered.

203. Irrigation in humid districts.—There is often a serious lack of moisture in humid regions, where because of the greater apparent requirements of the adapted plants, a drought of equal intensity may cause greater damage than in drier districts. Even in a region like Florida where the rainfall can be classed as heavy, both for the year and for the growing season, there are periods when practically all crops would be benefited by irrigation.

SUNSHINE OR LIGHT

Next to moisture, light is the most important external factor affecting the form of plants, as it plays an important part in controlling the plant structure.

204. Clouds.—Sunshine is usually considered under the head of moisture in the atmosphere as shown by the cloudiness, yet a careful consideration of the effect of sunshine will show that this is a separate climatic factor of very great importance.

205. Solar energy.—In some places where the rainfall is sufficient but the temperature is too low for the best growth of plants, as in Alaska, sunshine becomes the most important climatic factor. In fact sunshine and heat can hardly be separated. Solar energy is the factor that enables the plants to make use of the food brought to the roots by soil-moisture and carried to the leaves by transpiration, whether this energy is called "degrees" or "calories."

206. Sunshine-hour degree.—A value called the "sunshine-hour degree" has been obtained by multiplying the average daily heat necessary to grow and mature a crop, by the total possible hours of sunshine from planting to harvesting. In the eastern part of the United States, the sunshine-hour degree for corn is 80,313 between latitudes 30 and 35 degrees; 65,778 between latitudes 35 and 40, and only 47,887 between latitudes 40 and 45 degrees. This shows that the sunshine-hour degrees necessary to make a crop diminish as the latitude increases, and explains to a partial extent at least why there is a decided difference in the quantity of heat necessary to grow and mature the same crop at various latitudes because of the difference in the number of hours of daylight. It must be noted, however, that the varieties and even the types of corn grown in different latitudes account for part of this difference.

207. Variation with latitude.—From the pole to the equator, the luminous intensity of the sunlight increases by ten, but its duration during the growing season is twice as great at the poles as at the equator. The varying number of possible hours of sunshine, or hours of daylight, at different seasons of the year, for various latitudes is shown in the following table:

TABLE 7.—TOTAL NUMBER OF HOURS OF SUNSHINE POSSIBLE AT DIFFERENT LATITUDES

Season	*Latitude*				
	24	26	28	30	32
June 11 to 20	135.7	137.2	139.7	140.3	141.9
Dec. 11 to 20	106.2	104.8	103.3	101.7	100.1
	34	36	38	40	42
June 11 to 20	144.7	145.5	147.5	149.5	152.7
Dec. 11 to 20	98.4	96.7	94.8	92.9	90.7

TABLE 7.—TOTAL NUMBER OF HOURS OF SUNSHINE POSSIBLE AT DIFFERENT LATITUDES—*Continued*

Season	*Latitude*			
	44	46	48	50
June 11 to 20	154.1	156.7	159.6	162.8
Dec. 11 to 20	88.4	85.9	83.2	80.2

The increased production of pigments in flowers and fruits, as well as the ethereal oils, at higher latitudes is probably correctly attributed to the increased hours of sunshine during plant development.

208. The effect of light.—The action of light on plants may be invigorating or retarding, beneficial or detrimental, depending on its intensity and the precise physiological function involved. The unequal intensity of illumination in the different latitudes, and the increasing duration of the hours of sunlight from the equator to the poles, do not fail to stamp their mark on the vegetation.

209. Different intensities.—It is nowhere too dark or too light for plants to grow. The growth of length of stem and roots is at an optimum when light is totally excluded. The formation of chlorophyll and that of some of the pigments is at a maximum under light of moderate intensity. The minimum of light required for the reduction of carbon dioxide is considerably higher than that for the manufacture of coloring matter.

210. The effect of sunshine.—The effect of direct sunshine may be beneficial or detrimental to plant development, depending on other conditions, although few quantitative records have been made of its effects. Other things being equal, an increased amount of sunshine means a larger quantity of plant substances, especially sugar and starches.

211. Sunshine raises the temperature.—The temperature of objects in direct sunshine is higher than that of the surrounding air due to the absorption of the radiant energy. The effect on the ground is favorable in the spring as the soil is warmed more rapidly and is more favorable for germination and growth. During weather too cool for normal growth, direct sunshine promotes the activity of plants.

212. Sunshine sometimes unfavorable.—The soil sometimes becomes so highly heated in hot summer weather, however, that shallow roots are injured. Peas, beans, tomatoes, squash, melons, and strawberries are sometimes damaged in this way. Fruit-buds may be advanced too rapidly under warm sunshine, and frequently maturing fruit such as apples, oranges, and lemons are sunburned and damaged by direct sunshine. Sun-scald often occurs also by the direct effect of strong sunshine on the south sides of the bole and large limbs of fruit-trees in winter. Evaporation goes on rapidly; the temperature is raised to a high point under the solar energy and then falls rapidly after the sun goes down. The tissue next to the wood is thus killed and the bark peels off.

Bright sunshine raises the temperature of plants and thus promotes transpiration. It may injure the pollen if the weather is too hot, but generally bright sunshine favors insect activity and thus aids in pollination.

213. Sunshine for tomato pollen.—Experiments in Wisconsin showed that the percentage of germination and rate of growth of tomato pollen are favored by sunshine, as indicated by the following:

Temperature	*Average percentage of germination*		*Rate of growth in mm. per hour*	
Deg. C.	*Sunshine*	*Cloudy*	*Sunshine*	*Cloudy*
33	66	41	45	27
34	64	42	43	28
36	68	46	49	32

214. Diffuse light.—A certain amount of light is required by all of the higher forms of plants for the proper development of leaves, flowers, and fruit. Strong light aids in the decomposition of carbon and the elimination of water-vapor in plants.

215. Lack of knowledge.—Our knowledge of the relation of light to plant life is comparatively slight. It is known that, other things being equal, the longer the hours of daylight the higher the sugar-content in sugar-beets. It is also known that light has some effect on the coloring of and probably the texture of fruit, and that the coloring of some flowers is brighter in higher latitudes, due partly, it is thought, to increasing hours of daylight.

216. Knowledge of sunshine effect important.—Some experiments made in England show that sunshine at just the right time produced some extraordinary results. For example, if the yellow tomato received plenty of sunshine at the proper time the effect on the yield of fruit was marvelous, whereas if it had a sunless period at a certain quite unexpected hour a very poor yield resulted. The critical sunshine period for the red variety was not at all the same as for the yellow.

217. American Beauty rose.—It is now known that the setting of buds of the American Beauty rose is largely determined by the amount of light supplied. During extended periods of cloudy and dull weather in the winter season, the supply of these flowers is frequently less than the demand.

218. Sunshine, temperature, and moisture.—On the California coast near Carmel, there is a region exceptionally well fitted for growth of beans. On days having a temperature not higher than 70° there is usually no sunshine. Ocean fog-banks extend only a short distance inland. These days constitute about 70 per cent of the whole time from July 3 to September 10. In this period in 1916, the sunshine was only 9 per cent of the possible. Humidity is rather high; at night the temperature is rather low. This climate is ideal for many plants as the luxuriant growth of geraniums, fuchsias and foxgloves shows. It is such cool and humid conditions that make possible along the California coastal belt the growing of beans and many other vegetables to remarkable perfection.

WIND

Wind is an important climatic element and the factors considered are its velocity or total movement, prevailing direction, and the character of the country from which the wind blows.

219. Beneficial winds.—Wind aids in drying the soil in the spring and the chinook wind clears the snow from the ranges in some northwestern sections, allowing for winter grazing. It equalizes the temperature on the leeward sides of large bodies of water and sometimes prevents frost damage on clear nights.

220. Damaging winds.—The wind dwarfs trees, damages young grain or other crops in dry regions by blowing the soil, blows off fruit, scatters the seeds of some weeds, and increases evaporation and transpiration. In the central Great Plains region, young grain plants may be blown out, covered, or cut off by blowing sand. Strong winds may blow or strip blossoms from the trees or prevent insects from working among the blossoms. Long continued warm dry wind injures blossoms by evaporating the secretion from the stigmas thereby preventing the retention and germination of pollen. Damp warm winds, if long continued, are also unfavorable to pollination and fertilization. A cold dry wind at the time of the blooming of fruit seems to chill vegetation and stops the normal functions, not only of blossoms but of leaves. Winds distribute plant disease germs.

LABORATORY EXERCISES

1. Paragraph 142. Record the temperature of the soil at one inch depth and the temperature of a water surface in bright sunshine. Obtain similar data on a clear still night.
2. Paragraph 157. Determine the "zero" of vital temperature for various seedlings.
3. Paragraph 160. Obtain temperature and crop planting and harvesting data and calculate the total effective heat sums for several places by the different methods.
4. Paragraph 163. It may be possible for two or more students to work out some growth observations as developed by Lehenbauer.
5. Paragraph 166. Take a series of plant temperature observations.
6. Paragraph 175. Calculate Lissner's aliquot for some plant for different latitudes.
7. Paragraph 181. Make some records of soil temperature. Dr. Forrest Shreve, Tucson, Arizona, Secretary Ecological Society of America, is attempting to standardize soil temperature records. Consult him.
8. Paragraph 184. Take some soil temperature observations under different soil coverings.
9. Paragraph 185. Make some temperature observations at the surface of the ground under different thicknesses of snow covering. Compare these with simultaneous observations of air temperature.
10. Paragraph 193. More "wilting coefficient" observations are needed and where the necessary apparatus are available records should be made.
11. Paragraph 194. More transpiration records are needed. Consult the plant physiologist as to methods.
12. Paragraph 198. More records are needed of evaporation from the soil as compared with a free water surface. Consult the agronomist.
13. Paragraph 203. Tests should be made of the value of a sufficient water supply during periods of drought, in every state in the central and

eastern parts of the country. Arrangements can readily be made to irrigate small plats as needed. Careful records must be kept of all meteorological factors, water applied and growth results, as compared with those receiving natural rainfall.

14. Paragraph 206. Calculate sunshine-hour degree values for different latitudes.

15. Paragraph 208. Records of the action of direct and diffuse sunlight at different stages of plant growth, not only in summer, but in greenhouses in winter, are easily made and greatly needed.

In the Journal of Agricultural Research for March 1, 1920, Garner and Allard have given the results of some very valuable studies on the effect of differences in the length of the daylight period on plants. The following are among the important facts determined:

(1) The relative length of the day is a factor of the first importance in the growth and development of plants, particularly with respect to sexual reproduction.

(2) In a number of species studied it has been found that normally the plant can attain the flowering and fruiting stages only when the length of day falls within certain limits, and, consequently, these stages of development ordinarily are reached only during certain seasons of the year.

(3) The relationships existing between annuals, biennials, and perennials, as such, are dependent in large measure on responses to the prevailing seasonal range in length of day.

(4) The seasonal range in the length of the day is an important factor in the natural distribution of plants.

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CHAPTER VI

CLIMATE AND FARM OPERATIONS

Climate is the most fundamental of all the factors which determine crop distribution and hence farming methods.

221. Well-defined crop zones.—East of the Rockies the agricultural provinces have more or less definite climatic boundaries, extending in a general way in an east-west direction, conforming to the isothermal trend. In these regions there are five more or less distinct provinces, as follows: (1) the southern subtropical coast; (2) the cotton-belt; (3) the corn and winter wheat belt; (4) the spring wheat belt, and (5) the hay and pasture region.

222. The southern subtropical coast has a warm and comparatively equable climate, with an average winter temperature ranging from about 55° along the central Gulf coast to 70° in extreme southern Florida, and an average summer temperature of 80° to 82°. The principal crops in this province are winter truck, citrus fruits, sugar-cane, and rice.

223. The cotton-belt.—Most of the cotton-belt has an average winter temperature of 45° to 55° and an average summer temperature ranging from about 78° at the northern boundary to 81° at the southern. The frostless season along the northern border averages about 200 days in length. Cotton forms about 47 per cent of the acreage and 61 per cent of the value of all crops grown in this belt.

224. Corn and winter wheat belt.—The average winter temperatures of the corn and winter wheat belt range from 40° in the southern part to about 15° in southern Minnesota. The average summer temperatures range from about 70° in the northern part to 78° in the southern. The average frostless season ranges from 140 days at the north to about 200 at the south. This is a region of diversified farming, but corn usually contributes nearly 45 per cent and wheat nearly 15 per cent to the acreage of all crops.

225. The spring wheat belt lies mostly in the north-central section of the country, principally in the states of Minnesota, the Dakotas, and Montana. The average summer temperature along the Canadian boundary is about 65°, while the southern boundary of the belt conforms approximately to the mean summer isotherm of 70°. On the average, the frostless season varies from 100 days in the north to about 140 days in the south. Farming is rather diversified in this section also, but spring wheat forms 36 per cent of the crop acreage.

226. The hay and pasture region is less well defined than the others mentioned, and is, as a rule, a region of diverse agricultural conditions. It includes mostly the northern border states from Minnesota eastward, extending into the Middle Atlantic states and Appalachian Mountain districts. The average summer temperatures range from about 62° to 70° and the average winter temperatures from 10° to 25°. The dairy products in this region amount to more than one-half of the total for the United States.

227. The shifting of crop areas.—In a comparatively new country where transportation facilities are not well established, certain varieties of crops will be grown which, it will later be found, can be raised more economically elsewhere because of a more favorable climate, and the ground devoted to some better paying crop.

228. A change in farm operations.—There is sometimes an unconscious shifting of farm activities that may not be noticed for several years and then can be explained only by the influence of climate.

229. Butter- and cheese-making in Wisconsin.—At one time both butter and cheese factories were scattered over central and southern Wisconsin. Now, however, the commercial cheese factories are grouped into well-defined areas in the central and northern parts while the butter industry principally occupies southeastern Wisconsin.

By comparing the distribution of these two industries with climatic maps, it develops that the commercial cheese factories are almost exclusively within areas where the potential growing season is less than 150 days in length, while the commercial butter factories are where the season is over 150 days. It develops also that there are no cheese factories south of the mean summer isotherm of 70°, and that the mean isotherm of 65° for the cheese-making season approximately limits the cheese-producing regions in Wisconsin on the south.

230. Length of the growing season.—In all farm operations it is important to know the length of the average growing season, and the length of time from planting to maturity of the various crops. In Ohio, for example, the average time from planting to harvesting early potatoes is from 80 to 100 days, and for late potatoes 120 to 130 days. The average period between the last killing frost in the spring and the first in the autumn is from less than 150 to slightly over 170 days. It is clear, therefore, that while either early or late potatoes can be raised in Ohio, it is not possible to raise two crops on the same land. Farther south, however, where the length of the growing season is over 200 days, two crops may be successfully grown that do not require over 100 days to mature.

231. Climate and the number of crops.—Variations in the rainfall, temperature, and length of growing season make what have been termed the "no-crop climate," the "one-crop climate," the "two-crop climate," and the "continuous crop climate." Many so-called "worn-out" farms have been reclaimed by using the cropping system adapted to the climate.

232. The double-cropping system.—In the southeastern states there are two fairly well-defined wet seasons, one in winter and one in summer, separated by short drier seasons in spring and fall. Moreover, during the winter the temperature is high enough to keep the more hardy crops, such as grains, grass and winter legumes, growing. This region is, therefore, well adapted for a double-crop system, as distinguished from the Northwest, where the winters are too cold for growth and where there is only one wet season.

233. The distribution of rain.—It is important to know the seasonal distribution of rainfall as well as the annual amount, in considering available crops and farm methods. It would be very unwise, for example, to plant a crop that requires a good deal of moisture just before a normal dry season, or if a crop needs dry weather at certain periods of growth to seed it so that this critical period would come at a time that usually brings heavy rains.

234. Rain and harvesting dates.—There are sections where alfalfa can be grown very successfully, but where the frequency of rainfall during the summer months makes it almost impossible to cure it. There are other districts where the value of hay is less than that grown in other sections of the same state even, because frequent rains occur in one region during the harvesting period while it is comparatively dry in the other.

235. Arid and semi-arid regions.—More than one-half of the land area of the globe receives an annual rainfall of less than 20 inches. The large areas of arid or semi-arid lands in the western part of the United States make it necessary to practice irrigation or dry-farming methods for successful agriculture, both well-defined climatic types of farming.

236. Larger farms necessary in drier regions.—It has been pointed out that on some of the table-lands in western Nebraska where the rainfall is less than 20 inches, it takes about one and one-half sections of land to produce an amount of plant-food equal in value to that produced on one-quarter section of upland in the southeastern part of the state where the rainfall is 30 inches or more, the mean annual temperature is higher, and the length of the growing season is considerably longer.

237. Weather risk.—In order to be entirely successful in farm operation, a man must know and take account of the degree of risk that he runs from climatic conditions in raising any crop. He must calculate the risk of loss by rains and low temperature; the average length and intensity of drought periods; the probability of hail and wind damage, and the danger of frost in the spring and fall.

238. Spring frosts.—In raising any crop, for example, the value of which is determined by the earliness with which it can be put on the market, the grower must consider whether the price anticipated will make it wise for him to plant at such a date as to make the risk of loss by frost 75 per cent or 50 per cent or whether he should make the risk only 10 per cent or less.

The same considerations should be given to the probablity of fall frost damage, probability of loss by hail, and the like. The climatological publications of the Weather Bureau give very complete and definite information about all these matters.

LABORATORY EXERCISES

1. Paragraph 221. Chart crop zones in connection with temperature, sunshine, and rainfall maps.
2. Paragraph 229. Local inquiry may show other examples of the shifting of crop areas or of farm activities.
3. Paragraph 230. Determine the possible growing season locally (see frost maps) and determine what two crops can be grown on the same land.
4. Paragraph 231. What is the local climate? What sections of the United States have a "continuous-crop" climate? Are there any sections of the United States with a "no-crop" climate?
5. Paragraph 233. Obtain monthly rainfall data from the State section Director and chart the seasonal distribution. Are there any local crops that should be planted at a different date?
6. Paragraph 237. Calculate some of the weather risks in your state or locality.

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CHAPTER VII

WEATHER AND CROPS

Plant growth is the result of so many different factors, and these influences have such complex combinations that it naturally has been deemed difficult if not impossible to determine the relation to, or influence of, any one of these factors in varying the yield of a crop.

While it may never be possible to determine the exact influence of any particular weather factor at any specified period of growth, it is believed to be entirely feasible to learn which weather element has the greatest influence in varying the yield or what combination of weather factors are most favorable or unfavorable at certain periods of growth. By the three methods mentioned under paragraph 101 it is thought possible to find the most critical period in the development of a crop and then to determine the factor that has the greatest influence in varying the yield.

239. Weather variation effects relative.—As there are wide variations in climate within the limits of the United States, not only in mean temperature and annual rainfall, but in sunshine, temperature extremes and rainfall distribution, it follows that the critical period of growth of a crop plant will vary in sections of the country and the combination of weather factors will be different and affect crops differently. In other words, the study of the critical period of growth and of the weather factor producing the greatest influence on the yield must be for definite climatic districts.

240. Warm and cold season crops.—The field, orchard, and garden crops grown in the United States are native to various countries, although most of them originated in what are now tropical or subtropical regions differing widely in climatic condition. As many of these are grown in such differing climates, the same crop may be properly called a "warm season" crop in one region, and a "cool season" crop in another. In general, however, most crops fall into well-defined groups of cool or warm, dry or wet season crops.

The following classifications, therefore, are rather general, while the actual studies on the effect of weather on the yield of various crops are for the particular districts referred to. In all of these studies the wide varietal differences as well as the inter-relation of soil and climatic conditions, and the like, must not be lost sight of. Such comparatively few systematic experiments required to develop accurate information along these lines have been made that it is difficult to generalize too freely. Undoubtedly some of the prevailing ideas which have not been experimentally tested will require modification as the character, extent, and reason for plant reactions to environment are better understood. At the same time the subject is of such vital importance that it seems desirable to give the most available information, with the understanding that the whole matter is in need of further study and investigation.

241. A complex problem.—The ultimate yield of a given plant, or number of representative plants, is the sum total of all the influences of environment on it from the time of planting to harvesting, including the quality of the seed and the condition of the soil at time of planting. The problem becomes one of stating the condition of a plant or crop at a given epoch of its growth and combining therewith the results of subsequent growth as a function of weather and other factors.

Obviously the weather and other influences exert their effects as a function of time, and also it must be recognized that the effect due to any given weather depends on the age or condition of the crop at the time. The influence of past weather conditions as well as the inter-relation of two or more weather factors must not be lost sight of.

All these considerations serve to indicate the complexity of the problem and make it plain that in the beginning at least one must limit himself very largely to coarse approximations and to a comparatively small number of relatively potent factors.

It is unfortunate that census data on crop yields in 1909 must be used, as crop areas have changed very materially in some instances since that year.

FIBER CROPS

Under fiber crops will be treated cotton, flax and hemp, and the influence of climate on them.

Cotton

Cotton is of tropical origin but is now grown in many places as far north as 40° North Latitude and south to 30° South Latitude. It is a perennial shrub in the tropics but as it is killed by frost, the seed must be planted annually in the temperate districts.

242. Climatic limits.—The successful cultivation of cotton has definite climatic boundaries, established primarily by temperature, although the amount of rainfall appears also to influence the location of the principal producing areas within the region where temperatures are favorable.

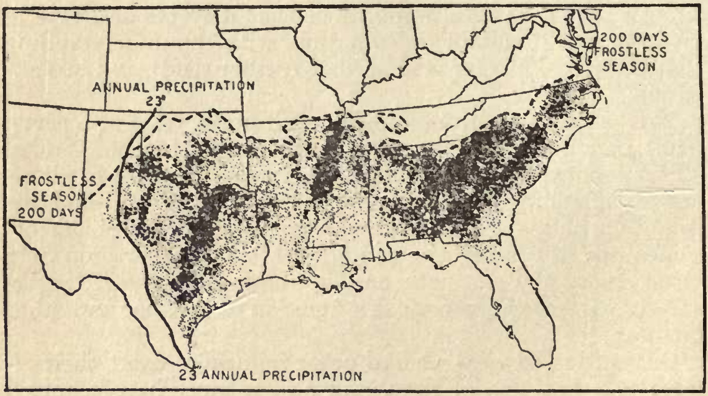

Fig. 25.—Cotton acreage in the United States in 1909. Each dot represents 10,000 acres.

243. In the United States.—Fig. 25 shows the distribution of cotton-growing in the southeastern part of the United States, although since the year 1909 the production of this crop has developed considerably in Arizona and California. Fully 60 per cent of the world's production of cotton is grown in the United States. There are three well-defined areas in this region in which cotton is cultivated more extensively than in other sections of the belt. One of these extends from central and northwest South Carolina through central Georgia into southeastern Alabama; another is from western Tennessee down the Mississippi Valley to about the latitude of southern Arkansas, and a third comprises a belt extending in a northeast-southwest direction through central Texas at about longitude 97°.

244. Length of growing season.—Cotton is a slow-growing crop and seldom matures in less than 180 days after the seed is planted. Very little is grown in the United States where there are less than 200 days between the average dates of killing frosts. Figs. 26 and 27 respectively show the dates when planting and harvesting are begun in the United States. The picking of the late top crop is sometimes not completed until late winter.

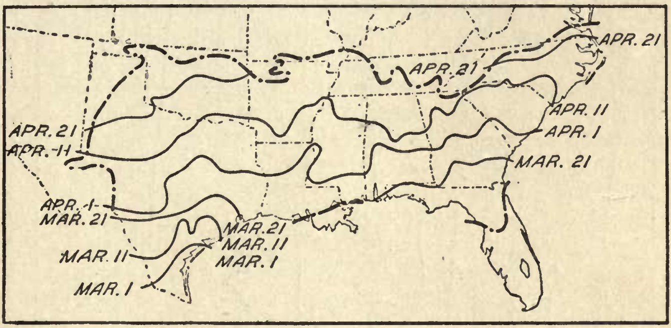

FIG. 26.—Average date when cotton planting begins.

245. Temperature and cotton.—Temperature is the principal limiting factor controlling the geographic distribution of cotton. It cannot successfully be grown commercially where the mean summer temperature is below 77° or 78°. The temperatures should be high both day and night for best growth. Cool nights with warm days cause premature ripening, but after the plant has made its vegetative growth cool nights are favorable for maturing the bolls and ripening the seed.

246. Fall frosts damaging.—Cotton, like most other warm weather crops, is subject to damage by frost in the fall,

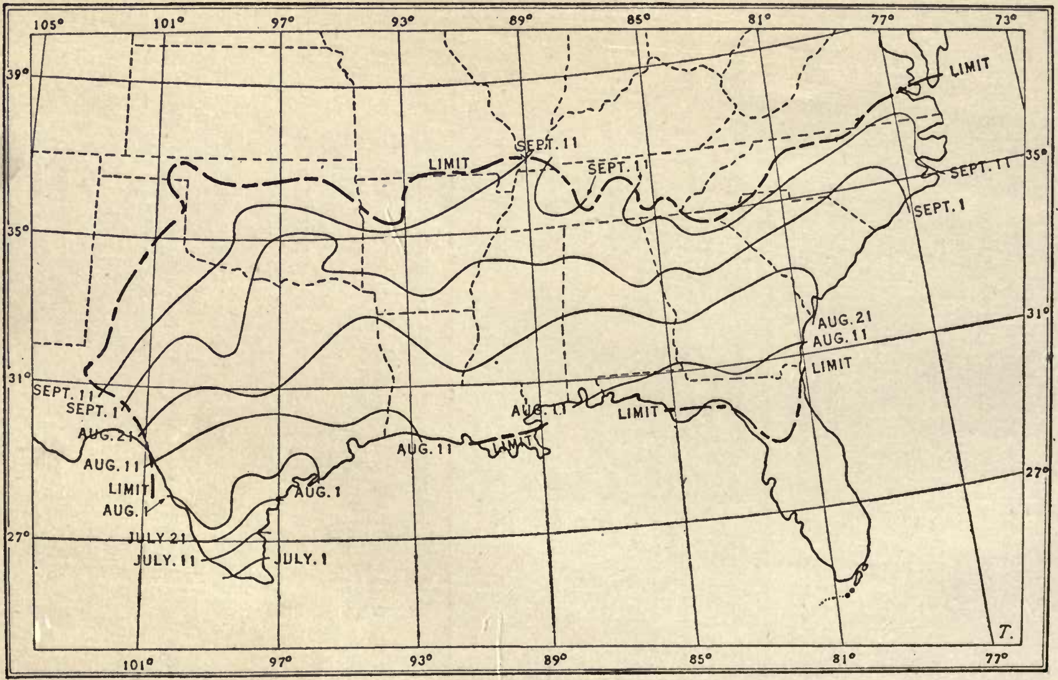

FIG. 27.—Average date when cotton picking begins.

especially when the development is slow during the growing season as a result of unfavorable weather. There is a rather close relation between the temperature during the early period of growth and the lateness or earliness of maturity.

247. Temperature and the progress of ginning.—The relative amount of cotton ginned to a given period during the early harvest season gives a good indication of the earliness or lateness of the crop and reflects this feature more than it gives an idea of the size of the crop. Fig. 28 shows the relation of the mean temperature for the months of May and June to the amount of cotton ginned to September 25, in the states of Georgia and Alabama for the period for 1905 to 1915. It shows a very marked influence of the temperature during these months on the advancement of the crop to maturity.

248. Rainfall and cotton.—Cotton needs a moderate but regular supply of moisture, hence light frequent showers with plenty of sunshine between produce the best condition for its growth. An over-supply of moisture causes too rank a growth at first, deferring the fruiting and causing a development of vegetative limbs instead of the fruiting branches. In the humid regions, too much moisture interferes with the development of the plant, either by stunting its growth or by causing the shedding of buds and young bolls. Shedding is also caused by too little soil-moisture, a content of 15 per cent being the critical point on the best cotton soils.

249. Rainfall distribution important.—The mean annual rainfall in the cotton-belt varies from 35 inches in the important cotton area in Texas to 50 inches or more in the central and eastern areas, hence has no great effect on the distribution of cotton production. Considering the warm season rainfall (April to September), however, it is found that the Texas belt averages about 21 inches; the Mississippi Valley belt between 21 and 24 inches; and the Carolina and Georgia belt about 23 to 25 inches.

250. Heavy rainfall.—Rainfall is frequently much heavier in the South than in most other sections of the country and there may be too much moisture as well as too little for the best development of cotton. In view of this, a satisfactory correlation is often impossible on the basis of a direct relation between rainfall and yield, that is by assuming that the greater the rainfall the larger the yield, as has been found to be the case during certain periods of corn development in the principal corn-producing area. To overcome this difficulty, Kincer has suggested that the amount of rainfall and degree of temperature necessary to produce a theoretical maximum crop be taken as a base with the assumption that departures therefrom would correspondingly reduce the yield. He concludes also that in the case of crops of this character in which

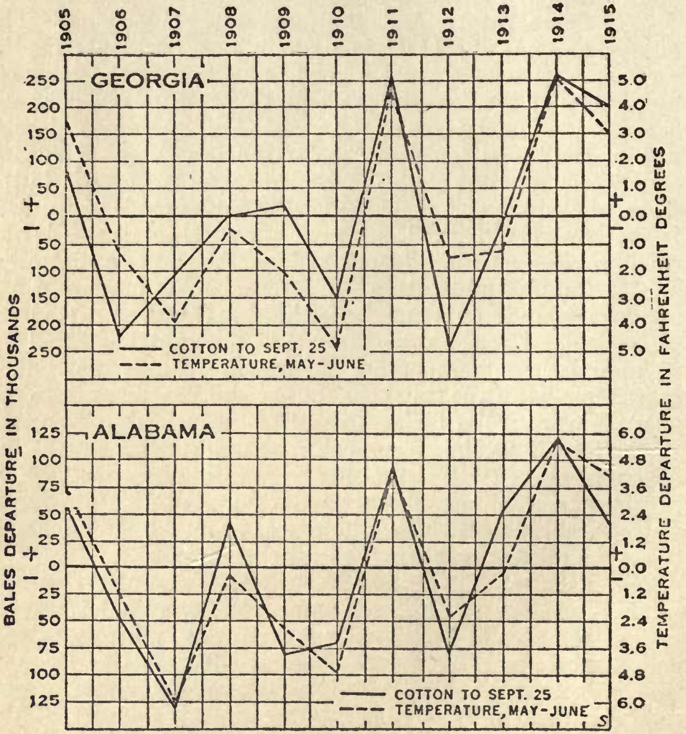

FIG. 28.—Showing the relation of the mean temperature from May 1 to June 30 and the amount of cotton ginned in Georgia and Alabama to September 25. The solid line shows the departure from the average amount ginned in thousand bales and the dotted line the departure of mean temperature from the normal.

the growing period is long and in which no short critical period is in evidence, that much more satisfactory results can be obtained by giving certain weights to the departures of rainfall and temperatures to represent the modifying influence of certain associated combinations of rainfall and temperature conditions, of the condition of the soil at the beginning of a month (or other period selected as a unit), and of intensified effect due to long sustained periods of unfavorable weather.

251. Weather-cotton equation.—In working out a correlation of weather and cotton yield in the state of Texas, Kincer employed the equation $X = d - \frac{\Sigma(ac + bc_1)}{n}$, when "X" represents the yield of cotton in pounds to the acre; "a" the departure of rainfall from the normal; "b," the departure of temperature from the normal; "c" and "c_1" weights to be applied to a and b; "n," the number of months (in this case April to September, inclusive) and "d" a constant to represent the number of points as computed from the rainfall and temperature departures from the normal to represent the average yield of cotton. The constant "d" in this case is necessary owing to the fact that the average rainfall and temperature would produce a cotton yield considerably above the average.

The values Kincer assigned to the auxiliary factors c and c_1 for the twenty-year period 1894 to 1913, inclusive, are given in the following tables. In Table 8 are entered the values for c, and in Table 9 those for c_1. These are of necessity arbitrarily or empirically fixed, but were assigned after a careful study of weather conditions for the period named, in conjunction with the resulting yield for the respective years, and from a general knowledge of the effect on plant development of certain combinations of weather. A careful study of the tables will disclose logical relations.

Under rainfall there may be four conditions: (1) a month of plus departure following a month of like departure; (2) a month of plus departure following a minus departure; (3) a month of minus departure following a like sign; (4) a month of minus departure following the opposite sign. The values assigned to c in each case are as follows:—

Table 8.—Rainfall Auxiliaries; Values for c

	Condition	*Apr.*	*May*	*June*	*July*	*Aug.*	*Sept.*
1	+ following 0 or +	4	8	8	4	4	4
2	+ following −	4	4	2[2]	2[2]	2[2]	3
3	− following −[1]	4	5	6	8[3]	10[3]	8[3]
4	− following 0 or +	2	2	3	6[3]	8[3]	4

Under temperature there can likewise be four combinations: (1) a plus temperature departure occurring with a plus rainfall departure; (2) plus temperature departure with minus rainfall departure; (3) minus temperature with minus rainfall departure; (4) minus temperature with plus rainfall departure. The values assigned to c_1 in each case are as follows:

Table 9.—Temperature Auxiliaries; Values for c_1

	Condition	*Apr.*	*May*	*June*	*July*	*Aug.*	*Sept.*
1	+Temperature with 0 or+ rainfall	1	1	1	1	1	1
2	+Temperature with −rainfall	1	1	2[4]	2[4]	2[4]	1[4]
3	−Temperature with−rainfall[5]	1	3	2	2	2	2
4	−Temperature with+rainfall[5]	1	4	4	2	2	2

It will be noted that prolonged periods of unfavorable conditions are provided for by increased values as indicated in footnotes.

Kincer gave the constant "d" in this state a value of 100, which means simply that a total value of 100 points, as computed from the rainfall and temperature departures, represents conditions favorable for production of an average yield

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[1] Minus departures of less than 0.3 of an inch for April and May are considered as normal.

[2] If following two or more months of minus departure, substitute 1 if departure more than 1 inch; and 0 if less than 1 inch.

[3] If fourth consecutive month of minus departure, increase value by 2; fifth month by 6, and sixth month by 8; all minus departures for July and August of more than 2 inches are given a minimum value of 12.

[4] If third month of minus rainfall increase value by 2; if the fourth, fifth, or sixth month, by 3.

[5] If third consecutive month of minus temperature departure, increase value by 1; fourth month by 2; and fifth or sixth month, by 3.

of cotton. When $\frac{1}{n}\Sigma(ac + bc) < d$, X would be positive and when $\frac{1}{n}\Sigma(ac + bc) > d$, X would be negative.

252. Equation in Texas.—Kincer applied this equation to the weather conditions in Texas for the period from 1894 to 1913, for the months of April to September, inclusive, with a resulting correlation coefficient of +0.88 and a probable error of only ±0.03. The actual results are shown in Table 10.

TABLE 10.—COMPARISON OF ACTUAL WITH COMPUTED DEPARTURES OF CROPS FROM NORMAL YIELD

Years	*Actual departures Lbs. acre*	*Computed departures Lbs. acre*
1894	65	46
1895	−19	−14
1896	−64	−64
1897	− 5	34
1898	42	47
1899	15	8
1900	56	− 9
1901	−11	− 6
1902	−22	−20
1903	−27	−29
1904	13	13
1905	− 6	−10
1906	55	54
1907	−40	−44
1908	26	24
1909	−45	−48
1910	−25	−36
1911	16	5
1912	36	30
1913	−14	−6

253. General weather effects.—Cotton has the characteristics of a weed and due to this fact and also owing to the long season during which growth and fruiting take place, there seems to be no comparatively short period in the development of the crop in which unfavorable weather is likely to prove disastrous. Whenever unfavorable weather prevails, the plant does not necessarily suffer permanent injury, but improves rapidly with the return of good growing weather even after a long period of adverse conditions.

254. Seasonal weather.—There are certain well-defined weather conditions, however, which hinder or promote growth. Rainy and cold weather early in the season hinders the preparation of the soil and the planting of the seed or proper germination; excessive rainfall in the first part of the season not only prevents proper cultivation, but encourages shallow root development; dry and hot weather later in the season is very detrimental.

255. April should be warm and moderately dry especially in the central and eastern part of the belt, as cold and wet weather hinders planting and cultivation, and may make the crop so late that it is liable to receive frost damage in the fall. In Texas, however, low yields have been more frequent with a dry April than an April with the rainfall above the normal. Cool Aprils in this state are followed by more low yields than high ones. Kincer found that of fourteen years with comparatively low cotton yield in Texas, nine of them had the average temperature for the state for April below the normal and five above normal.

256. May.—In the central and eastern states, May should be warm and comparatively dry, as cool and wet weather retards growth and final maturity and prevents proper cultivation.

257. June.—Cool and wet weather is harmful in June also as thorough cultivation is especially important owing to the length of time between the final chopping out period and the maturity of the last fruit, and the resulting tendency of the fields to become grassy.

Kincer found that in Alabama the rainfall was above the normal from May 1 to June 30 in ten of the years from 1900 to 1915 and in seven of these years the yield of cotton was below the average. The rainfall was above the normal in Georgia in May and June also and in these ten years the yield was below the average nine times. In Alabama of eleven years in which the temperature was below the normal in May and June, seven had yields below the average and four above, while for the eleven years in Georgia with cool weather during these two months nine had yields below the average and two above the average.

258. July and August.—Subnormal rainfall during the months of July and August is more frequently harmful in the western portion of the belt than in the central and eastern parts, owing to the normally greater amounts received in the latter districts. In general, the yield of cotton is largely affected by the rainfall during the months of July and August, especially the latter, but in the central and eastern parts of the belt temperature and moisture conditions during the early period of growth are of scarcely less importance. The influence of August rainfall in general, and especially in the western part of the belt, and the detrimental effect of cool and wet weather during the early growing season are indicated by the following.

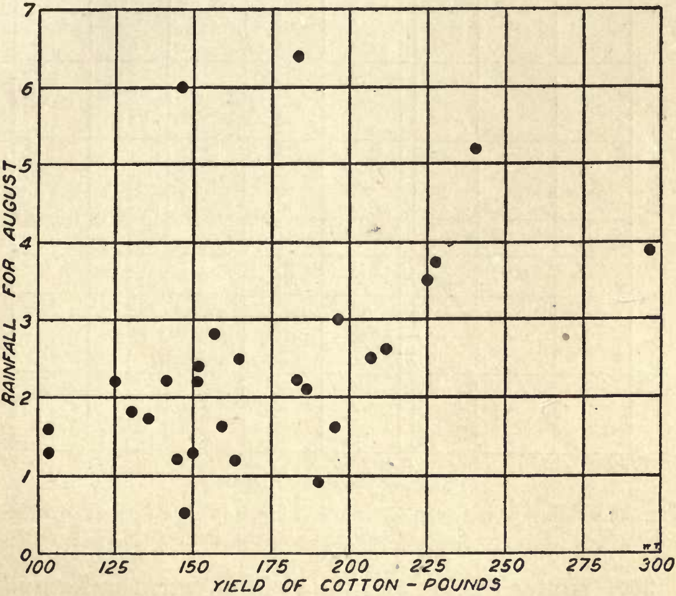

FIG. 29.—Relation between the rainfall in August and the yield of cotton in Texas, 1891–1918.

259. Rainfall in July and August not the controlling factor in Texas.—That the rainfall for neither August nor for

July and August combined are the controlling factors in the cotton yield in Texas is shown by Figs. 29 and 30. While there is a general increase in yield with an increase in rainfall, the relation is only approximate and no good estimate of the yield can be obtained from a knowledge of the rainfall.

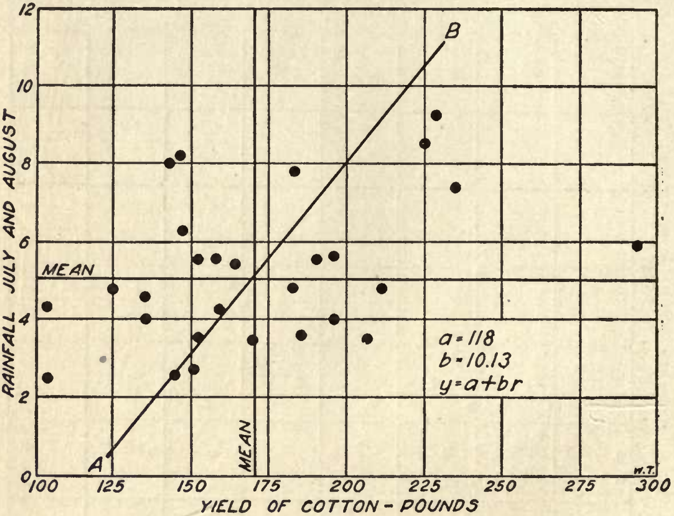

FIG. 30.—Relation between the rainfall for July and August combined and the yield of cotton in Texas, 1891–1918.

260. Winter rainfall and the yield of cotton in Texas.—The opinion is often expressed that the yield of cotton in Texas is largely dependent on the rainfall during the previous fall or winter. This belief seems to be disproved by Figs. 31 and 32. These charts indicate that small cotton yields are about as frequent with heavy as with light autumn or winter rainfalls. Also that heavy yields frequently occur with light winter precipitation, due to favorable weather in the spring and summer.

261. Some important comparisons.—For the sixteen-year period from 1900 to 1915, inclusive, the rainfall for August in Texas was normal or above seven times, and for these seven years the acre yield of cotton was above the sixteen-year average six times and below the average but once. For the nine years in which the August rainfall was below the normal, the yield was also below the average eight times and above the average once. For the same period in Alabama, the August rainfall was above the normal seven times, for which years the yield was above the average five times and below the average twice, while for the nine years with subnormal August rainfall the yield was below the average seven times and above twice. In Georgia, however, this period had six years with August rainfall above normal, four of which had yields below the average and two above the average, but for the ten years with subnormal August rainfall the yield was below the average seven times and above the average three times.

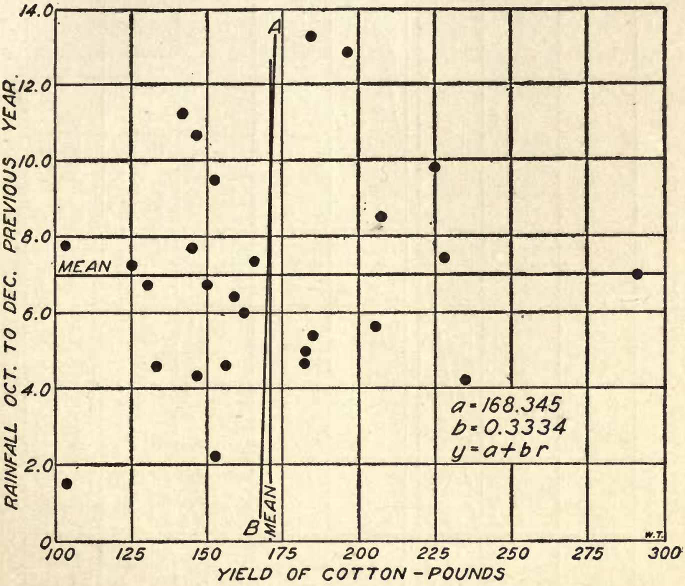

FIG. 31.—Relation between the rainfall from October to December and the yield of cotton in Texas during the following year, 1892–1918.

After the plants have attained their vegetative growth, the ripening of the fruit and seeds is favored by cooler nights.

262. September and October.—The cotton is liable to be beaten out and damaged by stormy weather after opening and while picking is going on. The amount of rainfall during the latter part of the growing season, particularly in September, is also of special significance, as this largely determines the amount of the top crop, which plays a considerable part in the total yield. A late fall with a delay in the first killing frost date also allows for the development of the top crop when not affected by weevil.

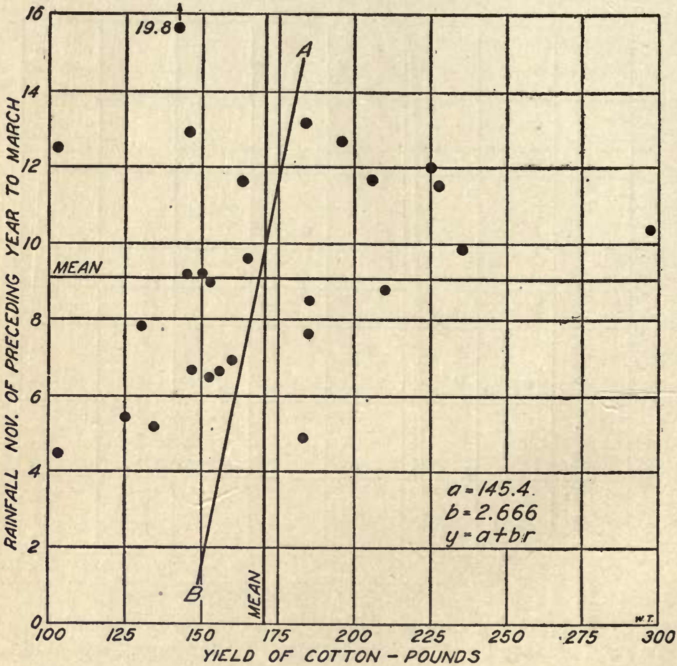

FIG. 32.—Relation between the rainfall from November to March and the yield of cotton in Texas the following fall, 1892–1918.

263. The weather effects of two seasons compared.—The Weather Bureau publishes diagrams each year in the National Weather and Crop Bulletin indicating the combined effect of rainfall and temperature variations on the growth and condition of several of the most important crops.

Figs. 33 and 34 are taken from these diagrams and show the effect of two quite different seasons on the condition of cotton in Oklahoma. Fig. 33 is for 1917, which was generally favorable for cotton, and Fig. 34 for 1918 when a severe drought prevailed in the western cotton states. In 1917 May was very cold and cotton was unfavorably affected, but with more favorable weather later there was an improvement in all of the states except Texas, and the earlier handicap was almost overcome. The generous rainfall in August in Oklahoma as shown by Fig. 33 was especially beneficial to this crop. In 1918 the weather during the spring was much more favorable, but drought and high temperature during most of the summer nearly ruined the crop in Oklahoma and Texas. The effect of these conditions in Oklahoma is especially shown in Fig. 34. During these months wet weather reduced the outlook for cotton in the eastern part of the area.

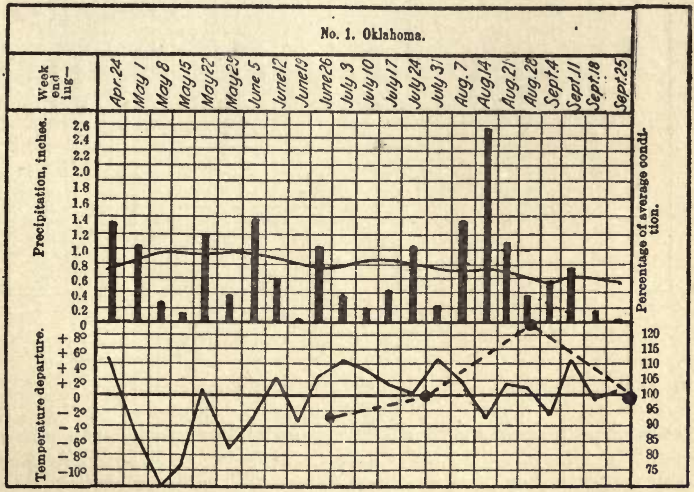

FIG. 33.—Diagram showing the effect of the weather on the condition of cotton in Oklahoma in 1917.

264. Insect pests.—Wet and cloudy weather favors the development of the boll-weevil, especially if wet enough to hinder cultivation; while in the eastern part of the belt, hot dry weather hastens the development of red-spider.

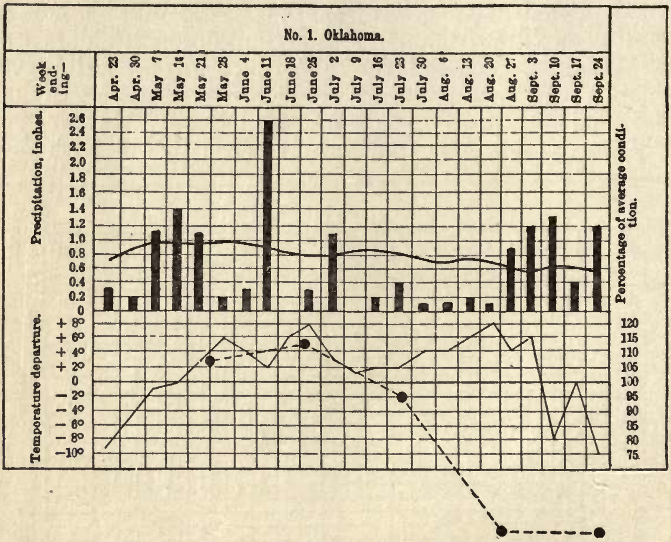

FIG. 34.—Diagram showing the effect of the weather on the condition of cotton in Oklahoma in 1918. In the upper part of each of the diagrams (Figs. 33 and 34) the heavy solid line indicates the normal weekly rainfall, while the average for the state for each week is shown by the heavy upright line. The rainfall values are indicated by the figures at the left. In the lower part of each diagram the heavy horizontal line represents the normal temperature, while the variable black line shows the temperature for each week from the normal, as indicated by the figures at the left. The condition of cotton on the 25th of the month, as compared with a ten-year average, expressed in percentages as shown by figures at the right, is indicated by the dots, and these are connected by broken lines.

265. Boll-weevil and temperature.—With a mean monthly temperature of 60°, the activities of the weevil are greatly reduced. Investigations by the Bureau of Entomology, United States Department of Agriculture, show that an exposure to a temperature of 20° for a period of six hours is fatal to the boll-weevil. It is probable, therefore, that whenever the winter temperature reaches a minimum of 10°, the weevil will be greatly reduced in all districts and almost entirely killed out in prairie sections, where there is less protection than in wooded areas. If only a few escape death, however, they may multiply so rapidly with favorable weather in the spring and summer as to cause great damage, although the damage will be later than if the winter is mild.

The following statement by L. O. Howard is of interest in this connection:

> The most important climatic factors which affect the boll-weevil are winter temperatures and spring precipitation. Naturally low winter temperatures reduce the weevils enormously in numbers, while high spring and early summer precipitation has the effect of increasing their numbers. It has been found in observations made during several seasons that no accurate forecast of weevil conditions during the summer can be made from winter mortality. Attempts to do this were made in the early days of the investigation of the weevil, but we have been forced to abandon further attempts. On several occasions the weevil has been decimated by low winter temperatures but wet weather the following May and June negatived the conclusion of summer scarcity which would appear to be warranted by the winter conditions. In a similar way the survival of an enormous number of the weevils through mild winters has not resulted in any proportionate damage of the crop, on account of dry weather during May and June.

266. Boll-weevil and rainfall.—The most important single factor in holding the weevil in check is dry weather during the growing season, as dryness increases the death rate of immature weevil in the fallen squares enormously.

267. Wind and spread of weevil.—The normal advance of the boll-weevil into new territory is 50 miles a year, but high winds, with other conditions favorable, may cause a much more rapid spread of this insect, as was the case from August 15 to 31 in 1915 when they advanced fully 100 miles.

Flax

Flax for fiber is grown in regions in Europe with high humidity, moderate rainfall, and rather cool and uniform summer temperatures, as even and rather slow growth is necessary to produce a long, even, fine fiber. Anything that checks the steady growth of straw during the period preceding boll formation is sure to result in an inferior type of fiber. In Egypt, the beginning of flax-culture dates back to 4000 B. C.

268. In North America.—Flax is grown mostly for seed in this country and principally in the Dakotas and Minnesota and the adjoining Canadian provinces. In this section of the United States, the annual rainfall is 15 to 20 inches and the rainfall during its growing season of 80 to 110 days is from 10 to 12 inches. As this is a region of rapid temperature changes and uneven rainfall, the straw is short and coarse and the fiber is uneven, hence only seed is produced. For the best development for seed also a steady even growth is desirable with only sufficient moisture to cause a sturdy type of stem growth and a heavy production of foliage.

Very recently the cultivation of fiber flax is becoming an established industry in eastern Michigan and the Willamette Valley in Oregon.

269. Moisture and flax.—Too much moisture results in a weak and imperfect stem and poor boll and seed formation. A severe drought near the time of flowering or boll formation will cause a hardening and ripening of the straw, especially of the slender stems on which the bolls form, thus cutting off the proper supply of food materials.

Hot dry winds and a lack of moisture when the plants are in bloom are detrimental to the seed crop, while cool and cloudy weather causes it to bloom for a long time and hence to ripen unevenly. Cool nights, fairly warm days, with plenty of moisture are conducive to extensive branching.

270. Frost effects.—A slight frost after flax has reached a height of 2 inches may not injure the plant, but if it is cut off by frost at a point below the first or "seed" leaves, the plant loses its power of growth.

271. Flax in North Dakota.—Warm weather with somewhat less than the normal rainfall during May and June, while planting and germinating are going on, produces the best condition for flax in North Dakota. The best results have been obtained with wet and warm weather in August, and wet and cool in early September. The maturing period falls in August and the first of September so it is necessary to have plenty of moisture to fill out the seed well.

The seeding of flax is mostly done in this state during the last half of May and the first half of June, although seeding may be continued until the middle of July. The crop is harvested in the latter part of August, September, and the first part of October.

Hemp

Hemp is cultivated in warm countries for the production of a narcotic drug, but in moist temperate climates such as the central part of the United States it is cultivated for fiber. It is one of the oldest fiber-producing crops, and is important in Japan, China, and India.

272. In the United States.—The principal hemp-producing districts in the United States are in central Kentucky and in parts of Wisconsin. Practically all the hemp seed in the United States is produced on narrow strips of land between the bluffs, along the Kentucky River.

273. Growing season.—In fiber production, the seed is planted about the 10th of April in Kentucky and the growing season is about 130 days. For seed, it is planted somewhat earlier and harvested in the first part of October.

274. Temperature.—Hemp grows best where the temperature ranges between 60° and 80°, but it will endure higher or lower temperatures. Light frosts will not greatly injure either the young or mature plants for fiber, but a frost before harvest will greatly damage the plants for seed.

275. Rainfall.—The most critical period of growth is shortly after it comes up, when it must have plenty of moisture, as a period of dry weather at this stage may cause great injury.

FRUITS

The climate should be carefully considered in the growing of fruit. The prevailing weather also influences the yield to a marked extent. The fruits will be discussed separately.

Almonds

(These nuts are classed with fruit in California.) Almonds are the first of the deciduous fruit-trees to start to grow and to bloom in the spring and the last to lose their leaves in the fall. Its period of dormancy in this climate is very short, usually being complete only during December and January.

276. Temperature and almonds.—The almond tree is hardy and will endure fully as much cold as the hardiest peach without injury. The blossoms on the other hand are very tender, and even when there is an entire absence of frost during blooming, sudden marked changes in temperature may greatly damage or ruin the crop. The most tender stage in the blossoming and development of the young fruit seems to be that immediately following the dropping of the calyx-lobes as the fruit first commences to swell rapidly.

277. Moisture and almonds.—Continued rainy, damp, and cold weather at the time of blooming is likely to sour the pollen or actually wash it away. Foggy or moist weather during ripening or harvesting is very objectionable.

Apples

In the eastern part of the United States, the area of extensive apple-culture does not extend south of the mean summer isotherm of 79°, or north of the mean winter isotherm of 13°. There are few orchards in the Great Plains states west of the 18-inch annual precipitation line. The leading apple states are New York, Michigan, Pennsylvania, and Missouri.

278. Weather and apple yield.—A study of the effect of the weather of different months on the yield of apples was made for Belmont County, Ohio, covering the period from 1889 to 1910. This showed that the most important months were February, of the current year, and June of the previous year.

279. February.—In the twenty-one years, the apple crop was always below the normal when February was warm and wet and usually above the normal when it was cool and dry. The correlation coefficient between temperature and yield was -0.51 and between the rainfall and yield, -0.50, the probable error in each case being ± 0.10.

280. March.—Wet weather in March was also detrimental, especially if warm, and cool and dry weather was favorable although these conditions were not so well marked as in February.

281. Other months.—No marked relation was shown between the yield and the weather in April, May, June, July, or September. August, however, should be warm and wet for best results. A comparison of the yield with the mean monthly temperature and precipitation of the previous year showed no relation with May or July conditions. It did show that dry weather in August was detrimental although a wet August was not always followed by a good yield. A cool and wet June, however, was always followed by a yield below the normal the next year while a dry and warm June usually preceded a good crop the following year.

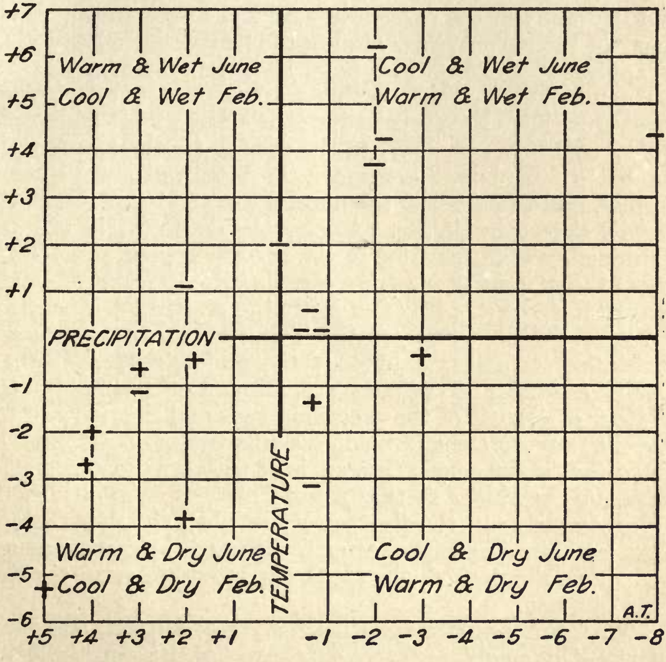

Fig. 35.—Combined effect of the weather of June of the preceding year and February of the current year on the yield of apples, Belmont County, Ohio, 19 years.

282. Fruit and leaf development.—As the fruit-buds develop in the preceding year and as wet weather favors active extension growth which is produced at the expense of fruit-bud formation, it follows that a dry and warm June should be favorable for the formation of a good number of fruit-buds for the next year's crop. A good rainfall in June produces a large amount of soil-moisture during succeeding weeks or months when the buds are developing, thus making a preponderance of extension growth and thus a larger percentage of branch and leaf-buds and a smaller percentage of fruit-buds.

283. Combined effect of June and February.—As a warm and dry June of the preceding year and a cool and dry February of the current year are both favorable for a good yield of apples, these conditions have been combined in Fig. 35. It should be noticed that in this chart the February temperature values have been reversed so that a warm June is grouped with a cool February. When the rainfall for the two months combined was above the normal, the yield was always below normal, and when below the normal the yield was above the normal eight times in ten. A correlation of the yield with the combined rainfall for June of the preceding year and February of the current year gave a correlation coefficient of -0.60 (probable error ± 0.10), and with the average temperature (with the February temperature departures reversed) gives a correlation coefficient of $+0.48$, with a probable error of ± 0.11.

284. August and February combined.—In Fig. 36 the weather of August of the preceding year and February of the current year were combined in a similar manner. It must be noted that a dry August is combined with a wet February by reversing the values so that a wet February is grouped with a dry August. In the thirteen years when the departure of these combined rainfalls, after reversing the August values, was above the normal, the yield was below the normal every year but one.

285. Combined precipitation for June, August, and February.—On combining the departure of the precipitation for June of the preceding year and February of the current year above the normal with the rainfall for August of the preceding year below the normal, the correlation with the yield gave a coefficient of -0.62 with a probable error of ± 0.09.

286. Apple diseases.—Bitter-rot or "ripe" rot of apples is a typical hot weather disease. It is serious in the more southern apple districts. Hot and wet weather with the prevailing temperature above 80° produces conditions favorable for its spread. A local shower on a hot July afternoon may supply just the right condition when the whole crop may be destroyed in a week. The outbreak may be checked by a few days of cool weather with the mean temperature below 70°.

Special forecasts of weather conditions favorable for the spread of this disease should be made by the Weather Bureau and distributed as in connection with the apple-scab, so that spraying may be done at the proper time.

287. Codlin-moth.—Warm and dry weather favors the development and multiplication of this apple pest. The beginning of emergence in the spring is hastened by high temperature in March, April, and May. In the state of Washington it is known that the codlin-moth does not become active unless the temperature is 60° or higher. In other words, no breeding takes place when the temperature drops below 60°.

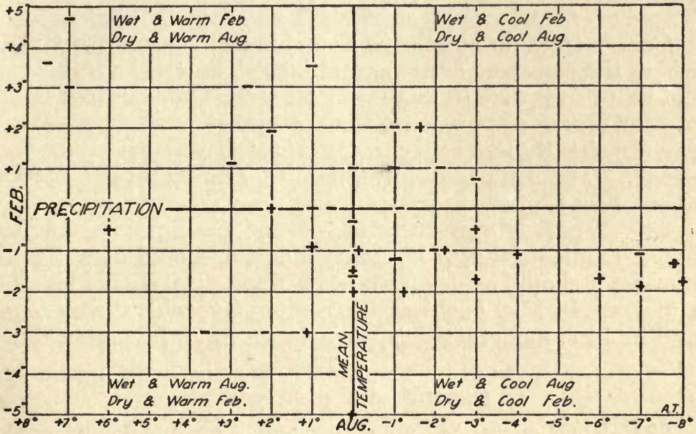

FIG. 36.—Combined effect of the weather for August of the preceding year and February of the current year upon the yield of apples, Belmont County, Ohio, 19 years.

Apricots

288. Apricots thrive best in the hot valleys of the Southwest. The fruit ripens at a time of the year when the relative humidity is at its lowest point and the danger of showers least, consequently the conditions are the most favorable for drying the fruit. They receive little injury from either the frosts of spring or the heat of summer, compared with apples or plums.

Avocado or alligator-pears

289. This is a tropical or semi-tropical fruit. The fruit of the hard-shelled type requires over a year to mature. Some varieties will stand from 5° to 10° below freezing. Strong winds are often damaging.

Cherries

Cherry trees do not thrive as a rule in the southern states where the summers are long and hot. The southern limit is not quite so far south as that of apples. The northern limit of sour cherries approaches that of apples while sweet cherries are slightly less hardy, corresponding more nearly to the peach. The fruit-bud formation in some cherries begins about July 1, of the previous year, in central latitudes.

290. Weather and cherries.—Some preliminary studies in Ohio indicate that if February is wet it should be cool and if warm it should be dry for best results. April should be cool and wet. In May cool weather is more favorable than warm, and in June moderately dry weather is more favorable than wet.

Currants and gooseberries

291. Both currants and gooseberries are natives of cool, moist northern climates and succeed best in the United States in the northern half of the country east of the 100th Meridian. They are injured by the long hot summers of the southern states, except in the higher altitudes of the Appalachian Mountains. Gooseberries are grown slightly farther south than currants. Both plants are very hardy and withstand extremely low temperatures, but as they blossom very early they are subject to frost damage.

Cranberries

Cranberries are indigenous to marshes, chiefly in the northern states, although wild cranberries are found at considerable elevations on moist mountain-sides in New England. Cranberries are cultivated intensively only in Massachusetts, New Jersey, and Wisconsin.

292. Cranberries and temperature.—The vines are subject to winter-killing and when water is available the cranberry bogs are kept covered during the winter months. While frost is not often experienced in the summer months in the eastern states, it may occur during any month in the low-lying bogs in Wisconsin. The minimum temperature in the cranberry bogs may be from 5° to 15° lower than on the surrounding slightly higher ground.

293. Protection from frost.—Cranberries are protected from light frosts by raising the water in the ditches that run through the bogs, but the vines must be entirely covered by flooding to protect from severe frosts.

Dates

294. Dates require intense summer heat and dry air, but will bear abundant crops only when well irrigated. The plants make their most rapid growth during the warmest part of the year. The dormant mature trees will endure an occasional temperature considerably below freezing, but there will be no development of the flowers or fruit when the temperature is below 64°. Even a light rain after the fruit has begun to ripen is very damaging. The date harvest season in California is in September and October.

Figs

295. Fig-growing is confined primarily to regions where the winters are comparatively mild. They are injured or killed to the ground by temperatures that do not affect most other fruits of the temperate zone when in a dormant condition, especially when young. As the trees get older, they become less subject to winter-injury, and in Arizona are rarely injured by the cold of winter or the heat of summer.

Grapes

Grapes are raised in the United States principally in California, western New York, northern Ohio, and southwestern Michigan. Most of the raisins used in the United States are grown in the Fresno district of California.

296. Temperature and grapes.—Winter-killing of grapes can be traced to a lack of maturity in the fall. An index to this immaturity is the incomplete ripening of the crop as shown by high acidity and low content of solids, especially sugar. A warm rainy September and a cool cloudy October leave the vines soft and succulent and give poor conditions for proper ripening of fruit. If these conditions are followed by marked temperature variations during the winter, the crop of the next year is likely to be poor.

297. Critical temperatures.—When the vines are well matured, they will withstand a winter temperature of at least 25° below zero. It was found in New York that the danger point in the winter is between −26° and −30°. When in bud bloom, and setting fruit, the critical temperature is 31°. The leafing of some native varieties occurs after ten or twelve days with a daily mean temperature of 52° to 53°. If freezing weather follows, the leaves and young growth will be killed and although they will grow new vines the crop will usually be reduced.

298. Weather and grapes.—A study of the effect of weather on grapes in northern Ohio showed that for best results, February and March should be dry and moderately cool, as wet and warm weather hastens growth and causes danger from later frosts. April should be moderately dry and warm as wet weather interferes with fertilization and anthracnose develops in cool and wet weather. May should be wet and warm to bring about vigorous growth. The grapes bloom in June in Ohio and a cold northeast wind or storm prevents pollination. Periods of warm sultry weather in June or July followed by dry warm weather may start the mildews and black-rot. A normal rainfall is needed in August and Septemper to develop the fruit and there should be plenty of sunshine. Warm weather with sunshine is necessary in the fall to allow for late picking.

299. Sugar-content.—In northern Ohio the sugar-content of white and Catawba grapes increases the longer they are left on the vines in the fall, consequently the growers delay picking as long as possible. Warnings of cold weather or sleet storms are desirable at this time to hasten picking. In the hot valleys of southwestern Europe, grapes have a very high sugar-content and although they ripen early they sometimes become very sweet before they are ripe.

Olives

300. Temperature.—The olive is very drought-resistant. Its range is restricted by temperature, although there is considerable difference in the varieties in the resistance to cold. In California, the winter mean temperature where olives are grown should not be below 48° and the summer mean should seldom exceed 80°. The dormant trees should not be subjected to a temperature below 15° to 20° and seldom below 28° or 30°. The fruit is very sensitive to frost and is seriously injured by a temperature of 28° even for a short time. The trees require a mean annual temperature of about 57°, and a mean temperature of over 66° for several months, at least during the first of the season, seems necessary. They blossom in an average year when the mean daily temperature reaches 66°.

Olives are peculiarly well adapted to southern Arizona where they are not injured by the heat of summer and very rarely is the fruit damaged by the cold of winter.

Peaches

Peaches are raised most extensively in the United States from northeastern Texas and Arkansas eastward to the Atlantic Coast and northeastward to the lower Lake region, and in California. About three-fourths of the peach trees are south of the Ohio and Missouri rivers and in California. The mean winter isotherm of 25° is a fairly well-defined northern limit for extensive peach production.

301. Temperature effects.—When thoroughly dormant, peach-buds will withstand a temperature of 12° to 20° below zero (F.), depending somewhat on the variety. Thorough dormancy is, however, somewhat indefinite and not very constant. Peach-buds are advanced easily by short spells of warm weather in even late fall or early winter and will then be killed by temperatures only slightly below zero.

302. Critical temperatures in Missouri (Chandler).—The killing temperature of peach blossoms when the tree is just coming into full bloom, under Missouri conditions, seems to vary from about 22° to 26°. After the blossoms are old enough so that they are probably pollinated, and from that time until the peaches are as large as half an inch in diameter, they continue to grow more tender until they will withstand but a few degrees below 32°, the seeds of the young peaches killing at a higher temperature than other peach tissue. The length of time subjected to the low temperature is an important factor.

303. Temperature and peach trees.—Thoroughly dormant peach trees will usually stand a temperature of 5° to 10° lower than the buds. The injury to trees depends, however, on the condition of the trees, the duration of the cold, the soil and surface cover, and the rapidity of thawing.

304. Moisture and peaches.—Like other stone-fruits, peaches require plenty of moisture for proper development. The Utah Agricultural Experiment Station Bulletin No. 142 states that "No amount of water applied early in the season to a crop of peaches on gravelly soil will compensate for the lack of water during the month before harvest."

305. Weather and the yield of peaches.—Quite extensive studies of the relation between the mean temperature and total rainfall for different months and the yield of peaches in northern Ohio have given no well-defined correlation.

306. Diseases of peaches.—Leaf-curl in Ohio is developed by cool, rainy, and cloudy weather. It is said that profitable spraying may be predicted with fair certainty from a knowledge of the temperature and rainfall in the first half of April. Warm moist weather conditions during May and June appear to be especially favorable to the development of the peach-scab fungus in New Jersey.

Pears

307. Pears are raised most extensively in the northeastern part of the country, in the Pacific states, and in a small area in western Colorado, although many are grown in other districts except in the upper Mississippi and Missouri valleys and in the central and upper Great Plains.

Plums

308. Plum trees of different varieties are widely scattered over the eastern half of the country, but the most intensive development of this crop, particularly the variety that is dried for prunes, is in central California. Plums thrive best in an equable climate with a long growing season, plenty of sunshine, freedom from frosts and from early fall rains and fog. They cannot endure extremes of heat and cold and of wet and dry weather.

Prunes are a variety of plum that can be dried without the removal of the pit, without fermenting. "All prunes are plums, but all plums are not prunes."

Strawberries

Strawberry cultivation is widely distributed, but the largest intensive areas are in southern New Jersey and eastern Maryland and in northwestern Arkansas.

309. Moisture and strawberries.—The plants need an ample supply of moisture in the soil constantly during the growing season and particularly while bearing fruit.

310. Temperature effects.—The blossoms are injured by a temperature below 30°. The young fruit endures a temperature below 24° at the ground and green fruit lower than this. The ripening fruit endures less cold. Moderate temperature and comparatively dry weather is desirable during the harvest season. High maximum temperatures during blossoming are detrimental as it prevents the setting of fruit.

311. Harvesting.—The average date of harvesting the crop is as follows:

South-central Florida	Dec. 1 to April 1.
North Florida	Feb. 10 to May 15.
South Texas	March 1 to May 15.
South Louisiana	March 15 to May 20.
North Gulf and South Atl. Coast	April 15 to June 1.
Lower Ohio Valley and Northern Maryland	May 15 to June 20.
Southern New England and lower Lake region	June 1 to July 15.

312. Adaptation to climate (Farmers' Bulletin No. 1043).—"In the selection of a variety for a given locality one should first determine whether it is suited to its climate. Thus, the Missionary, which is a good shipping variety in central Florida, is not a good shipping variety in the upper Mississippi Valley. In the southern States the Missionary and Klondike make a quick growth in early spring, producing large crops of early berries and in those parts of the South suited to them they are excellent shipping sorts. Neither of them, however, is adapted to the climatic conditions found in the northern states. In like manner, the Dunlap, a leading northern sort, is not adapted to southern conditions; when grown there it is too soft for shipping and sometimes too soft even for local markets.

"Other varieties, such as the Glen Mary, Belt (William Belt), and Marshall, which are grown to a considerable extent in the northeastern States, are not adapted to conditions farther south because of their greater susceptibility to leaf-spot diseases. The Clark, Jucunda, and other varieties grown in the dry atmosphere of the irrigated sections of the West are not grown in the East, and whether they would do well under the humid conditions in eastern sections is perhaps doubtful. It is important, therefore, to know the climatic adaptations of the different varieties before selecting them for extensive planting."

313. Strawberry diseases.—Leak, caused by *Rhizopus nigricans* is by far the most important rot of strawberries after picking. It develops very slowly at 50° but increases rapidly with higher temperature. Berries picked early in the morning are cooler and will ship better than those picked near the middle of the day. *Botrytis sp.* is a field rot of strawberries that is most abundant and serious under conditions of excessive moisture.

Citrus fruits

Citrus fruits are of tropical origin and the intensive cultivation of oranges, lemons, grapefruit, and limes is generally confined to places without severe frosts. They are successfully grown, however, in regions in California where frosts occur, although artificial protection from low temperature damage is usually resorted to.

314. Oranges.—The most extensive orange orchards in the United States are in central Florida and southern California, although they are raised in central California and in the Gulf coast districts of Texas, Louisiana, Mississippi, and Alabama. It has been found in California that the ripe orange begins to freeze when the temperature of the fruit itself reaches 28° F. The rind freezes first and the rapidity with which the freezing extends inward depends on the air temperature and radiation. The temperature of the fruit lags from one to two and one-half hours behind the air temperature, depending on the rate at which the air temperature falls. When the temperature is falling rapidly, that of the fruit is sometimes 7° higher than that of the outside air.

315. June drop of navel oranges.—Navel oranges grown in the interior valleys of California and Arizona are subject to a large shedding of young fruit usually called "June drop" although it may occur at any time from the petal-fall in April to maturity. The period from petal-fall until the fruit is about 1 inch in diameter is the most serious. While this drop increases with high average daily temperature, many practical orchardists in California believe that the amount of the June drop depends primarily on low temperature during the preceding winter and secondly on the high temperature in summer.

316. Oranges in Florida.—The annual growth of oranges in Florida is divided into four well-defined periods: (1) when spring blossoms are appearing and the young fruit forms. This is the most critical time from a moisture standpoint as dry weather may cause the young fruit to drop. (2) During the summer when fruit takes on size. Rain is needed, as a dry period may do serious harm by preventing fruit from attaining full size and color. (3) Fall and early winter when fruit is maturing and harvest begins. A severe cold wave at this time may cause great damage by freezing. (4) Dormant season which is usually through December and January.

317. Lemons.—The principal lemon district is in southern California. The lemon is more tender than the orange and the fruit is injured at 26° to 28°, and sometimes at even higher temperatures. Young small sized fruits, "button lemons" are more tender than those large enough to harvest. The damage to lemon trees by winter cold depends in a large degree on the age of the trees. Trees five years old have been frozen to the ground with a temperature of 19°, while old trees were not seriously injured.

318. Limes are raised in Florida and California. They are more tender than lemons and the fruit is killed at temperatures of 28° to 30°.

319. Pomelos (grapefruit).—The grapefruit trees are more hardy than the lemon but are more tender than orange trees. The fruit is not so easily frozen as are oranges.

Temperatures withstood

320. Critical frost temperatures for fruit.—The temperature at which fruit-buds will be killed depends on so many factors that no well-defined limit can be designated. The condition of the tree, the stage of advance of the buds or blossoms, their position on the tree or limb, the moisture in the atmosphere, the length of duration of the low temperature, and the previous weather that the tree has been subjected to, all enter into the problem of frost damage.

321. Percentage of damage.—It has been pointed out that there is a range of at least 5° between the temperature at which all of the buds will be killed and that at which only 5 per cent will be lost. If there are few blossoms on a tree, the critical temperature, therefore, will be higher than when it blossoms so freely that a large percentage can well be lost and yet leave as many as should develop fruit. As a usual thing, if only 2 per cent of the live buds of peaches remain to mature, it will mean a fair crop of fruit. It is frequently said that a fruit-tree in an average year should lose about 90 per cent of its buds or blossoms.

322. Critical temperatures relative.—The critical frost temperature then is a relative term depending on the percentage of blossoms that need to be saved from loss.

323. Safe temperatures.—The following table gives what are believed to be safe temperatures for the normal tree in an average season under usual conditions. Under some conditions it is known that the temperature may fall several degrees below these values without serious loss. In general, however, when protection by heating is practiced, it is wise to prevent the temperature going below the point indicated for any great length of time. The figures are from observations by a number of experts or from actual tests by men of authority.

Careful records of minimum temperatures and amount of damage on cold nights should be kept for future reference by every orchardist, especially if heating is done.

PLATE V.—The Hamilton oil heater. The size of the burning surface can be controlled by the sliding cover.

TABLE 11.—PROBABLY SAFE TEMPERATURE FOR DIFFERENT FRUITS

Kind of fruit	*Buds showing color*	*In full bloom*	*Fruit setting*
Apples	27	29	30
Apricots	30	31	32
Almonds	28	30	31
Blackberries	28	28	28
Cherries	25	28	30
Grapes	31	32	32
Lemons	—	32	30
Pears	28	29	30
Peaches	25	28	30
Plums	30	31	31
Prunes	30	31	31
Oranges	30	30	—
Raspberries	28	28	28
Strawberries	28	28	28

324. The orange tree when fairly dormant will stand a temperature of 25° to 26° for an hour or so. At 20° to 22° the twigs begin to die back and the leaves fall. At 17° to 18° for four to five hours, the branches will be killed back to 2 or 3 inches in diameter, unless the trees are quite dormant.

325. Peaches.—West and Edlefsen in freezing experiments in Utah in which by an ingenious device they were able to freeze the buds on a detached limb or on the whole tree, found that the temperatures which will kill about 50 per cent of buds of the Elberta peach are as follows:

When	slightly swollen,	14°
"	well "	18°
"	showing pink,	24°
"	full bloom,	25°
"	setting fruit,	28°

326. Cranberries.—Careful records in Massachusetts show that in the greenish white stage that immediately percedes the ripening of fruit, the berries will endure a temperature of 26° without harm, and 25° with little injury, but 24° seems to harm such fruit greatly if it continues long.

327. Dormant period.—In the northern part of the United States, fruit-trees should stop growing early so as to become fully dormant before the low temperatures of late fall and winter occur. In the southern states, however, where little or no damage occurs during the dormant period, the problem is to keep the fruit-trees growing as late as possible so that the short dormant period will carry the trees through the spells of warm winter weather. Otherwise the buds develop too far and are killed by later cold.

328. Most susceptible period.—It is believed that the peach is the least resistant to cold when it is about the size of a pea, when the calices are falling. The seed kills at a higher temperature than other plant tissue. After setting, the damage to young apples is due to the freezing of the stems.

329. Weather and the setting of fruit.—Warm dry sunny weather is most favorable for the setting of fruit while cold and rainy weather is detrimental. Rain prevents bees and insects from carrying the pollen while the secretion on the stigmas or the pollen on the anthers may be washed away, or the pollen-grains may swell and burst.

330. Temperature effects.—In very warm weather the stamens, or male part of the blossom, will develop more rapidly than the pistil, or female organ. Thus under high temperatures the stamens may be forced so much faster than the pistil that the pollen is shed before the pistil is ready to receive it. In cool weather the pistil develops most rapidly. The pistil is often injured by a light frost that does not affect the stamens. It has been determined that the pollen of the apple will withstand much lower temperatures than will any other tissue of the flower when in full bloom.

331. The killing of plant tissue.—During freezing weather ice forms in the inter-cellular spaces of the plant tissues and withdraws the water from the protoplasm in the plant-cells. It was formerly taught that if plants thawed slowly enough so that the cells could reabsorb the moisture as fast as the ice melted, little harm would result. Chandler and others have demonstrated from experiments, however, that the rate of thawing does not have anything to do with the amount of killing, at a given temperature.

332. Frost is most damaging when fruit is wet.—A plant tissue with a wet surface kills worse at a given temperature than tissue with no moisture on the surface.

333. Sun-scald on the southwestern or sun-exposed side of the trees is brought about by some interaction of sun and cold in late winter, and is common in northern districts. The injury occurs late in winter or early in spring when warm days are followed by cool nights. The bark is subjected to rapid and extreme temperature changes, becomes unhealthy, dies, dries up, and falls away. It is prevented by spraying or painting trunks with whitewash.

LABORATORY EXERCISES

The possibilities of personal investigation on the part of the student are self-evident in Chapters VII, VIII and IX.

Each student should be given some specific crop, plant disease, or insect, and directed to show the relation between the weather and its development from past records.

At the proper season valuable information can be obtained by noting the effect of current weather on crops, particularly fruit or truck.

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CHAPTER VIII

THE EFFECT OF WEATHER ON THE YIELD OF GRAINS

The bread and feed grains are the fundamental crops, aside from the earth-cover of grass. The yields of them are major factors in determining the financial movements of the year, and the quotations on them figure largely in stock exchanges and price-currents. The relations of weather and climates to these crops is a question of large public concern.

BARLEY

Spring barley has a shorter growing season than either wheat or oats and is cultivated farther north and at higher altitudes than other cereals. It is grown up to latitude 70 degrees in Norway and to 65½ degrees in Alaska. It ripens in 80 to 95 days after seeding in Alaska, and in about the same time in Wisconsin.

334. Range in the United States.—The main spring barley districts are in Wisconsin, Minnesota, North Dakota, South Dakota, and California. Some winter barley is grown in the South.

335. Temperature and barley.—While some varieties of barley are grown on the tropical plains of the Ganges and in the hot districts of northern Africa, most of the crop in the United States is grown in a cool region. It serves as a crop where it is too cool for corn. All of the principal barley districts in this country do not have any month during the season of growth with the mean temperature above 75°. It has been found in England that the chief requirement as far as yield is concerned, is a cool summer, especially after mid-June. It is affected by spring frosts more than either wheat or oats but recovers quickly. Winter barley is not so hardy as winter wheat or rye.

336. Rainfall and barley.—The principal barley-growing districts of the United States receive an annual rainfall of less than 35 inches. In parts of California it matures on an annual rainfall of less than 10 inches, although spring barley should have about 10 inches of rain during the three months of growth. For brewing purposes, barley must be raised where there is little rainfall during the latter part of its growth and none while in shock. The crop needs plenty of sunshine and should ripen in dry weather without dews.

337. Critical period of growth.—April, June, and July are the critical months for barley. Barley is not an important crop in Ohio, but a study covering thirty-eight years shows that the best yields are nearly always with a comparatively dry June, while wet Junes are almost never accompanied by yields much above the normal.

338. In Wisconsin.—A correlation of the weather with the yield of barley in Wisconsin, during the period from 1891 to 1917, shows the following:

	Rainfall		*Temperature*	
Month	*Correlation coefficient*	*Probable error*	*Correlation coefficient*	*Probable error*
April	−0.36	±0.11	+0.32	±0.12
May	+0.32	±0.12	−0.05	......
June	+0.20	±0.12	−0.55	±0.09

BUCKWHEAT

Buckwheat will mature in a shorter period than any other grain crop, ten to twelve weeks being sufficient under favorable conditions. It is, therefore, well adapted to high altitudes and short seasons, but its period of growth must be free from frosts as it is very sensitive to cold. Because of its short growing season, it is successfully cultivated as far north as 70 degrees. Its cultivation in the United States is confined largely to the northern states east of the Mississippi River. The district of chief production is in the Appalachian region from West Virginia to New York, with a secondary district in Michigan.

339. Weather and buckwheat.—A cool moist summer climate best suits this crop, very little being grown in the United States where the summer mean temperature is over 70° and practically none where it exceeds 75°.

The seeds will germinate best when the soil temperature is about 80°F., although they will germinate when the temperature is anywhere between 45 and 105. In order to germinate, the seeds must absorb about one-half their weight of water. Considerable heat in the early stages of growth is an advantage, but it should be cool and moist during the latter part of growth and especially when seeds are forming, The plants are very sensitive to high temperature and dry weather at blooming time, especially when both day and night are hot or when accompanied by hot, drying winds. Hot weather with constant rain is also unfavorable. In experiments in Russia covering a period of fifteen years, the good years were with a comparatively low temperature during the second half of the flowering period and the poor yields where the temperature was relatively high. It was found there that a drought during blossoming caused a large production of straw, but of very little grain. By sowing buckwheat before April 25, through a long series of years in Russia a type had been produced that resists a temperature several degrees below freezing.

CORN

Corn or maize is a sun-loving crop of tropical origin, but is so flexible in its requirements and so readily adapts itself to its surroundings that it is successfully grown over wide climatic ranges. It does not mature, however, anywhere north of the 50th parallel of latitude, although it may be grown for green fodder in favored localities somewhat farther north.

340. Where grown.—The great corn regions of the world are areas of continental climate. Except where irrigation is practiced, most corn is grown in regions having an annual rainfall of over 20 inches and a summer temperature averaging about 75°. A comparatively small area of the earth's surface is devoted to the intensive cultivation of this crop as the optimum climatic conditions for corn are found in only a few regions of the world. Outside of the United States, the important corn-producing regions are in Roumania, Hungary, Mexico, Argentina, and India. Corn does not thrive in regions of cool cloudy summers.

341. In the United States.—Corn is preëminently an American crop and is grown on three-fourths of all the farms of the United States. Every fourth acre, almost, of improved land in this country is a corn field. In America "corn is king." This country contributes about 70 per cent of the world's total production. The corn acreage as well as its value is greater than that of wheat, oats, barley, rye, buckwheat, rice, fruits, and nuts combined. The 1910 census shows that for each dollar the farmers of the nation received for grains over 50 cents came from corn. Fig. 37 shows two centers of greatest production in this country, and makes plain the fact that a large percentage (three-fourths) is raised in the Mississippi Valley. While a large proportion of the total corn crop is raised in this comparatively limited area, it is an important crop in nearly all the eastern states.

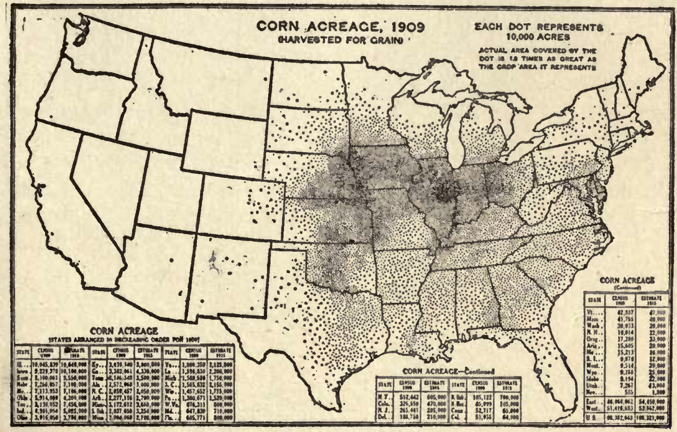

FIG. 37.—Where corn is grown in the United States.

342. Climatic factors.—The region of most intensive culture in this country is within a territory where the mean summer temperature is from 70° to 80°; the average daily minimum temperature in summer is over 58°; the average frostless season is over 140 days; has an annual precipitation between 25 and 50 inches, and a rainfall of 7 to 8 inches in July and August.

343. Climatic limits.—The growth of corn in any quantity is limited on the north by the mean summer isotherm of 66° and by the average summer night temperature of 55°. The western limit of extensive cultivation agrees closely with the summer (June, July, and August) rainfall line of 8 inches, especially in the Southwest where summer droughts are likely to prevail, and where evaporation is hastened by hot winds. As a result, very little corn is grown along the northern border of the country or in the West except in the more favorable locations.

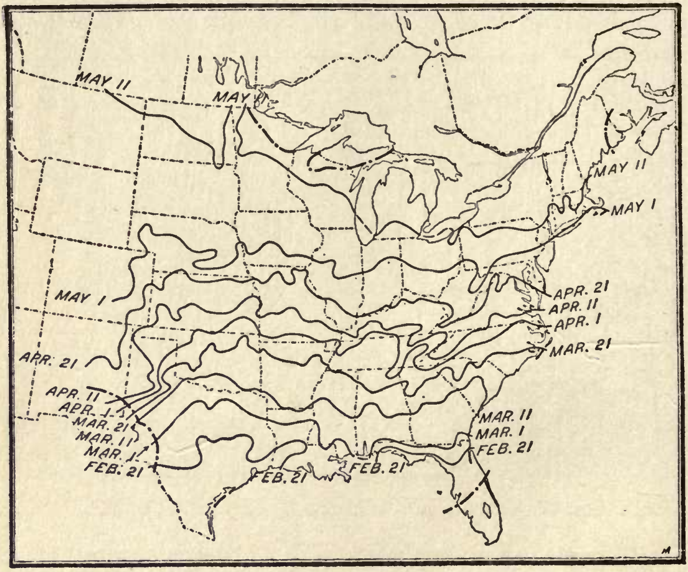

Fig. 38. Dates when corn planting begins.

344. When planted.—As shown by Fig. 38, the planting of corn usually begins in extreme southern Texas the latter part of January and this work progresses northward at an average rate of thirteen miles a day, reaching the northern limits of the country about the middle of May. Planting becomes general in the principal corn states about May 15, and is usually completed by June 1.

345. Temperature and planting dates.—It is an interesting phenological fact that the average date of the beginning of corn planting agrees closely with the date when the seasonal rise in the mean daily temperature reaches 55°. If the date lines on Fig. 39 are drawn on the beginning of planting chart, the lines of the same dates would almost exactly coincide all the way from the Gulf to the Lakes.

Fig. 39.—Mean daily temperature when corn planting begins in different parts of the United States east of the Rocky Mountains, and the dates on which these temperatures are reached.

346. Corn planting and average frost dates.—As the average last spring frost date lines also agree closely with the temperature of 55°, it follows that the average date on which the last killing frost in the spring occurs has been found to be the best date for beginning of corn planting. The ground becomes warm enough by that time for the germination of seed and the danger of serious frost damage will be over by the time the corn comes up.

347. When harvested.—The beginning of the corn harvest does not progress so regularly as the beginning of planting, partly because of various methods of harvesting the crop in different sections. Fig. 40 shows the average date when cutting and shocking begins.

348. Length of the growing season of corn.—Taking the dates for the beginning of planting and those of cutting and shocking as a basis, the average length of the growing and maturing season of corn is obtained. This varies from 150 to 180 days in the South to 120 to 130 days in the North. In the main corn-growing states it varies from 130 to 150 days.

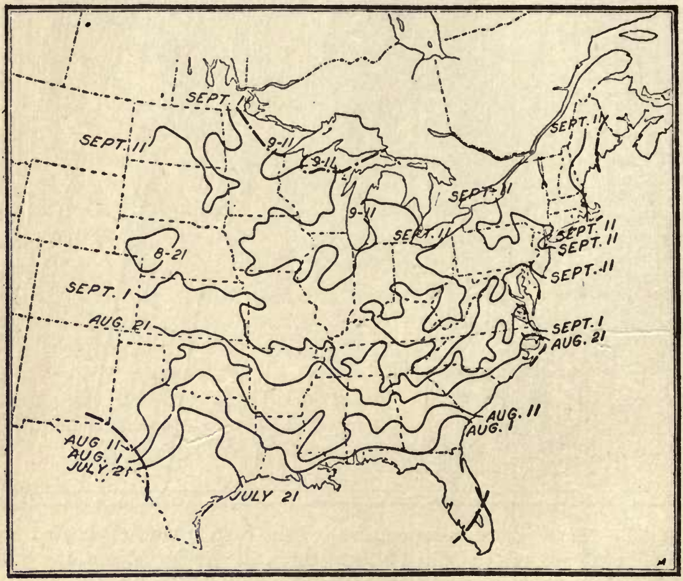

FIG. 40.—Dates when the cutting and shocking of corn begins, in an average season.

349. Varieties and length of growing season.—Although a tropical plant, corn will adapt itself to the climatic requirements so that different varieties have developed that will mature in the possible growing season even beyond the 47th degree of latitude. That this is not a recent development is shown by the fact that corn was being successfully grown by the Mandan tribe of Indians in the Missouri Valley in North Dakota when first visited by the whites as early as 1738, and had apparently been so cultivated extensively for several centuries at least. They were growing varieties that matured in 70 to 90 days.

350. Temperature and corn.—Corn will germinate in three to four days at a temperature of 62°. The length of time necessary for germination increases as the temperature lowers until the minimum temperature for possible germination is reached. In some experiments in New York, one variety of corn required 430 hours and another 460 hours to germinate at temperatures between 37° and 42°. In a test by Haberlandt,[1] eleven days was required at a soil temperature of 51° for the sprouts to show, while only three days were necessary when the soil temperature was 65°. In De Candolle's experiments corn germinated in ten to twelve days at temperatures of about 49°, but in less than two days at temperatures from 70° to 84°. The optimum temperature for germination is given as 91° to 93°, and the maximum beyond which germination will not take place as slightly above 115°.

351. Growth and temperature.—Lehenbauer determined from experiments that corn seedlings in practical darkness and a constant relative humidity of 95 per cent, made almost no perceptible growth when the temperature was 40° F. (4.5° C.), the most rapid growth was at 89.6° F. (32° C.) and that the growth ceased at 118.4° F. (48° C.). (See Fig. 19). His experiments showed that the rate of growth doubled with each increase in temperature of about 18° F. from the minimum to the optimum temperature and decreased in about the same proportion from the optimum to the maximum temperature. The rate of growth was practically the same at 116° as at 40° while at 88° it was 122 times as great. The rate of growth at the different temperatures varied with the length of time exposed, which at the figure cited was twelve hours. The experiment is valuable only as an indication, as corn plants in the field are never subjected to the conditions imposed on the seedlings in the experiment.

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[1] Ill. Agr. Exp. Sta. Bull. 208.

352. Moisture and corn.—The corn plant is made mostly from water and air, with food taken in solution from the soil by the roots, and carbon taken from the air by the blades. The plant makes the grain by the aid of the sun. The heat, moisture, and sunshine must be properly balanced to produce the best results.

353. Transpiration and leaf area.—The amount of water transpired from a given leaf area of corn (based on expanse of leaf rather than both surfaces) has been found to be about one-third as great as the evaporation from a free water surface of the same area. In hot dry weather, the rolling of the leaves reduces the transpiration rate.

354. The moisture requirements of corn vary at different periods of growth and with plants of various sizes. Young and small plants do not require as much moisture as larger and older ones. The amount of water used each week of growth gradually increases until the maximum leaf area has been developed. This brings the maximum water requirement of corn when it is tasseling and earing. The requirement continues high for four or five weeks, then falls off rather rapidly until ripening takes place.

355. Best dates for planting corn.—Wherever the length of the growing season will allow for varying the date of planting, it is important to have the corn reach the tasseling and ear-forming period when a large amount of rain usually falls and when the temperature is relatively high. If the crop is irrigated, it should be given the maximum amount of water at this time. When the plant is tasseling, it has received practically all of its growth. It builds frame-work and constructs cells which will be filled with food matter later.

356. Measurements of water requirements vary, as investigators have used different methods of determination and under varied environments. Briggs and Shantz determined that corn requires an average of 368 pounds of water for every pound of dry matter produced. (See par. 201.) Taking into consideration the water lost by evaporation, it is calculated that the water requirement for each pound of dry matter, under average field conditions, will be at least 500 pounds.

357. The amount of dry matter in the stalks and leaves is about the same as in the grain. Hence 112 times 500 or 56,000 pounds (28 tons) of water will be required to produce each bushel of corn. A 50-bushel crop of corn then requires 1,400 tons of water. As one inch of water over an acre of ground weighs 113 tons, it will require theoretically 12.39 inches of rainfall to produce a crop of 50 bushels to the acre, on an average. The run-off is probably one-third of the rainfall in an average season, so that something like 18 inches of rain would be required for a 50-bushel crop.

358. Seasonal rainfall.—A study of rainfall charts shows that the actual rainfall from planting to harvesting of corn is greater than this in the southern states, but considerably less in the North.

359. Rainfall and the yield of corn.—Rainfall is the most important weather factor in varying the yield of corn in the corn-belt district of the United States. The critical period when rain is most essential is from the middle of July to the middle of August; the most important calendar month, however, is July.

360. July rainfall and corn yield.—Fig. 41 shows the relation between the rainfall for the month of July and the yield of corn over the states of Ohio, Indiana, Illinois, Iowa, Nebraska, Kansas, Missouri, and Kentucky for the twenty-eight years from 1888 to 1915, inclusive. The average rainfall over these states for July for twenty-eight years is 3.9 inches. The average yield of corn is 29.7 bushels to the acre. The lines show the variation of the rainfall and yield for each year from the mean for the whole period averaged for the eight states as a whole. For example, in 1889 the average rainfall was 1.0 inch above the normal and the yield of corn was three bushels to the acre above the normal or close to 32 bushels. In 1902 the rainfall was close to 5.0 inches and the yield averaged nearly 33 bushels or about 4 bushels to the acre above the normal.

361. The two curves agree.—The two curves run closely together most of the time, although there are some well-marked exceptions. This shows that while the rainfall in July is an important variant, it is not the controlling factor. The temperature must be considered, as well as the rainfall in August, and, to some extent in June. An inspection of the diagram shows that whenever the rainfall for July has been above the normal, the yield was above the normal in every instance, although in 1896 and 1915 the rainfall was evi-

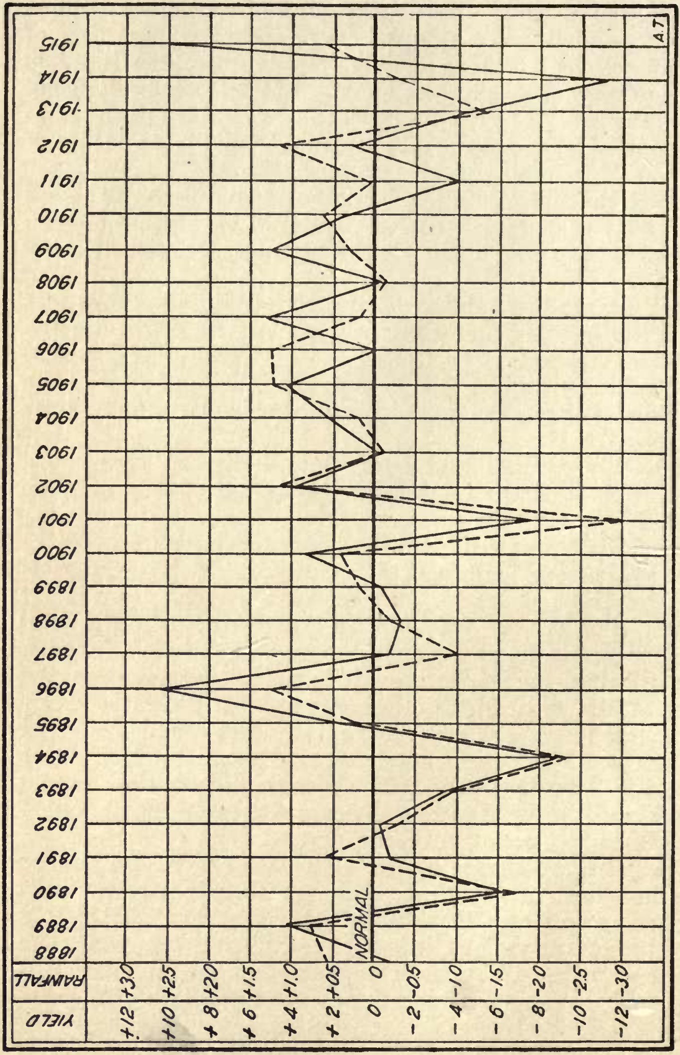

FIG. 41.—Relation between the rainfall for the month of July and the yield of corn in eight states, 1888–1915.

dently too great for the best yield. Whenever the rainfall was below the normal, the yield has been also below in every year except five and in two of these exceptions the rainfall was practically normal or only slightly below, and in one other the yield was just about normal.

362. July rainfall and corn yield averages.—If the years of different rainfall amounts are grouped together, it will be found that whenever the rainfall has been one-half inch or more above the normal, the yield of corn has averaged 10 bushels to the acre more than when the rainfall has been one-half inch or more below the normal. Taking into consideration the average acreage devoted to corn in these states and the average yield in bushels to the acre for the past ten years, it will be found that this average of 10 bushels to the acre means a definite increase in the corn crop over the eight states of something like 500,000,000 bushels, with this variation in rainfall. When corn is worth $1.00 a bushel, this increase in the corn yield will increase the purchasing power of the farms in the central part of the United States fully $500,000,000 through corn alone.

363. The four greatest corn states.—It is stated that, of the total acreage of corn in the United States, 30 per cent is grown in the four states of Indiana, Illinois, Iowa, and Missouri. Of the total amount shipped out of the county in which it is grown, 60 per cent is raised in these four states. The average yield of corn is 32 bushels to the acre, and the average rainfall for July is 3.9 inches. Fig 42 shows the relation between the rainfall over the four states for the month of July, as compared with the yield of corn in bushels to the acre, over the same area.

The years are shown at the top of the diagram and run from 1888 to 1915, inclusive. The lines show the variation of the rainfall and yield for each year, averaged for the four states as a whole, from the mean for the entire period. While the two curves are fairly uniform, there are some variations which show plainly that other weather factors besides the rainfall for the month of July must be taken into account in considering the effect of the weather on the yield of corn in these states.

364. Comparisons close.—However, when the rainfall has been above the normal, the yield has been above the normal in every year but two. This shows a probability of the yield

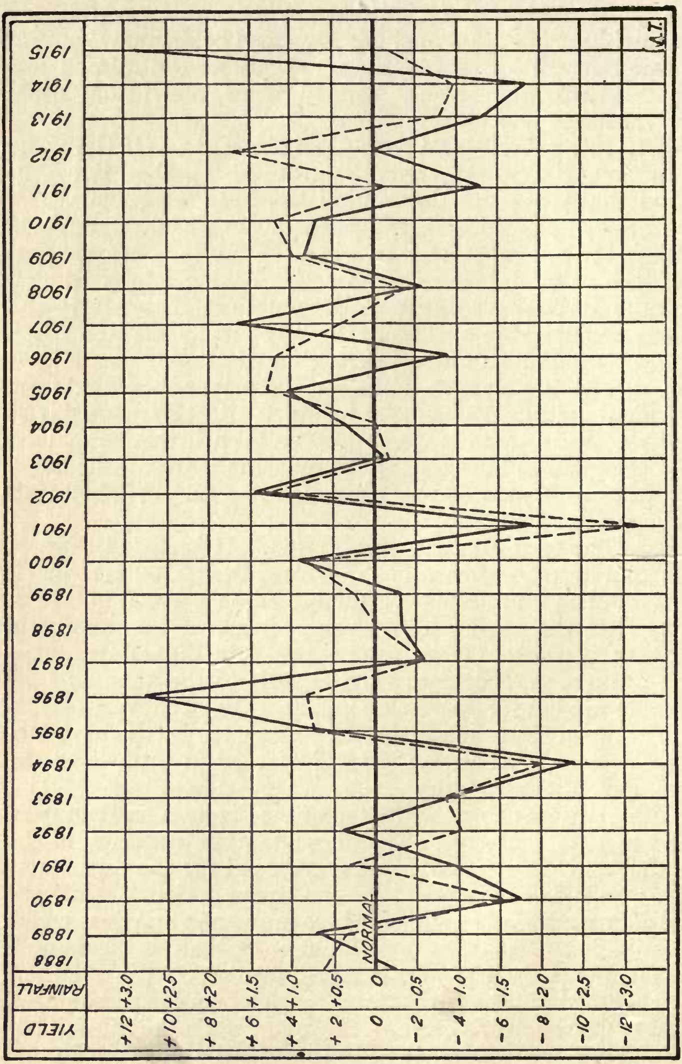

FIG. 42.—Relation between the July rainfall and the yield of corn in four states, 1888–1915.

Plate VI.—Oil heaters in a grape orchard.

of corn being above normal 85 per cent of the time when the rainfall in July is greater than the average. An inspection of the curves shows also that in only four of the years when the rainfall was below the normal was the yield greater than the average. This makes a probability of 73 per cent that the yield of corn will be below normal if the rainfall for the month of July is below the average.

365. Striking averages.—A complete analysis of the rainfall and yield data in these states shows that the average increase in the yield of corn with each increase of one-half inch in the rainfall in July amounts to 2 bushels to the acre, or a total increase in the corn yield of 60,000,000 bushels. When the rainfall for July in these four states has been between 2 and 2.5 inches, the yield of corn has averaged 23 bushels to the acre, and when the rainfall has been between 2.5 and 3 inches the yield has averaged 33 bushels to the acre. This is an increase of 10 bushels to the acre with an increase of only one-half inch of rain at the critical rainfall stage. This increase amounts to the enormous quantity of 300,000,000 bushels, worth something like $300,000,000. This also means an increase in the value of the corn crop of $10 an acre when corn is worth $1.00 a bushel.

366. Rainfall and temperature, and corn yield.—Fig. 43 shows by means of a dot chart the combined effect of the July rainfall and temperature on the yield of corn in Ohio during the period from 1854 to 1915, inclusive. In the chart, the heavy horizontal line represents the normal temperature for Ohio for the month of July, which is 74°. The figures at the left mark lines which represent the variation of the temperature above or below the normal as indicated by the prefixes plus or minus. The heavy perpendicular line indicates the normal rainfall for the state for July, and is close to 4 inches. At the top the figures indicate the variation of the rainfall above or below the normal. The plus and minus signs in the diagram indicate yields of corn above or below the normal, respectively.

The dot chart is made by placing a yield mark for any year at a spot on the chart where lines showing temperature and rainfall departures from the normal for that year will intersect if drawn across the chart; for example, in 1866 the temperature for July averaged 2° a day above the normal while the rainfall was one inch greater than the normal. The corn yield dot will therefore be placed at the intersection of the lines representing these values and as the yield for that year was greater than the average, the plus mark was placed at this point. The amount of the variation of the yield from the normal is not indicated.

If, in making a diagram of this kind, the plus and minus signs are scattered promiscuously over the chart, it will show that there is no relation between the weather conditions and the yield. If, however, there is a grouping of like signs on one side or in one quarter of the diagram, then a relation is shown.

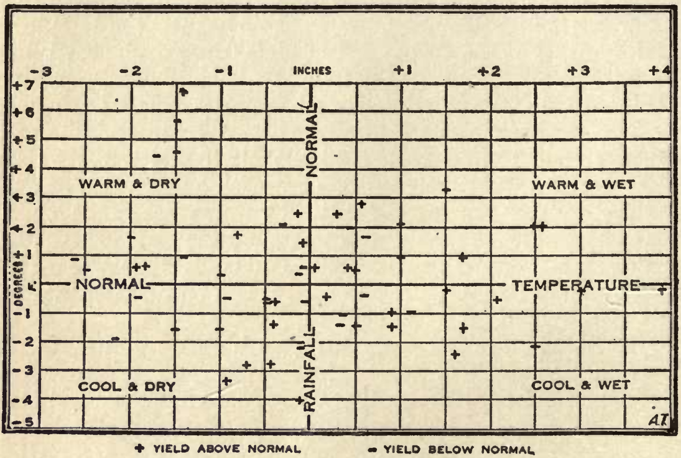

FIG. 43.—Effect of July rainfall and temperature on the yield of corn, Ohio, 1854–1915.

367. Wet weather important.—In this diagram, it will be seen clearly that there is a decided grouping of the plus marks to the right or on the "wet" side of the normal rainfall line, and of the signs to indicate the yield below the normal on the left or "dry" side of the rainfall normal. If only those years are considered when the rainfall departed one inch or more from the normal, it will be seen that when it was wet the corn yield was above the normal thirteen times, and below only once. This indicates that when the rainfall in

Ohio for July is one inch or more greater than the normal, the probability of a good corn crop is 93 per cent. On the other hand, when the rainfall was one inch less than the normal the yield was above the normal three times and below thirteen times. This indicates a probability of a good corn yield of only 19 per cent when the rainfall in July is 3 inches or less.

368. Rainfall and corn yield averages.—If all the years when the rainfall for July in Ohio has been less than 3 inches be grouped together, it will be found that the yield of corn averaged 30.3 bushels to the acre, and when the rainfall has been 5 inches or more the yield has averaged 38.1 bushels to the acre. This difference of 7.8 bushels an acre means a variation of 27,300,000 bushels of corn for the state, worth nearly $8 an acre or over $27,000,000, depending on whether the state has had an average rainfall of 3 inches or less in July or whether the fall has been 5 inches or more.

369. Temperature effect not so important.—The effect of a difference in the mean temperature in July in Ohio in varying the yield of corn is not so well marked, as is shown by the fact that there is an irregular grouping of the plus and minus signs above and below the normal temperature line in Fig. 43.

370. Combined rainfall and temperature effect.—The combined effect of these two weather factors is shown by the grouping of like signs in the different quadrants of Fig. 43. For example, in the upper right-hand quadrant, which would indicate a wet and warm July, there are eleven plus signs and only two minus signs. This indicates that when July in Ohio is warm and wet, the probability of the corn yield being greater than average is 85 per cent. When it is cool and wet, the probability of a good corn yield is 73 per cent. On the other hand, when July is cool and dry, the probability of a good corn yield is only 38 per cent, and when July is warm and dry it is only 33 per cent.

371. Average July rainfall and corn yields in Ohio.—In this state, with each increase of one-fourth inch in the rainfall in the month of July, the average increase in the yield of corn will be close to 1 bushel an acre; and between 2 and 4 inches the average increase in the yield with each increase of one-fourth inch in the rainfall will amount to 1½ bushels to the acre, the value of which will be almost $6,000,000. A further combination of the figures will give the results that each increase in the rainfall in July of one-half inch will cause an average increase in the corn yield in Ohio of 4,200,000 bushels, and when the rainfall in July passes the 3-inch mark the increase in the corn crop with an increase in the rainfall of only one-half inch will, on the average, amount to 15,050,000 bushels, valued at over $15,000,000 when corn is worth $1.00 a bushel.

372. Correlation for shorter periods than months.—The rainfall in the preceding correlations and discussions was for complete months, so the next step seems to be the tabulation of the rainfall into shorter periods to try and determine the exact time during which rainfall has its greatest effect on the corn yield. Therefore, the average yield of corn for the three counties of Franklin, Madison, and Pickaway, in central Ohio, has been calculated and the average rainfall for eighteen coöperative stations in and around these counties. The period covered was from 1891 to 1910, inclusive, and it is believed that a correlation with the averages obtained in this manner has a high degree of accuracy. The correlation was made for each ten, twenty, thirty, forty, and fifty days, as shown by the following tables:

TABLE 12.—RELATION BETWEEN RAINFALL AND YIELD OF CORN IN CENTRAL OHIO FOR 10-DAY PERIODS, 1891 TO 1910

Periods	*Correlation coefficient* r	*Probable error*
June 1 to 10	—0.09	———
June 11 to 20	+0.12	———
June 21 to 30	—0.04	———
July 1 to 10	+0.16	———
July 11 to 20	+0.36	±0.13
July 21 to 31	+0.36	±0.13
August 1 to 10	+0.52	±0.11
August 11 to 20	+0.29	±0.14
August 21 to 31	—0.06	———

373. August 1 to 10 most important.—This table seems to show plainly that the ten-day period from August 1 to 10 has the greatest influence on the yield of corn in central Ohio. The probable error for that correlation coefficient is ±0.11, which is fairly low.

TABLE 13.—RELATION BETWEEN RAINFALL AND YIELD OF CORN IN CENTRAL OHIO FOR 20-DAY PERIODS, 1891 TO 1910

Periods	*Correlation coefficient* r	*Probable error*
June 1 to 20	+0.03	———
June 11 to 30	−0.10	———
June 21 to July 10	+0.07	———
July 1 to 20	+0.36	±0.13
July 11 to 31	+0.41	±0.13
July 21 to August 10	+0.50	±0.11
August 1 to 20	+0.45	±0.11
August 11 to 31	+0.20	±0.15

The highest value of r in this table is +0.50 from July 21 to August 10, and this is about five times the probable error.

TABLE 14.—RELATION BETWEEN RAINFALL AND YIELD OF CORN IN CENTRAL OHIO FOR 30-DAY PERIODS, 1891 TO 1910

Periods	*Correlation coefficient* r	*Probable error*
June 1 to 30	−0.02	———
June 11 to July 10	+0.11	———
June 21 to July 20	+0.26	±0.14
July 1 to 31	+0.43	±0.13
July 11 to August 10	+0.49	±0.11
July 21 to August 20	+0.48	±0.11
August 1 to 31	+0.37	±0.13

374. Thirty days from July 11 to August 10 most important.—Here the greatest coefficient is for the period July 11 to August 10, when r is +0.49, and the probable error is ±0.11. These last three tables seem to show that the rainfall before July 10 does not have a very great effect in varying the yield of corn. Also that the variations in the rainfall after August 31 need not be taken very seriously into account. The tables show further that the correlation coefficient for the ten days of August 1 to 10 is higher than for any twenty- or thirty-day period, although the difference is slight.

TABLE 15.—RELATION BETWEEN RAINFALL AND THE YIELD OF CORN IN CENTRAL OHIO FOR 40-DAY PERIODS, 1891 TO 1910

Periods	*Correlation coefficient* r	*Probable error*
June 1 to July 10	+0.07	——
June 11 to July 20	+0.24	——
June 21 to July 31	+0.36	±0.13
July 1 to August 10	+0.53	±0.11
July 11 to August 20	+0.60	±0.10
July 21 to August 31	+0.52	±0.11

There seems little question in this table of the dominating influence of the rainfall during the period from July 11 to August 20. This correlation coefficient of +0.60 is six times the probable error.

TABLE 16.—RELATION BETWEEN RAINFALL AND THE YIELD OF CORN IN CENTRAL OHIO FOR 50-DAY PERIODS, 1891 TO 1910

Periods	*Correlation coefficient* r	*Probable error*
June 1 to July 20	+0.17	——
June 11 to July 31	+0.36	±0.13
June 21 to August 10	+0.49	±0.11
July 1 to August 20	+0.59	±0.10
July 11 to August 31	+0.55	±0.10

The correlation coefficient from July 1 to August 20 in this table is +0.59 and is slightly less than six times the probable error.

It is believed that the district covered by the yield and rainfall figures in Tables 11 to 16 makes them very reliable and that the values may be taken as a standard for this section of the country. Similar tables should be worked out for other districts, however, as the correlations might vary under different distribution of rainfall or different temperature and sunshine.

375. Weather effects during different periods of development.—After showing the relation between the corn yield and a single element, the rainfall, during certain definite periods, the question naturally arises as to what is the effect of all the elements, *i. e.*, the "weather," during different periods of development of the corn plant. This can be answered by a study of certain data that have been compiled at Wauseon, Fulton County, Ohio.

In Table 17 there have been entered certain important data relating to corn growth and development from 1883 to 1912 as taken from the records of Mikesell. As will be seen, they cover the dates planted, dates that plants appear above ground, dates in blossom, and the dates ripe, together with a statement of the quantity and quality of the crop, From 1883 to 1901 the dates are for operations on his own farm, and during the balance of the period for certain nearby fields, the same field being used for the entire season. The average dates and periods of development are given at the bottom of the table.

376. Thermal and rainfall constants at Wauseon, Ohio.—Thermal and rainfall constants have been worked out for the different stages of growth of corn at Wauseon, Ohio, for 1883 to 1912, and appear in Table 18. In addition, the amount of available heat and the rainfall for ten days before the date of planting was determined and appears in the table.

This table should be studied in connection with the data in Table 17 for the dates of planting, blossoming, and so on, and the number of days between these dates during different years.

377. The average date for planting corn is May 14, and the average number of days for the plants to appear above the ground is nine. Table 18 shows that the average total number of thermal constant degrees during this period has been 143°, and the average rainfall 1 inch. The average time from the date the plants appear above the ground until they are in blossom is sixty-two days, and the thermal constant averages 1,599°; the rainfall averages 7.4 inches. The average date when the corn is in blossom at Wauseon is July 25, although this date has varied between July 10 and August 6. The average date when the corn has ripened is September 13, or fifty days after the time of blossoming. The average thermal constant during this time is 1,337°, and the average rainfall 4.6 inches.

TABLE 17.—PHENOLOGICAL DATES AND DATA FOR GROWTH OF CORN AT WAUSEON, OHIO, 1883 TO 1912, BY THOMAS MIKESELL

(Lat., 41° 35′ N.; Long., 84° 07′ E.; alt. 780 ft., A. M. S. L.)

Year	*Date planted*	*Date above ground*	*Days from planting to above ground*	*Date in blossom*	*Days from above ground to blossoming*	*Date ripe*	*Days from blossom to ripe*	*Per cent of good crop*	*Quality of crop*
1883	May 12	May 25	13	July 29	65	Oct. 10	73	60	Poor
1884	16	24	8	24	61	Sept. 15	53	90	Good
1885	18	25	7	23	59	26	65	65	Fair
1886	11	19	8	17	59	15	60	85	Good
1887	20	25	5	24	60	15	53	60	Fair
1888	15	25	10	25	61	20	57	75	Fair
1889	15	23	8	Aug. 3	72	30	58	85	Good
1890	27	June 1	5	July 26	55	20	56	50	Fair
1891	12	May 22	10	27	66	18	53	60	Good
1892	June 18	June 23	5	Aug. 6	44	25	50	60	Fair
1893	May 18	May 28	10	July 25	58	12	49	60	Good
1894	1	10	9	17	68	Aug. 30	44	60	Fair
1895	1	7	6	22	76	Sept. 10	50	80	Good
1896	9	14	5	10	57	Aug. 30	51	100	Good
1897	22	June 5	14	20	45	Sept. 12	54	80	Good
1898	18	May 25	7	20	56	Aug. 31	42		
1899	18	27	9	17	51	30	44	90	Good
1900						Sept. 6			
1901	May 12	27	15	18	52	5	49		
1902 [1]						3			
1903									
1904	7	17	10	25	69	10	47	80	Good
1905	9	15	6	18	64	Aug. 30	43	75	Good
1906	10	16	6	17	62	Sept. 10	55	80	Good
1907	April 26	6	10	30	85	3	35	75	Good
1908	May 21	28	7	30	63	15	47	80	Good
1909	14	21	7	Aug. 6	77	25	50	80	Good
1910	11	21	10	1	72	30	60	90	Fair
1911	10	17	7	July 20	64	8	50	80	Fair
1912	10	20	10	22	63	2	42	95	Good
Aver.	May 14	May 23	9	July 25	62	Sept. 13	50	76	

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[1] Data for the years 1883 to 1901, inclusive, apply to Mikesell's own estate; data for 1902 to 1912 apply to certain nearby fields, the same field being used for the entire season.

Table 18.—Thermal Constants (Base 43° F.) and Rainfall During the Growth of Corn at Wauseon, Fulton Co., Ohio, 1883 to 1912

Year	*Thermal*						*Rainfall*						
	10 days before planting	*Planting to above ground*	*Above ground to blossoming*	*Blossoming to ripening*	*10 days before blossoming*	*10 days after blossoming*	*10 days before planting*	*Planting to above ground*	*Above ground to blossoming*	*Blossoming to ripening*	*5 days before to 5 days after blossoming*	*10 days before blossoming*	*10 days after blossoming*
	°F	*°F*	*°F*	*°F*	*°F*	*°F*	*In*	*In*	*In*	*In*	*In*	*In*	*In*
1883	139	141	1,583	1,264	270	290	0.6	2.7	13.7	6.1	0.7	3.7	0.0
1884	114	161	1,496	1,412	240	290	1.0	0.8	6.0	5.9	1.1	0.0	4.5
1885	114	147	1,520	1,432	330	340	0.1	1.6	6.6	8.4	1.8	0.2	2.6
1886	134	128	1,477	1,565	290	260	0.9	0.9	2.8	5.5	T	T	0.2
1887	205	131	1,693	1,371	350	330	0.1	1.4	8.4	1.9	1.0	1.0	0.0
1888	128	110	1,600	1,410	270	320	1.4	0.4	5.6	2.7	0.1	0.1	0.4
1889	250	143	1,649	1,239	250	240	1.3	0.4	15.3	2.3	1.0	1.6	0.9
1890	167	131	1,365	1,330	270	360	1.1	T	4.4	6.3	T	T	T
1891	103	148	1,568	1,366	260	250	0.4	0.6	6.6	4.0	0.4	0.4	0.4
1892	318	165	1,253	1,238	310	310	1.0	1.2	5.3	6.2	0.3	1.2	T
1893	140	163	1,634	1,411	300	300	1.0	0.3	8.4	1.4	0.4	1.0	0.4
1894	139	161	1,638	1,309	290	330	0.9	1.3	5.3	1.1	0.2	T	0.2
1895	157	175	1,919	1,428	250	270	T	1.2	2.3	3.8	0.7	0.2	0.5
1896	235	154	1,443	1,490	280	290	0.2	0.6	8.2	13.8	4.0	1.4	6.4
1897	153	186	1,232	1,486	290	320	1.0	1.2	5.4	3.5	1.0	1.7	1.3
1898	150	177	1,566	1,259	...	...	1.7	1.4	6.1	4.7	...	...	...
1899	169	154	1,478	1,344	290	320	1.4	1.2	4.7	2.3	2.8	2.2	1.2
1900	...	...	.....	.....	...	...	...	...	....	....	...	...	...
1901	151	201	1,468	1,546	...	...	0.8	1.8	8.3	2.2	...	...	...
1902	...	...	.....	.....	...	...	...	...	....	....	...	...	...
1903	...	...	.....	.....	...	...	...	...	....	....	...	...	...
1904	146	109	1,637	1,140	290	270	0.1	0.6	6.5	3.6	0.8	1.6	0.6
1905	142	97	1,526	1,210	290	270	0.8	3.3	10.2	2.9	0.1	0.1	0.2
1906	91	127	1,574	1,607	300	280	0.6	0.4	6.8	6.1	0.3	2.3	0.2
1907	–25	36	1,762	897	290	160	0.4	0.8	10.7	3.3	1.4	1.3	2.0
1908	213	199	1,735	1,229	300	300	2.6	0.4	9.6	3.4	0.0	2.1	0.2
1909	135	107	1,984	1,223	310	300	2.5	0.4	10.7	6.0	0.5	1.1	2.6
1910	78	114	1,811	1,453	290	260	1.0	0.7	6.6	6.9	0.1	3.4	T
1911	125	166	1,913	1,322	290	230	0.1	T	10.2	5.0	1.1	1.0	0.8
1912	168	123	1,645	1,107	300	270	0.8	2.2	5.3	5.1	0.6	0.8	0.8
Means	150	143	1,599	1,337	296	286	0.9	1.0	7.4	4.6	0.8	1.1	1.1

Table 18 also gives the thermal and rainfall constants for ten days before blossoming and for ten days after blossoming, as well as the rainfall during the ten-day period from five days before to five days after blossoming.

378. Thermal constants and corn yield, Wauseon, Ohio.—In Table 19, the correlation coefficient has been given between the thermal constants during different periods of corn development and the percentage of a good crop, as reported by Mikesell. It is unfortunate that we do not have the yield of corn in bushels to the acre, yet believe that the percentage figures have been carefully considered by the observer.

TABLE 19.—RESULTS OF CORRELATION BETWEEN THERMAL CONSTANTS AND CORN YIELD, WAUSEON, OHIO, 1883 TO 1912

Periods	*Correlation coefficient* r	*Probable error*
(1) For 10 days before planting	−0.03	——
(2) From date of planting to date above ground	−0.03	——
(3) From date above ground to date of blossoming	+0.18	±0.12
(4) From date of blossoming to date ripe	+0.08	——
(5) Daily mean temperature for 10 days before blossoming	−0.003	——
(6) Daily mean temperature for 10 days after blossoming	−0.28	±0.10

There is a slight positive relation between the temperature from the date when the corn appears above the ground and the date of blossoming and the yield of corn, as well as a negative relation between the temperature for ten days after blossoming and the yield, but these correlation coefficients are all too low to be given any consideration. This table seems to show that there is little or no relation between the daily mean temperature and the yield of corn.

379. Rainfall constants and corn yield, Wauseon, Ohio.—In Table 20 the correlation coefficients between the yield of corn and the rainfall during the different periods of growth are shown.

TABLE 20.—RESULTS OF CORRELATION BETWEEN RAINFALL AND CORN YIELD, WAUSEON, OHIO, 1883 TO 1912

Correlation factors	*Correlation coefficient* r	*Probable error*
(1) For 10 days before planting	+0.01	——
(2) From date of planting to date above ground	—0.06	——
(3) From date above ground to date of blossoming	—0.03	——
(4) From date of blossoming to date ripe	+0.29	±0.11
(5) From 5 days before blossoming to 5 days after blossoming	+0.45	±0.10
(6) For 10 days before blossoming	+0.20	——
(7) For 10 days after blossoming	+0.74	±0.05
(8) For 20 days after blossoming	+0.57	±0.08
(9) For 30 days after blossoming	+0.46	±0.09

The results from this table are very important. It seems to make plain that there is no relation between the variations in rainfall in the first part of the period of growth of the corn crop and the variations in the yield. The average date of blossoming as determined in Table 17, is July 25, or sixty-two days after the plants appear above the ground and seventy-one days after planting. The correlation coefficient for the first three items in Table 20 is much too near zero to receive consideration. The correlation coefficient in item 4 indicating the effect of the rainfall between the dates of blossoming and ripening is +0.29, but as this is only two and one-half times the probable error, even this is not very close.

380. Rainfall near the blossoming time important.—The value of the coefficient for the rainfall for ten days before the date of blossoming as stated in item 6 is also too low to be given serious consideration. In item 5, however, covering the time from five days before blossoming to five days after blossoming, the correlation coefficient is four times the probable error and a relation is apparently established.

It is in item 7, however, that there is the highest correlation coefficient. This shows that the rainfall for the ten days after blossoming has the greatest effect on the yield of corn of any period in the development of the plant. This value is +0.74, and it is fifteen times the probable error. This coefficient is considerably higher than even that for the twenty or thirty days following the date of blossoming. In Tables 12 and 16, there were given the correlation coefficients for the rainfall for the state of Ohio as a whole, compared with the yield of corn, for arbitrary ten-, twenty-, and thirty-day periods. All near the average date of blossoming gave high values. These facts combined with the high value in item 7 of Table 20 go to show that the rainfall immediately after blossoming has a very dominating effect on the yield of corn.

381. Combined effect of rainfall and temperature.—Item 7 in Table 20 indicates a direct relation between the rainfall for ten days after blossoming and the yield of corn, and item 6 in Table 19 seems to show an opposite effect of the temperature on the yield during the same period.

382. Effective rainfalls.—It is well known that small rainfalls during a drought may actually do more harm to a crop than good, because by merely wetting the surface of the ground an effective dust mulch may be destroyed and thus more water be lost to the crop by evaporation than has been gained by the shower. Or numerous light showers during the early growth of the corn, by merely wetting the surface may cause the plants to root near the surface where the soil will quickly dry out in later dry spells. In investigations of accumulative effects of weather, it was found that when July was quite dry the final yield was greater if the previous June was moderately dry also. The rate of growth and development of corn plants have been determined with certain definite amounts of water in the laboratory. But to try to answer the often repeated question as to just what rainfall amounts are actually beneficial or are most beneficial to the growing corn, the following plan has been adopted: The rainfall for a definite district and period is multiplied by the total number of days with a certain amount of rain, and divided by the whole number of days in the period. The equation is simple; $\frac{ab}{c}$, where a is the total rainfall for the period, b the number of days with 0.10 inch, 0.20, 0.30 inch, and so on, rainfall or more, and c the total number of days in the period.

In Table 21 the effective rainfall was determined by taking the rainfall at Columbus, Ohio, for the fifty-one day period from June twenty-one to August ten for twenty years, working out new factors in accordance with the formula as above, and correlating these new factors with the yield of corn in Franklin County, Ohio.

This method shows whether a certain amount of rain is as effective coming in many small showers, as it is in a few heavy showers and it is accomplished by eliminating consideration of days with rainfalls below 0.25 inch.

The general rule has been stated that for equal quantities of rain its value to agriculture increases as the number of rainy days diminishes, and on the other hand diminishes as the number of rainy days increases. This can be true, however, only up to a certain point.

TABLE 21.—CORRELATION TABLE FOR DETERMINING THE MOST EFFECTIVE RAINFALL IN THE YIELD OF CORN IN COLUMBUS AND FRANKLIN COUNTY, OHIO

Correlation factor	*Correlation coefficient* r	*Probable error*
Rainfall for July and yield of corn	+0.48	±0.11
Rainfall, June 21 to August 10, and yield of corn	+0.60	±0.10
Factor determined for the amounts given below as per formula and the yield of corn		
Days with 0.01″ or more	+0.61	±0.10
“ “ 0.10″ “ “	+0.61	±0.10
“ “ 0.20″ “ “	+0.61	±0.10
“ “ 0.25″ “ “	+0.64	±0.09
“ “ 0.30″ “ “	+0.59	±0.10
“ “ 0.40″ “ “	+0.61	±0.10
“ “ 0.50″ “ “	+0.70	±0.08
“ “ 0.60″ “ “	+0.55	±0.10
“ “ 0.70″ “ “	+0.56	±0.10
“ “ 0.75″ “ “	+0.57	±0.10
“ “ 0.80″ “ “	+0.38	±0.13
“ “ 0.90″ “ “	+0.59	±0.10
“ “ 1.00″ “ “	+0.41	±0.12

383. Rainfalls of 0.50 inch or more most effective.—This table indicates that rainfalls of 0.50 inch or more are the most effective in determining the yield. For fear that the results might be affected by taking the rainfall at only one station, similar correlations have been calculated for the yields in Franklin, Madison, and Pickaway counties, in central Ohio, and for the rainfall at all of the stations in and around those counties, eighteen in all, for the period from July 21 to August 10. The results follow in Table 22.

TABLE 22.—RESULTS FROM CORRELATIONS FOR MOST EFFECTIVE RAINFALLS, CENTRAL OHIO, 1891 TO 1910

Rainfall factors	*Correlation coefficient* r	*Probable error*
Rainfall, July 21 to August 10, and corn yield	+0.50	±0.11
Factor determined for the amounts below as per formula and the yield of corn		
Days with 0.01″ or more	+0.44	±0.12
“ “ 0.10″ “ “	+0.51	±0.11
“ “ 0.20″ “ “	+0.43	±0.13
“ “ 0.25″ “ “	+0.49	±0.11
“ “ 0.30″ “ “	+0.50	±0.11
“ “ 0.40″ “ “	+0.47	±0.11
“ “ 0.50″ “ “	+0.64	±0.09

The differences in the correlation coefficients for the lower rainfall amounts are not great and could be purely accidental. But the higher value of r for 0.50 inch or more corresponds to that determined in Table 21 and seems to show that one-half inch of rain is more beneficial than lesser amounts.

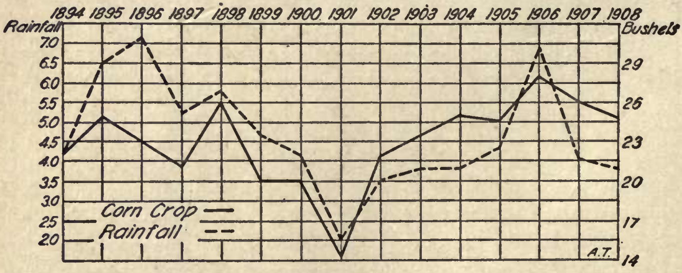


FIG. 44.—Relation between the July rainfall and the yield of corn in Tennessee, 1894–1908.

384. Rainfall and corn in Tennessee.—Fig. 44 illustrates the relation between the rainfall for July and the yield ot corn in Tennessee. In this state the corn tassels in July and is favorably affected by an abundance of rain as in other sections.

385. The accumulated effect of the weather on the condition of corn in Iowa and Missouri in 1917 is shown in Fig. 45. The spring and early summer of 1917 were cold and wet, but on July 1 the condition of the crop as reported by the Bureau of Crop Estimates of the Department of Agriculture was not far from the ten-year average in all of the principal corn-growing states. Dry and warm weather the latter part of June and most of July lowered the prospect in the western Plains region, but in Iowa and Missouri, although drier than normal, the lack of moisture was not sufficient to lower the condition.

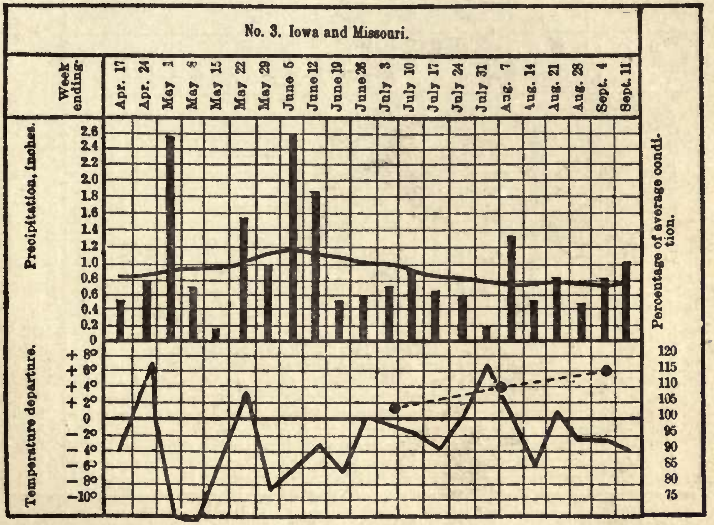


FIG. 45.—Diagram showing the effect of the weather on the condition of corn in Iowa and Missouri in 1917.

386. Weather and corn, 1918.—Fig. 46 shows that warm and wet weather in May and the first of June, 1918, was favorable for corn in Missouri and the condition was well above the ten-year average the first of July. From the week beginning July 3 until about the middle of August, however, the precipitation was constantly deficient in Missouri, four of the weeks being practically without rain. As a result, together with the high temperature in August, there was a marked deterioration in the condition of corn through July and August in this state.

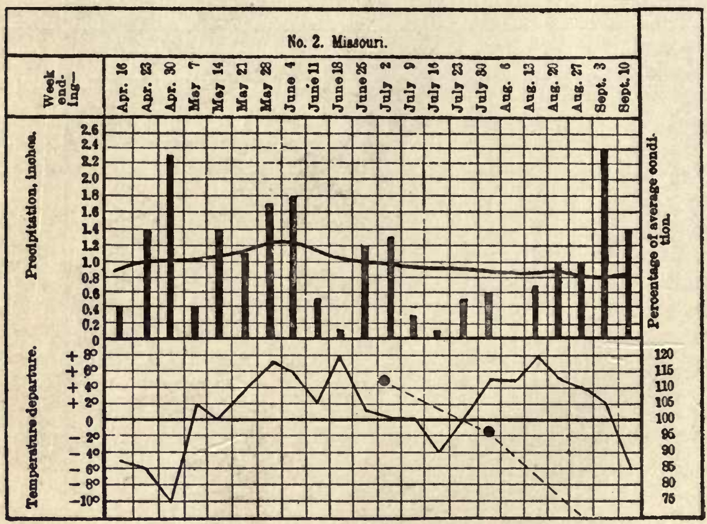


FIG. 46.—Diagram showing the effect of the weather on the condition of corn in Missouri in 1918. The condition of corn on the first of each month, as compared with a ten-year average, expressed in percentages, is indicated by the dots which are connected by broken lines. The significance of the temperature and rainfall values is explained under Fig. 34.

387. Spring frosts and corn.—Early planted corn makes a slow growth and hence is not so susceptible to frost damage as that planted later and which may be growing more rapidly when a late frost occurs. Very young corn may be cut by frost without serious injury to the plants.

388. Fall frost damage.—Frost in the fall is seldom early enough or covers sufficient territory to cause widespread loss of the corn crop. Even if some fodder is frosted, a light or moderate frost may cause more rapid ripening.

389. Frost in 1917.—In 1917, however, a cold late spring and generally cool summer was followed by unusual and severe frosts, the first early in September. As a result, no corn fully matured in northern North Dakota, Minnesota, and Wisconsin, and less than 50 per cent as far south as northern Ohio, Indiana, and Illinois, and in northeastern Iowa. In an average year, 90 per cent or more matures in the southern part of this area, and 50 to 75 per cent in that part of the district where none matured in 1917.

390. Freezing injury to seed corn.—The germ of a sound kernel of corn is an embryonic living plant with stalk, leaves, and root. When this living germ contains a large amount of moisture, some physical or chemical change is brought about by freezing which results in death. Corn containing 10 to 14 per cent of moisture will not be injured by any amount of winter cold, but when it contains 60 per cent it may be killed by a prolonged exposure to a temperature but slightly below freezing. In fact, a very close relation exists between the moisture-content of the kernel and the degree of cold required to kill the germ.

391. Damage to seed corn in 1917.—Some of the corn that was seemingly mature in 1917 was so full of moisture that while it showed a fairly high germination in the early winter, it was so injured by very cold weather later that the germination was greatly reduced.

392. Short periods of drought and pollination.—Corn has two kinds of flowers situated some distance apart and in a normal season these will both appear at the proper time for fertilization.

Drought, however, often hastens the shedding of the pollen, but delays the appearance of the silk. In this case, the pollen is wasted before the silk appears, proper fertilization is prevented, and no amount of rain later can produce a good crop. Cold and wet weather retards or even prevents shedding of the pollen.

393. Temperature and growth.—Corn makes most of its growth during the season of highest temperature, and this growth is retarded by cool weather or cold nights. It requires its greatest moisture in the summer when droughts are liable to occur, and when rainfall is less effective on account of the greater evaporation due to high temperatures.

394. Drought and transpiration.—The maximum transpiration in corn is during the warmest part of the day. On days of extreme temperature in very dry spells, there may be an atmospheric demand of ten pounds of water from a single average corn plant during twenty-four hours, the greater part in the seven hours in the middle of the day. Such days are very critical for corn if there is not a sufficient amount of moisture in the soil to meet this demand. It is evident that a drought during a brief period may affect the yield more than can be overcome by abundant rains at other stages of its growth.

395. Rate of seeding.—When the hills of corn are 3½ feet apart, there will be a stand of 10,668 stalks to the acre if an average of three kernels to the hill germinate and grow, or 14,224 to the acre if four kernels grow in each hill. In field practice, it has been found that from 3,630 to 7,260 stalks to the acre are all that can be properly supplied with the moisture that is available in the average year. It is stated that the great corn crop raised in South Carolina a few years ago was planted at the rate of 30,000 stalks to the acre, and happened to receive an abundant rainfall just at the right period of its growth.

396. Weather and corn in the South Temperate zone.—The following extracts from the "Agricultural Gazette" of New South Wales, Vol. XXVI, are of decided interest as they substantiate the results of studies in the North Temperate zone:

> It is well known that there is a critical stage in the growth of maize called the "cobbing stage," during which absence of sufficient moisture has a marked effect on yield. It has been determined by considerable observation and by statistics that the yield of a maize crop is almost directly proportional to the amount of rain received by the crop for the three or four weeks following flowering, other factors, of course, being equal.
>
> Hot, blasting winds during flowering are known to have very injurious effects on fertilization, either scorching up the pollen so that it will not germinate, or drying out the silks to such an extent that they have not sufficient moisture to germinate the pollen grains. To avoid damage by these winds, it has been found advisable in maize growing

for grain on the Murrumbidgee Irrigation Area to plant early varieties, either early in September or late in December, so that these crops do not tassel during the hotter months of the year—December to February, inclusive.

When the flowering period extends regularly over some weeks, it is possible that the crop possesses an adaptability that will enable it to weather through a few days' scorching winds more successfully than if the flowering period is limited to a few days, as is the case with some varieties.

The value of sunlight is so well known that it calls for little comment. Many maize growers have recently been allowing greater width between the rows, and many have a fancy for running the drills in a north and south direction, so that the maximum amount of sunshine reaches the plants. It is sufficient here to say that if enough sunlight does not reach the plants at the flowering stage, the size of the cobs and also their fertilization generally suffers. This is particularly observed to be the case in a thick stand in a very cloudy season.

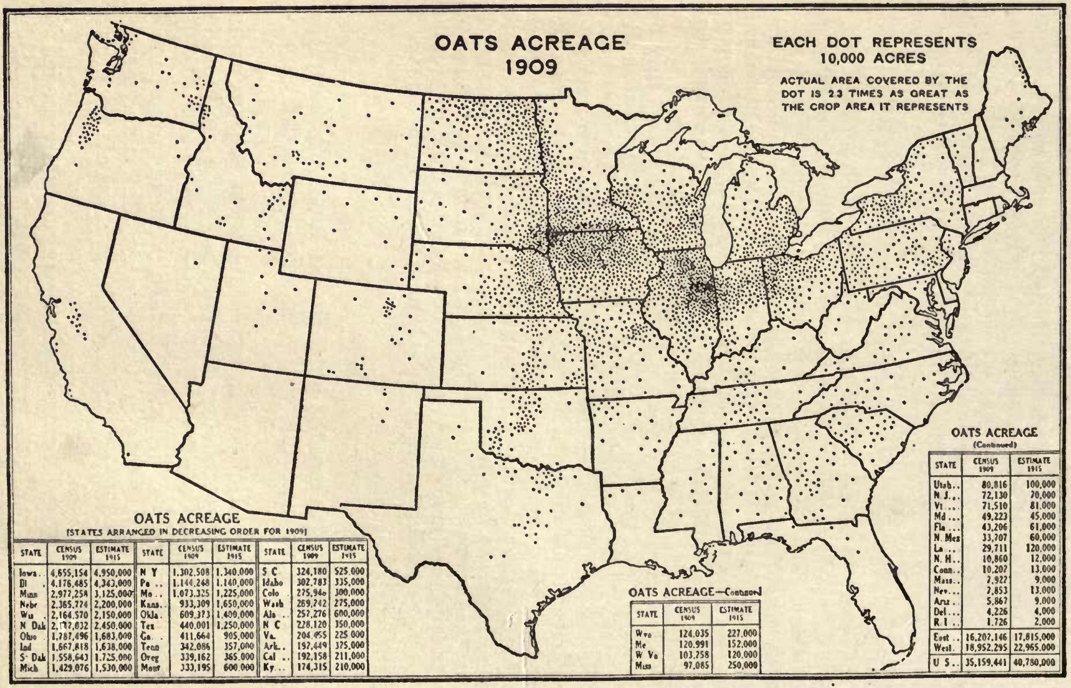
It has been stated by some writers on maize that a crop may be "starved for rain" during the early growth, and yet yield excellently if it gets sufficient rain during the late growth. It is admitted that one of the worst things that can happen to the maize crop is for it to get plenty of rain during the early stage and a dry time during the later stage, but there is no doubt that the best crops are produced when there is a sufficiency of rain throughout the growing period, although it is preferable to have a dry period during the early half of growth rather than during the later half. In fact, some farmers go so far as to say that it does a crop good to get a set-back during the early growth, and it may be said that this is desirable when the later growing period is unfavorable.

OATS

The oat plant is most at home in cool moist climates; it is one of the most important grain crops in the North Temperate zone.

397. Range in United States.—Oats are widely grown in this country, but about four-fifths of the crop is produced in an area from western New York westward along the lower Lakes to the central Missouri Valley. The centers of most intensive cultivation are in northeastern Illinois and northwestern Iowa, as is shown by Fig. 47. Spring oats are grown in this district.

398. Seeding and harvesting.—Spring oats are seeded in the late winter and very early spring, when the mean daily rise in temperature reaches 43° on an average. The crop is



OATS ACREAGE

[STATES ARRANGED IN DECREASING ORDER FOR 1909]

STATE	CENSUS 1909	ESTIMATE 1915	STATE	CENSUS 1909	ESTIMATE 1915	STATE	CENSUS 1909	ESTIMATE 1915
Iowa..	4,655,154	4,950,000	N Y	1,302,508	1,340,000	S C	324,180	525,000
Ill .	4,176,485	4,343,000	Pa ..	1,144,248	1,140,000	Idaho	302,783	335,000
Minn	2,977,258	3,125,000	Mo ..	1,073,325	1,225,000	Colo .	275,946	300,000
Nebr	2,365,774	2,200,000	Kans..	933,309	1,650,000	Wash	269,242	275,000
Wis .	2,164,570	2,150,000	Okla .	609,373	1,400,000	Ala ..	257,276	600,000
N Dak	2,177,032	2,450,000	Tex	440,001	1,250,000	N C	228,120	350,000
Ohio .	1,787,496	1,683,000	Ga. .	411,664	905,000	Va.	204,455	225,000
Ind	1,667,818	1,638,000	Tenn	342,086	357,000	Ark..	192,449	375,000
S. Dak	1,558,643	1,725,000	Oreg	339,162	365,000	Cal ..	192,158	211,000
Mich	1,429,076	1,530,000	Mont	333,195	600,000	Ky...	174,315	210,000

OATS ACREAGE—Continued

STATE	CENSUS 1909	ESTIMATE 1915
Wyo	124,035	227,000
Me	120,991	152,000
W Va	103,258	120,000
Miss	97,085	250,000

OATS ACREAGE
(Continued)

STATE	CENSUS 1909	ESTIMATE 1915
Utah..	80,816	100,000
N J...	72,130	70,000
Vt....	71,510	81,000
Md ...	49,223	45,000
Fla ...	43,206	61,000
N. Mex	33,707	60,000
La ..	29,711	120,000
N. H..	10,860	12,000
Conn..	10,202	13,000
Mass..	7,922	9,000
Nev...	7,853	13,000
Ariz ..	5,867	9,000
Del ...	4,226	4,000
R I ..	1,726	2,000
East ..	16,207,146	17,815,000
West.	18,952,295	22,965,000
U S ..	35,159,441	40,780,000

FIG. 47.—Where oats are grown in the United States.

harvested in the early summer in the south-central and midsummer in the northern states. The period between planting and harvesting winter oats is about 210 days. The average growing period for spring oats is close to 110 days in the northern part of the country and 120 days in the southern part.

399. Winter oats.—In the Gulf and south Atlantic states winter oats are best adapted and the crop is seeded in the fall and harvested in the late spring. The region of winter-oat production in the United States is bounded on the north, approximately, by the winter mean isotherm of 35°, which extends broadly from Virginia and Kentucky westward across southern Missouri and central Oklahoma and then southward to the Gulf. Winter oats are less hardy than winter wheat. Fall-sown oats usually grow more vigorously and mature from ten days to two weeks earlier than those sown in the spring. They yield less than spring oats.

400. Weather and oats in Portage County, Ohio.—This county is in northeastern Ohio and produces a large acreage of oats. The following table shows the correlation between the temperature and rainfall and the yield of oats covering a period of fifty-three years.

TABLE 23.—CORRELATION BETWEEN TEMPERATURE AND RAINFALL AND YIELD OF OATS IN PORTAGE COUNTY, OHIO, 1860 TO 1913

Month	*Rainfall*		*Temperature*	
	Correlation coefficient	*Probable error*	*Correlation coefficient*	*Probable error*
April	−0.12	———	+0.26	±0.08
May	−0.14	———	+0.04	———
June	+0.25	±0.08	−0.30	±0.08
July	+0.39	±0.07	−0.04	———

While none of these correlations is very high, yet they show plainly that a warm April and a cool and wet June are the conditions most favorable for oats. Oats seeding becomes general in that region between April 11 and 21 and harvest begins during the last decade in July. A more detailed study of the data shows that a dry and warm April is decidedly favorable for oats in this county, while June should be cool and wet for the best results. When June is warm and dry, the yield will be below the normal nearly 80 per cent of the time.

As oats are seeded in April in this region, it indicates that dry and warm weather produces conditions for a good seedbed and for the work of planting, while a cool wet April apparently makes conditions unfavorable for planting.

401. In Wood County, Ohio.—A similar study of weather and the yield of oats in Wood County in northwestern Ohio covering a period of twenty years gave no decided correlation for any single month. It showed, however, that when the average temperature for April and May, combined, was higher than normal the yield was above normal with two exceptions, one quite marked.

402. For the state of Ohio.—As oats are grown largely in the northern part of the state, a correlation of the yield with temperature and rainfall for the state as a whole, should not be expected to give high coefficients. The highest coefficients found, however, are for a cool June, while a wet June and July are the most favorable for the crop.

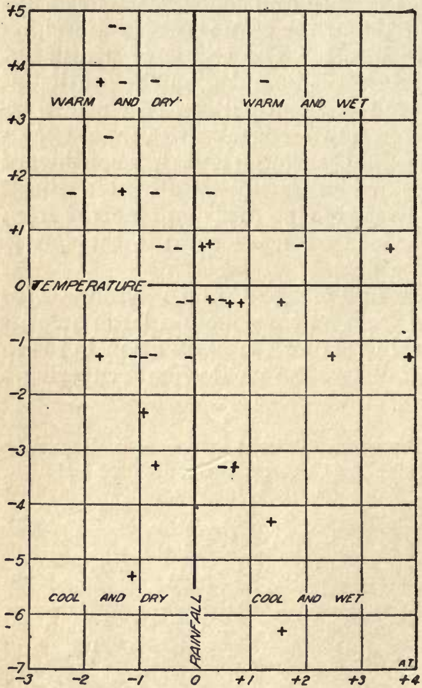


FIG. 48.—Effect of the rainfall and temperature in June on the yield of oats in Illinois, 1878–1915.

403. In Indiana.—A moderately wet May is favorable for oats in Indiana. In thirty-two years the rainfall in May for that state averaged above the normal eighteen times and below the normal fourteen times. In the eighteen years with a wet May the oat yield was above the normal twelve times and below the normal six times. In the fourteen years with a deficient rain, the yield of oats was less than normal twelve times and above only twice. Cool weather is desirable in June in this state for the best yield of oats.

404. Illinois, 1878 to 1915.—June is also the most important month in this state in the effect of weather on the yield of oats. Fig. 48 shows that cool and wet Junes have been followed by yields above the normal 82 per cent of the time, while dry and warm Junes have been followed by good yields only 18 per cent. None of the other months shows a marked relation.

405. Iowa.—April is an important "weather" month for oats in Iowa. During the period from 1890 to 1915 when April was warm and dry, the yield of oats was above the normal 73 per cent of the time and when the month was cool and wet the yield was below the normal 71 per cent. As seeding becomes general in this state in the first part of April, this indicates the importance of a good seed-bed. There is some evidence that the temperature in June and July should be slightly below the normal for the best yield of oats in Iowa.

406. Maryland.—Seed formation of spring oats is prevented in southeastern Maryland if there is hot humid weather at heading time.

407. North Dakota, 1892-1915.—Oats are seeded in North Dakota generally later than about the middle of April and are not harvested until August. This later season of crop development makes the critical period for oats extend into July although June is an important month. During the period from 1892 to 1915 whenever June was warm and dry, the yield of oats was below the normal in every instance and when cool and wet the yield was above the normal 90 per cent of the time.

The yield of oats in bushels per acre is lower in North Dakota than in the upper Mississippi valley and Lake region because of the lighter rainfall and the later critical period of growth. Hot weather in July may cause blighting and rust development.

408. Wisconsin.—The following shows the correlation between the weather and the yield of oats in Wisconsin for the period from 1891 to 1917:

TABLE 24.—CORRELATION BETWEEN TEMPERATURE AND RAINFALL AND YIELD OF OATS IN WISCONSIN, 1891 to 1917

Month	*Rainfall*		*Temperature*	
	Correlation coefficient	*Probable error*	*Correlation coefficient*	*Probable error*
April	−0.31	±0.12	+0.39	±0.11
May	+0.23	±0.12	+0.004	———
June	+0.12	———	−0.47	±0.10

409. Critical period for oats.—Notwithstanding the fact that oats are a cool weather crop and that spring oats should be seeded as early as practicable, the facts given above show that the temperature should be above the normal for the season and locality and the precipitation below the normal to produce the best conditions for seeding and the germination of the grain.

While the heads are forming, however, and the grain being developed, the crop must have cool and moderately wet weather to produce the best yields. Cool weather favors the ripening of the grain, while the crop is often materially reduced by a few hot days when it is near maturity.

410. Weather and oats in Russia.—Brounoff found that the critical period of oats in respect to moisture is within the ten-day period before heading. Oats were seeded in his investigations early in April, headed the last of June, and were harvested the last of July. An abundance of moisture was found necessary in June when the plants "are ready to develop a great number of new important vegetative organs."

He found further that cold weather and morning frosts from the time of seeding up to the appearance of tillers were not seriously damaging, but contribute to the formation of strong and thick roots. After tillering, however, frosts were very injurious. He states that hot days with mean daily temperatures above 75° and with maximum temperatures above 86° between the "earing" and milk stage endangered the yield of oats, especially if there were a number of such days in succession. A similar temperature after the milk stage may cause a falling out of the grains.

411. In England.—The following is quoted from R. H. Hooker and agrees with the results obtained in the United States:

Oats are similar to barley inasmuch as they urgently require a cool summer; the partial coefficients between oats and temperature being almost identical with those of barley in the 17th–36th weeks. But they differ from barley in requiring rain in the spring; in fact for the spring (season) the coefficient with rainfall (+0.70) is just above the summer coefficient with temperature (−0.69). Before harvest (25th to 32nd week), however, they would seem to like dry weather. There are some suggestive negative coefficients with rainfall during autumn. Can they mean that seed does not keep well during a damp autumn? The coefficients with the preceding summer all seem insignificant.

Comparing the three cereals, it is noteworthy that with barley and oats spring and summer are of preponderating importance, seed-time being relatively unimportant: with wheat, on the other hand, there are several different periods which may materially affect the crop, the seed-time being the most influential.

RICE

Rice is a tropical cereal and thrives best in regions of great heat, heavy rainfall, and high humidity; but can be successfully grown in the warmer parts of the temperate zone. Fully 93 per cent of the world's production is raised in southern and eastern Asia and the nearby islands.

412. Rice districts in the United States.—The most important rice-growing district in the United States is in southern Louisiana and southeastern Texas, but other locations where the crop is cultivated to a considerable extent are in north-central California, eastern Arkansas and in the coast counties of South Carolina and Georgia.

413. Temperature and rice.—The great part of the crop is cultivated where the mean summer temperature is over 75° to 77°, although certain varieties are grown in Japan where the average is not over 70°. The maximum temperature limits are unknown, but the minimum limits are of great importance. At temperatures lower than 46° to 50°, the tender leaves are partially arrested in growth and the greener parts of the stem turn yellow. The maximum rate of growth corresponds to the highest minimum temperature and where there is a lowering of the minimum below the critical point there is a decrease in all its functional activities. It requires a growing season of at least 135 days.

414. Water requirement.—The largest rice regions have an annual rainfall of 50 inches, and a rainfall of 5 inches a month during the growing season. Irrigation is necessary in the United States. In the Atlantic Coast districts the fields are flooded as soon as the seed is planted to cause sprouting; this is called the "sprout" flood. The water remains from 6 to 12 inches deep over the fields until the small white sprouts show through the hulls. The fields are then drained to prevent rotting. A little later the second flooding called the "point" or "stretch" flood is given. After the plants are about 6 inches tall, the water level is lowered to about 4 inches deep and it is held at this depth from fifteen to thirty days. The average length of the irrigation season in the Mississippi Valley and Texas is about eighty-six days.

RYE

Rye is adapted to a wide range of climate, but by nature it is a plant of high latitudes and cool climates. Fully 99 per cent of the crop in the United States is fall-sown.

415. Range in the United States.—The bulk of the present rye production in the United States is from New Jersey and New York westward to North Dakota. The northern limit follows rather closely the mean winter temperature line of 15° in Wisconsin and Michigan, but in northwestern Minnesota it is grown where the mean winter temperature is about zero and a temperature of 40° below zero is occasionally reached.

416. Weather and rye.—Rye may be sown later in the fall than wheat, as it will germinate more quickly and at a lower temperature. It will germinate and grow with a temperature but little above freezing, when wheat would be practically at a standstill. Rye in the milk is not damaged by light frosts.

417. Rye in Wisconsin.—A correlation of weather with the yield of rye in Wisconsin for the period from 1891 to 1917 shows the following:

TABLE 25.—CORRELATIONS BETWEEN TEMPERATURE AND RAINFALL AND YIELD OF RYE IN WISCONSIN, 1891 TO 1917

Month	*Rainfall*		*Temperature*	
	Correlation coefficient	*Probable error*	*Correlation coefficient*	*Probable error*
April	−0.40	±0.11	+0.14	———
May	+0.29	±0.12	−0.11	———
June	−0.14	———	−0.43	±0.11

This indicates that dry weather in April and cool weather in June are the important factors in the growth of rye in Wisconsin.

Experiments in Russia showed that for the best development rye needs abundant moisture and heat before the formation of the heads; cool and damp weather during the formation of the heads; moderate temperature and dry weather during blooming as it does not fill well if it rains while in bloom, and moist and warm weather during the ripening period.

GRAIN SORGHUMS

Grain sorghums are of tropical origin and are at home in regions with a rather dry, hot, and sunshiny climate. They are able either to resist or escape drought damage by their ability to suspend growth during periods of protracted drought without being destroyed, recovering and making good growth and fair yield when rain comes. Broom-corn is most profitable where there is but little rain at the time of harvest as otherwise the heads are apt to be discolored.

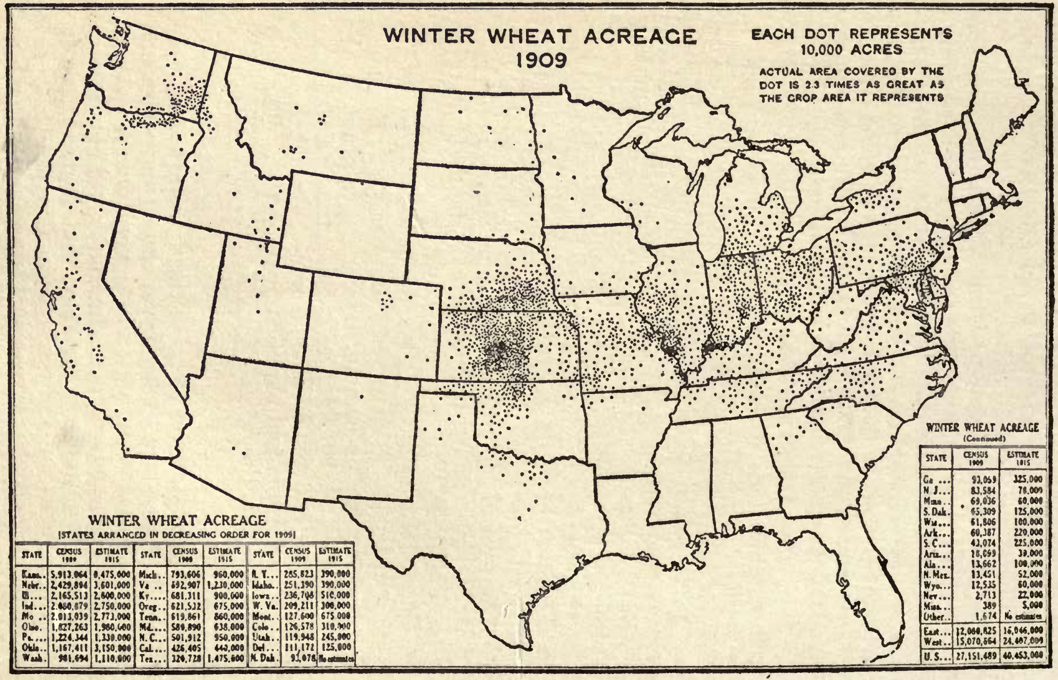
418. Temperature and sorghums.—The grain sorghums are sensitive to low temperatures and will not do well at high altitudes because of cool nights. The northern or upper limit of Kafir is a mean summer temperature of about 75° and that of milo is about 70°.

419. Range in the United States.—The lower Great Plains is the home of most of the grain sorghums raised in this country. In that region the summer temperatures are high, the percentage of possible sunshine great, the annual rainfall from 15 to 30 inches, and the frequent summer droughts are intensified by hot winds and excessive evaporation. The bulk of the crop is within the rainfall lines of 15 to 30 inches.

WHEAT

Wheat is the great bread cereal of the moderate temperate climates. In prehistoric times it had spread over Asia and Europe. Wheat has been found in the vegetable remains of the Lake Dwellers, and grains in the tombs and illustrations in the bas-reliefs on monuments show that it was raised in Egypt three or four thousand years before Christ.

420. Range.—Wheat is grown in Europe as far north as latitude 65°; in North America, to 50° north latitude; and in



WINTER WHEAT ACREAGE
[STATES ARRANGED IN DECREASING ORDER FOR 1909]

STATE	CENSUS 1909	ESTIMATE 1915	STATE	CENSUS 1909	ESTIMATE 1915	STATE	CENSUS 1909	ESTIMATE 1915
Kans..	5,913,064	8,475,000	Mich..	793,606	960,000	N. Y...	285,823	390,000
Nebr..	2,429,894	3,601,000	Va ..	692,907	1,230,000	Idaho..	251,390	390,000
Ill....	2,165,513	2,600,000	Ky....	681,311	900,000	Iowa..	236,798	510,000
Ind....	2,080,879	2,750,000	Oreg..	621,532	675,000	W. Va.	209,211	300,000
Mo ..	2,013,039	2,773,000	Tenn..	619,861	860,000	Mont..	127,600	675,000
Ohio.	1,827,263	1,980,000	Md....	589,890	638,000	Colo..	126,578	310,000
Pa....	1,224,344	1,330,000	N. C...	501,912	950,000	Utah..	119,948	245,000
Okla..	1,167,411	3,150,000	Cal....	426,405	440,000	Del....	111,172	125,000
Wash.	981,694	1,110,000	Tex....	320,728	1,475,000	N. Dak.	93,078	No estimates

WINTER WHEAT ACREAGE
(Continued)

STATE	CENSUS 1909	ESTIMATE 1915
Ga	93,069	325,000
N. J....	83,584	78,000
Minn..	69,036	60,000
S. Dak.	65,309	125,000
Wis....	61,806	100,000
Ark....	60,387	220,000
S. C....	43,074	225,000
Ariz...	18,099	38,000
Ala....	13,662	100,000
N. Mex.	13,451	52,000
Wyo...	12,535	60,000
Nev....	2,713	22,000
Miss...	389	5,000
Other..	1,674	No estimates
East....	12,080,825	16,046,000
West...	15,070,664	24,407,000
U. S....	27,151,489	40,453,000

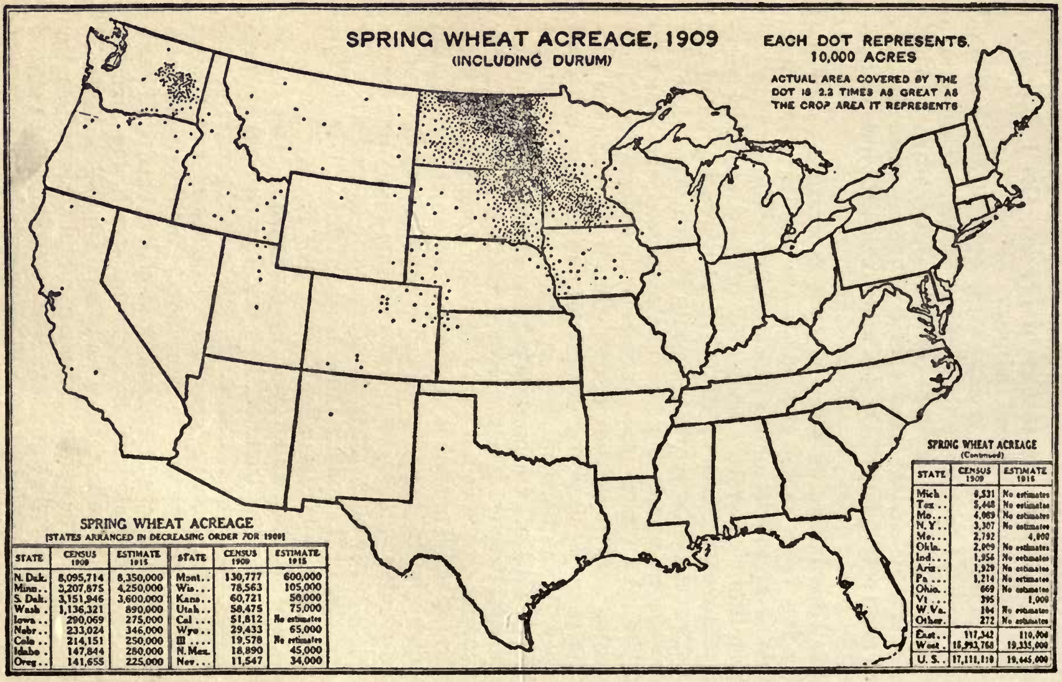
FIG. 49.—Winter wheat area in the United States.

South America and Australia nearly to 45° south latitude. It is raised within the tropics in Mexico, the Philippines, Egypt, India, and central Africa.

421. In the United States.—Figs. 49 and 50 show the distribution of wheat in the United States. These make plain that the most important center of winter wheat production is in west-central Kansas, and of spring wheat in northern and eastern North Dakota and northeastern South Dakota.

422. Distribution as affected by temperature.—The dividing line between the principal spring and winter wheat-producing areas east of the Rockies agrees closely with the mean winter temperature line of 20° or the mean daily minimum temperature line of 10°. The southern border of the winter wheat belt agrees closely with the isotherm of 68° for the two months preceding the date of harvesting. The northern limit of spring wheat agrees approximately with the mean summer temperature of 58°, which is found in the United States only in the western mountains. Wheat will yield a crop, except in unusual years, at elevations up to 8,000 feet in the central Rocky Mountain regions where the mean temperature for the year is not below 38°, and where the mean for the summer season is not below 58°. In India the soil temperature at seeding time is very important in the production of winter wheat. When sown too early while the ground is warm, plants may start well but will soon decay and be attacked by white ants. It is considered safe to seed when the temperature of the soil has fallen to about 25° C. (77° F.) but not when it is as high as about 30° C. (86° F.).

423. Distribution as affected by moisture.—Most of the important wheat districts of the world have an annual precipitation of less than 30 inches. In Australia the main wheat-producing areas receive less than 20 inches of rain during the growing months and in New South Wales and Victoria the chief areas are where the winter rainfall is between 10 and 15 inches. The intensive winter wheat-producing areas in Kansas and Nebraska receive an annual rainfall of 20 to 30 inches, while in the central Mississippi and Ohio valleys the amounts are somewhat greater. The most important spring wheat areas in South Dakota and Minnesota have an annual rainfall of 20 to 30 inches, while in most of North Dakota the



SPRING WHEAT ACREAGE
[STATES ARRANGED IN DECREASING ORDER FOR 1909]

STATE	CENSUS 1909	ESTIMATE 1915	STATE	CENSUS 1909	ESTIMATE 1915
N. Dak.	8,095,714	8,350,000	Mont. .	130,777	600,000
Minn. .	3,207,875	4,250,000	Wis. . .	78,563	105,000
S. Dak.	3,151,946	3,600,000	Kans. .	60,721	50,000
Wash. .	1,136,321	890,000	Utah . .	58,475	75,000
Iowa . .	290,069	275,000	Cal . . .	51,812	No estimates
Nebr . .	233,024	346,000	Wyo . .	29,433	65,000
Colo . .	214,151	250,000	Ill	19,578	No estimates
Idaho .	147,844	280,000	N. Mex.	18,890	45,000
Oreg . .	141,655	225,000	Nev. . .	11,547	34,000

SPRING WHEAT ACREAGE
(Continued)

STATE	CENSUS 1909	ESTIMATE 1915
Mich .	8,531	No estimates
Tex . .	5,448	No estimates
Mo. . .	4,069	No estimates
N. Y. .	3,307	No estimates
Me. . .	2,792	4,000
Okla. .	2,009	No estimates
Ind. . .	1,956	No estimates
Ariz. .	1,929	No estimates
Pa . . .	1,214	No estimates
Ohio .	669	No estimates
Vt . . .	395	1,000
W. Va.	104	No estimates
Other.	272	No estimates
East. .	117,342	110,000
West .	16,993,768	19,335,000
U. S. .	17,111,110	19,445,000

FIG. 50.—Spring wheat in the United States.

fall is between 15 and 20 inches. In this state, however, about one-third of the annual rainfall is received during the three spring months and fully one-half of the annual fall comes during March to June, inclusive.

The successful growth of wheat is not limited by heavy rains, but other crops are usually found to be more profitable in regions of heavier rains, and, as in our southern states, where the annual rainfall is 45 inches or more, rusts and fungus diseases are prevalent due to warm and moist springs. It has been found in India that good soil aëration, by means of which the soil organisms and the roots of the wheat plant can obtain abundant oxygen, is quite as important as the water supply. It seems that any interference with aëration at ripening time prevents maturing and tends to increase rust attacks.

In general, a hot dry climate produces a fine-stemmed plant the grain of which is hard, glassy, and rich in nitrogen, while a cool moist climate produces a coarser-stemmed plant with the grains relatively soft and mealy and poor in nitrogen.

424. Dates of seeding and harvesting.—The work of seeding and harvesting wheat is being carried on in some parts of the world during every month of the year, as is shown by the following table:

TABLE 26.—WHERE WHEAT IS BEING HARVESTED

Month	*Country*
January	Australia, New Zealand, Chili.
February	India, Egypt.
March	India, Egypt.
April	Africa, Asia, Mexico, Cuba.
May	Central Asia, China, Japan, extreme southern United States.
June	Southern Europe, southern and central United States.
July	Central Europe, Northern United States, Canada.
August	Western Europe, Canada, extreme northern United States.
September	Northern Europe.
October	Northern Europe.
November	Western and southern South America.
December	Southern South America.

Figs. 51 and 52 show the average dates of beginning of seeding and harvesting spring wheat in the United States, and Figs. 53 and 54 similar data for winter wheat. Winter wheat can be seeded too early and also too late for the best results, while between there is an optimum or best date for seeding in an average year.

425. The best date to seed winter wheat.—There is usually greater danger by winter killing of late-sown wheat than of early-sown, especially with a dry fall, as there may be a failure to establish a good root system; the probablity of good tillering is also reduced. On the other hand, wheat seeded too early is subject to damage by the hessian fly in some districts. Fig. 55 shows the date for seeding which will, in the normal year, reduce or avoid injury by the hessian fly and probably give a greater yield. By comparing the charts, it will be seen that the safest date in much of the winter wheat belt is from ten to twenty days later than the date when seeding usually begins. The state entomologist should be consulted, however, as to the prevalence of the hessian fly and its activities.

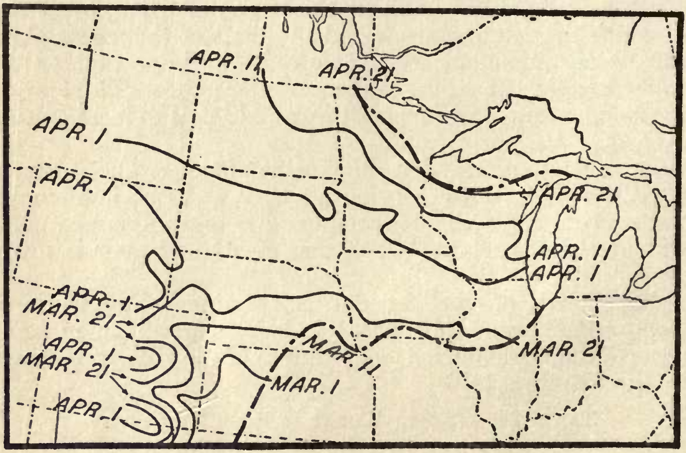


Fig. 51.—Average date when the seeding of spring wheat begins.

426. Important periods of growth.—Well-recognized stages in the development of grains are germination, tiller-

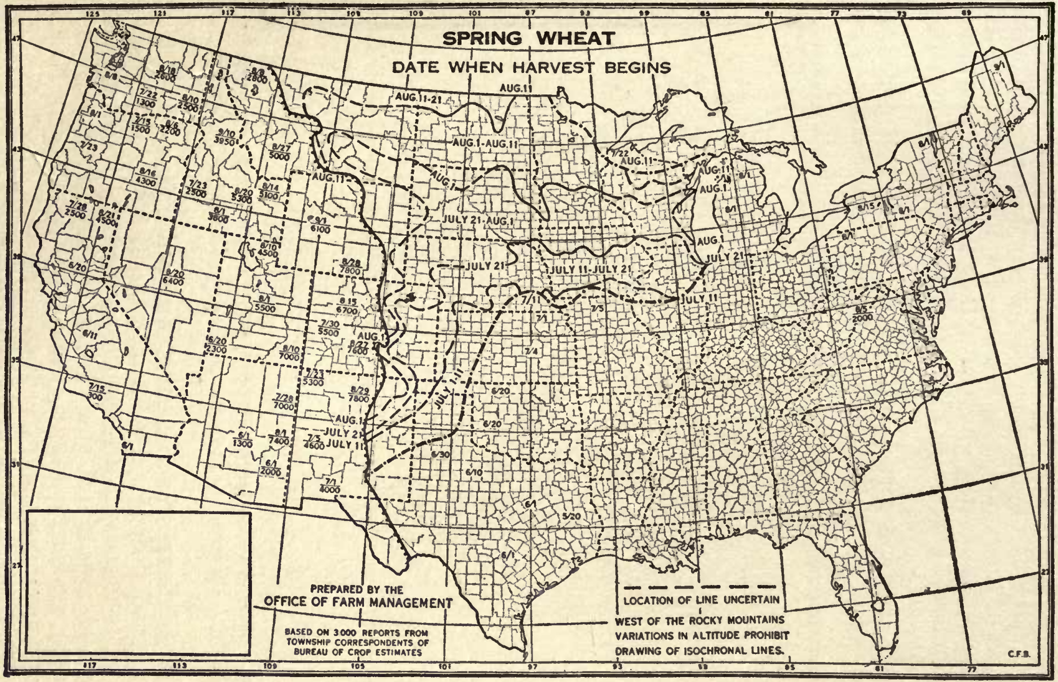


FIG. 52.—Average date when the harvest of spring wheat begins.

ing, jointing, heading, blossoming, and ripening. Records covering thirty years show that in northwestern Ohio the length of the period from seeding of winter wheat until the plants appear averages nine days; from the appearance above ground until blossoming 253 days; from blossoming until ripe twenty-six days.

427. Fruiting period.—In Kansas the fruiting period or average length of time between heading and ripening of fifteen varieties of winter wheat is twenty-nine days. The fruiting period varies for the different varieties from twenty-five to thirty-four days. In Ohio the average time between heading and ripening of one variety is thirty-six days. The fruiting period for four varieties of spring wheat in North Dakota averages thirty-five days.

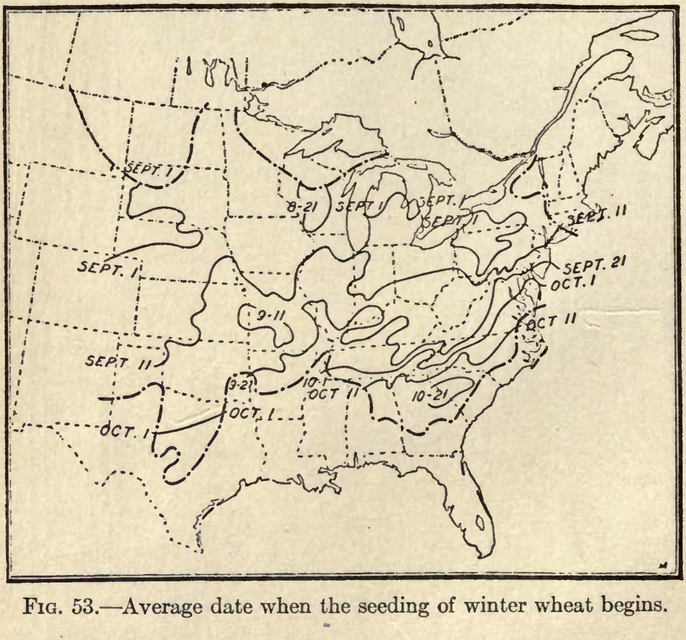


FIG. 53.—Average date when the seeding of winter wheat begins.

428. Days from sowing to harvesting.—The total number of days from sowing to harvesting east of the Rocky

FIG. 54.—Average date when the harvest of winter wheat begins in the United States.

DATES AT DIFFERENT ALTITUDES AND LATITUDES IN THE APPALACHIAN REGION

ALTITUDE IN FEET				LATITUDE
500	1000	2000	3000	
9/10				44
9/14	9/9			43
9/19	9/14	9/4		42
9/23	9/18	9/9		41
9/28	9/23	9/14		40
10/3	9/28	9/19	9/10	39
	10/3	9/24	9/14	38
	10/9	9/29	9/19	37
	10/15	10/5	9/24	36
10/24	10/20		9/30	35
10/27	10/24			34

FIG. 55.—Date for seeding winter wheat which in a normal year will reduce or avoid injury by hessian fly and probably give a greater yield.

Mountains varies from 250 to 290 days for winter wheat, and 120 to 130 days for spring wheat. The time for spring wheat is from 130 to 180 days in the Pacific states. Some varieties of spring wheat will mature grain in 100 days at Fairbanks, Alaska, two degrees from the Arctic Circle.

429. Critical periods of growth.—All authorities agree that the wheat plant must have an abundance of moisture at the heading stage. Some would place the most critical stage just as the plants are beginning to head, others between the boot and bloom periods and still others between the bloom and milk. It was found in Utah that the period prior to the boot stage is very critical. If the plant is injured by drought at this time, it does not recover even if given water later; the yield of grain is affected more than the yield of straw. High temperature and lack of moisture while in bloom produce sterile heads.

430. Moisture and wheat.—It is agreed by different investigators that wheat needs only sufficient moisture during the first six weeks of its life to keep it growing vigorously. A strong root system is obtained by a moderate amount of moisture although it needs sufficient during its early stages of growth to induce tillering.

It is advised in Utah to begin irrigation when the plants are 6 to 8 inches high and to stop at about the time that it comes into bloom. It was found in Nevada that the greater yields were obtained by a 6-inch irrigation before heading and a 12-inch after heading. During about forty to sixty days between the first six weeks and the last three weeks of its growth, the plant should have its greatest moisture.

Soft wheats are usually less able to endure drought, hot winds, and severe winter-killing than hard wheats. Hard wheats, for example, are best adapted to central and western Kansas, while soft wheat is better in eastern Kansas. Warm and wet weather in midsummer is likely to promote an epidemic of rust. Rust is an injurious disease in the southeastern states and the factor that limits the successful culture in warm humid regions.

431. Weather and spring wheat.—Spring wheat is grown in regions where the winters are cold and comparatively dry, and where there is little snow for the protection of winter grains. Durum wheat is a sub-species that is adapted to re-

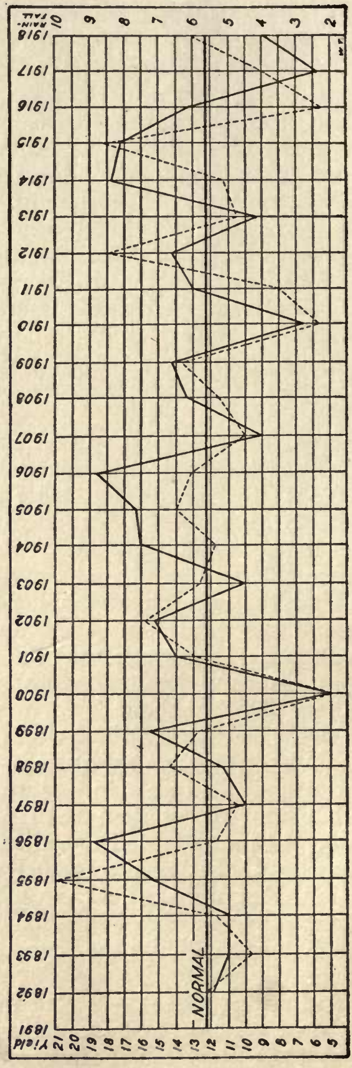


FIG. 56.—Relation of rainfall in May and June to yield of spring wheat. North Dakota, 1891–1918.

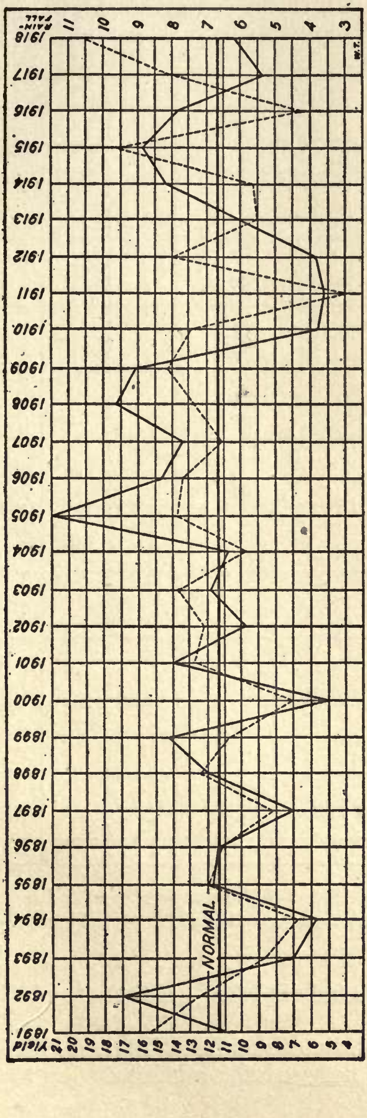


FIG. 57.—Relation of rainfall in May and June to yield of spring wheat, South Dakota, 1891–1918.

gions of low rainfall, rather high summer temperatures, and when the loss of moisture by evaporation is rapid. These

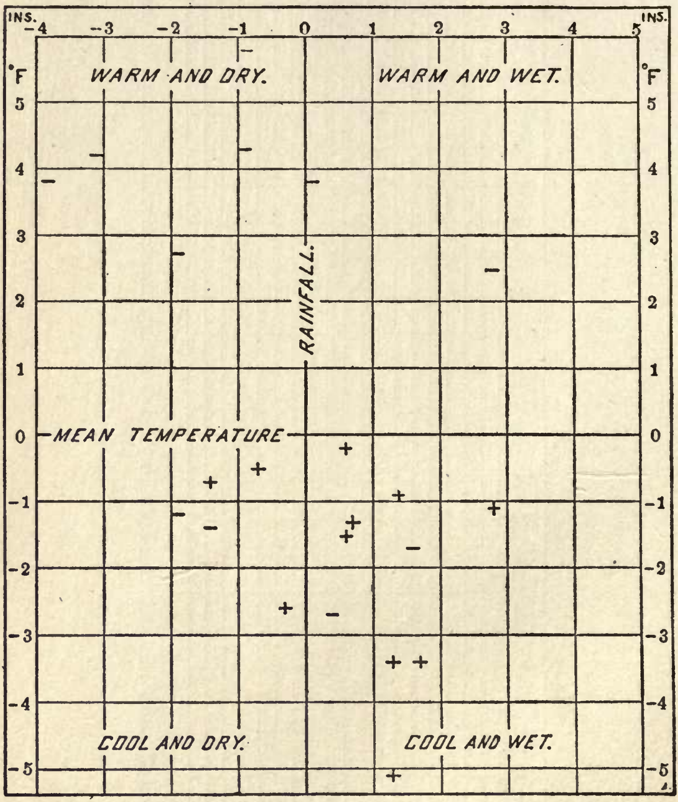


FIG. 58.—Combined effect of the temperature for June and the rainfall for May and June on the yield of Spring wheat in North Dakota, 1891–1913.

conditions are found in the northwestern Great Plains region.

432. Rainfall and spring wheat (Blair).—Figs. 56 and 57 show the relation between the rainfall during May and June and the yield of spring wheat in North Dakota and South Dakota, respectively, as noted by T. A. Blair in 1913 and completed in 1918 by the author. These indicate that relatively dry weather in these states during May and June is almost invariably followed by a low yield of wheat, while an abundant rainfall is usually followed by a good yield. In Minnesota, on

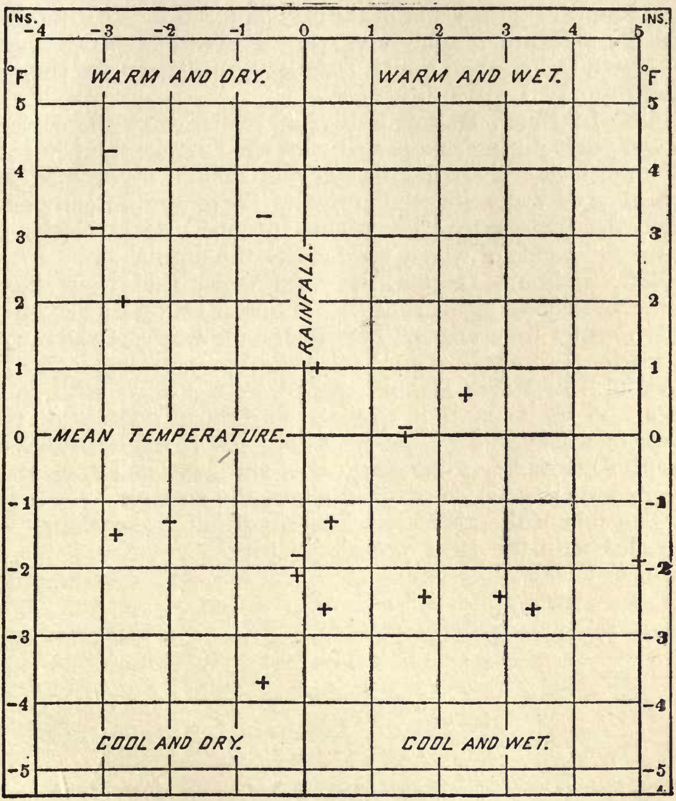


FIG. 59.—Combined effect of the temperature for June and the rainfall for May and June on the yield of spring wheat in South Dakota, 1891–1913.

the other hand, there is little relation between the rainfall for May and June and the yield of wheat.

433. Temperature and spring wheat (Blair).—Figs. 58 and 59 indicate the effect of the rainfall for May and June and the temperature in June in varying the yield of spring wheat in North Dakota and South Dakota, respectively, for the period from 1891 to 1913, inclusive.

434. In North Dakota.—Fig. 58 shows that there were seven years during this period with the average temperature in June higher than the normal and that in every case the wheat yield was below the normal. There were fifteen years with the temperature lower than normal and in eleven of these the yields of wheat were above the normal.

435. In South Dakota.—Fig. 59 shows that there have been some good yields of wheat in South Dakota when June was warmer than normal, but when June was cool there was a greater percentage of good yields in this state than in North Dakota. In North Dakota there were ten years with June cool, and May and June wet, and in eight of these years the yield of wheat was greater than normal. In the six years in South Dakota when June was cool and May and June wet, every year gave a wheat yield above the normal.

The following table gives the results of a correlation of weather with the yield of spring wheat:

TABLE 27.—CORRELATION COEFFICIENTS BETWEEN SPRING WHEAT AND RAINFALL AND TEMPERATURE (T. A. BLAIR)

	Rainfall		*Temperature*	
	Correlation coefficient	*Probable error*	*Correlation coefficient*	*Probable error*
North Dakota	*(1892–1912)*		*(1892–1913)*	
May and June	0.63	±0.09	−0.39	±0.12
May	0.48	±0.11	0.02	±0.14
June	0.35	±0.13	−0.67	±0.08
July	0.30	±0.13	−0.19	±0.14
South Dakota	*(1891–1912)*		*(1891–1913)*	
May and June	0.59	±0.09	−0.62	±0.09
June	0.35	±0.13	−0.73	±0.07

TABLE 27.—CORRELATION COEFFICIENTS BETWEEN SPRING WHEAT AND RAINFALL AND TEMPERATURE (T. A. BLAIR)—*Continued*

	Rainfall		*Temperature*	
	Correlation coefficient	*Probable error*	*Correlation coefficient*	*Probable error*
Minnesota	*(1891–1912)*			
May and June	−0.02	±0.14		
May and June (omitting 4 wettest years)	0.26	±0.13		
North Dakota	*(1892–1917)*			
May and June	0.61	±0.08		
June			−0.45	±0.11
South Dakota	*(1891–1917)*			
May and June	0.49	±0.10		
June			−0.62	±0.08

This table clearly shows the importance of cool weather in June and an abundance of moisture in May and June in the Dakotas.

436. Weather and spring wheat, 1918.—The effect of the weather in 1918 on the condition of spring wheat in the states of North Dakota and South Dakota is indicated in Fig. 60. The variation of the average monthly temperature and the total monthly rainfall from the normal is shown for the months of March to July in each state. The dots showing the condition of spring wheat on June 1, as compared with the ten-year average are placed on the vertical line indicating the departures of the temperature and rainfall from the normal for the month of May, because the condition on June 1 is the result largely of the weather during May. For the same reason the dots for July 1 and August 1 are placed on the June and July lines, respectively.

437. Dry weather detrimental.—While there was a steady advance in the condition of wheat in South Dakota due to the generous rainfall throughout the season, it is evident that the deficient rainfall in June in North Dakota was responsible for the lack of improvement in wheat in this state. Frequently the condition of this crop will be lowered to a marked

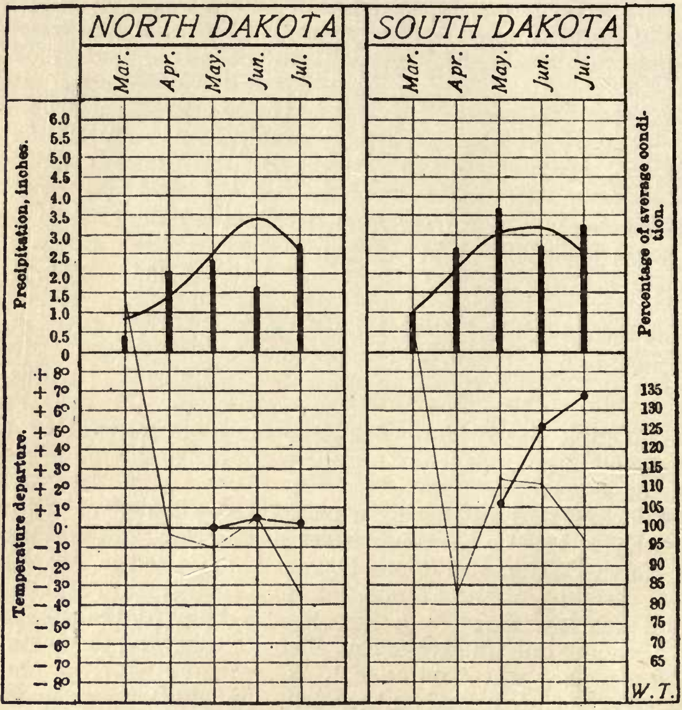


FIG. 60.—Effect of the weather on the condition of spring wheat in North Dakota and South Dakota in 1918. See the note under Fig. 34 for an explanation of the various lines, except that in Fig. 60 monthly instead of weekly rainfall and temperature conditions are indicated.

extent by insufficient moisture in two successive months, as was the case in Montana in 1917.

438. Weather and spring wheat in Manitoba, Canada.—From studies in the field in Manitoba, Connor found that "if in the earlier stages of growth it is cool and rainy, the heading will be delayed, and the yield will be heavy, but if warm and dry, heading is hastened and the yield will be light." He correlated the rainfall, range of temperature, and minimum temperature for successive thirty, sixty, ninety, and 120 day periods with the yield of spring wheat in Manitoba. The record covered the time from 1883 to 1917 and the highest correlation for the thirty-day period was for the third thirty days after seeding. The values were:

	Correlation coefficient	*Probable error*
Rainfall	0.42	±0.11
Range of temperature	−0.55	±0.10
Minimum temperature	−0.40	±0.12

He fixes the average time of the critical period as the last week in June and the first three weeks in July, and the critical factor in wheat production in Manitoba the "variability of early July weather."

Winter wheat

439. The effect of weather on the yield of winter wheat.—The opinion is frequently expressed that the yield of winter wheat will be greatly affected by a warm or cold fall or winter, or by the temperature or rainfall of a single month or group of months.

440. Comparison of records in Ohio for fifty-four years.—In order to determine the ground for these opinions, correlations were made by the author between the weather factors for different periods and the yield of wheat in Ohio for the years from 1860 to 1913, inclusive.

Table 28 shows the correlation coefficients between the average rainfall and temperature and the wheat yield for the state of Ohio.

TABLE 28.—CORRELATION OF WEATHER AND WINTER WHEAT FOR THE STATE OF OHIO, 1860 TO 1913

	Precipitation		*Temperature*	
Period	*Correlation coefficient*	*Probable error*	*Correlation coefficient*	*Probable error*
September	0.04	±0.09	0.16	±0.09
October	0.16	±0.09	0.09	±0.09
November	−0.02	±0.09	0.14	±0.09
December	−0.17	±0.09	0.05	±0.09
January	0.09	±0.09	0.21	±0.09
February	0.01	±0.09	0.26	±0.08
March	0.06	±0.09	0.46	±0.07
April	0.02	±0.09	−0.10	±0.09
May	0.02	±0.09	−0.11	±0.09
Autumn (Sept. to Nov.)	0.17	±0.09	−0.03	±0.09
Winter (Dec. to Feb.)	−0.17	±0.09	0.17	±0.09
Spring (March to May)	0.15	±0.09	0.19	±0.09

441. Precipitation and yield.—It will be seen that the correlation coefficient for rainfall is not high enough for any month or group of months to show any relation to the yield. In other words, the precipitation in Ohio is not the determining factor in wheat yield. The precipitation is always sufficient and never so great as to affect the yield materially.

442. Temperature and yield.—The table also shows that the average temperature for a month, or for the group of months designated as "season," is not the all important factor in affecting the yield.

443. Mean temperature for March.—The most important weather factor in the table is the mean temperature for March. This gives a correlation coefficient slightly more than seven times the probable error and so can be said to have a marked influence on the yield. Fig. 61 gives the dot chart showing the relation between these factors. An inspection of this chart makes plain that a warm March has been followed by a wheat yield above the normal twenty-one times out of twenty-four, or 88 per cent of the time. On the other hand, when March averages colder than the normal, the yield

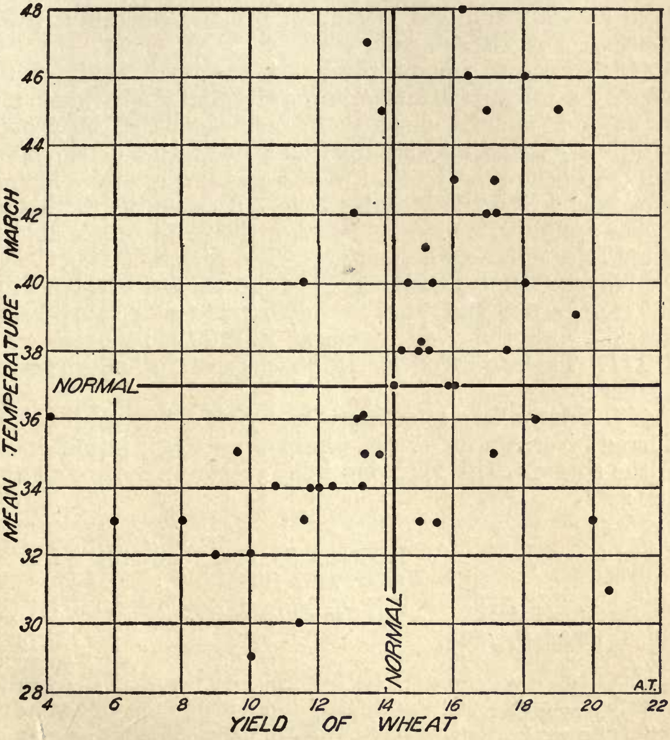


FIG. 61.—Relation between the mean temperature for March and the yield of winter wheat, Ohio, 1860 to 1915.

of wheat will be below the normal 63 per cent of the time. When March averaged 2 degrees a day or more above the normal, the probability of the yield of wheat being above the normal in Ohio is 94 per cent, covering a period of fifty-six years. When March averages 2 degrees or more a day cooler than the normal, the probability of the wheat yield being above the normal is only 25 per cent.

444. March temperature in other states.—A similar study, though covering a shorter period of time, shows no such relation between the March temperature and wheat yield in Maryland and Delaware, Illinois, Nebraska, Iowa, Kentucky, or Oklahoma.

445. Effect of a snow cover.—A thorough study of the effect of a covering of snow during the winter as a whole and for different months, shows that a lack of snow on the ground with freezing and thawing weather is not such a detriment as has been believed. Instead, a lack of snow covering in January seems to be beneficial, possibly because the earth thus settles around the roots and makes the plant better able to stand later unfavorable weather. The correlation coefficient for Wayne County, Ohio, between the number of days without snow cover and with the minimum temperature below freezing with the yield of wheat is +0.49, probable error ±0.11. This is not conclusive, however, and should be given further study.

446. Snowfall as affecting wheat yield.—Snowfall is considered favorable for winter wheat especially if it comes late in the spring. The following table seems to controvert this idea:

TABLE 29.—CORRELATION BETWEEN SNOWFALL AND THE YIELD OF WHEAT, 1892–1914

Period and place		*Correlation coefficient*	*Probable error*
Jan.,	Fulton Co., Ohio	0.42	±0.13
Feb.,	" " "	0.12	±0.15
March,	" " "	−0.84	±0.04
"	Wayne Co., "	−0.69	±0.08
"	Seneca Co., "	−0.48	±0.11

This indicates that a heavy snowfall in January is favorable even though a large number of days with a snow covering has an opposite effect.

447. Snowfall in March detrimental.—The most remarkable fact in this table is the evidence that snow falling in March is decidedly unfavorable to winter wheat as shown by the high negative value for the correlation coefficient. This is brought out more clearly in Fig. 62 which shows the relation between the snowfall for March and the yield of wheat in Fulton County, 1892 to 1914. In nearly every case when the snowfall is above the normal, the yield of wheat is correspondingly below. The figures at the left show both inches of snow and bushels of wheat. A similar correlation between the March snowfall and the wheat yield in other northern Ohio counties gives much the same result, although no such marked effect has been found in other states.

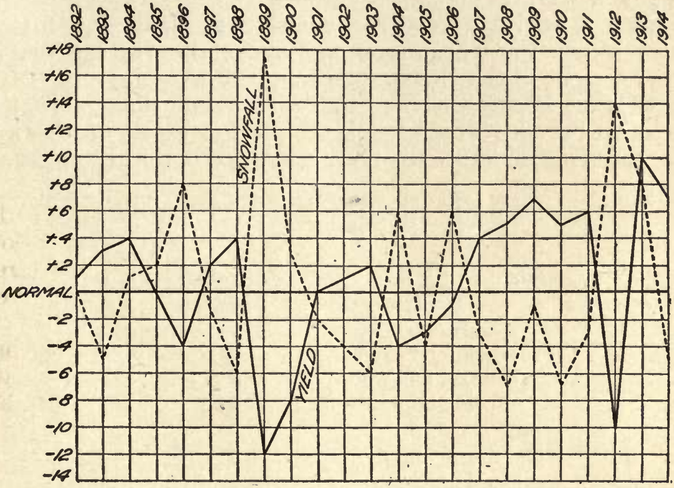


Fig. 62.—Relation between the snowfall in March and the yield of winter wheat in Fulton County, Ohio, 1892–1914

448. In Indiana.—Cool weather during the month of April is decidedly favorable for winter wheat in Indiana. In the thirty-two years from 1887 to 1918, April was cooler than the normal eighteen times. Following the cool Aprils, the wheat yield was above the normal thirteen times and below five times. Following the fourteen warm Aprils, the yield was above the normal seven times and below seven times.

449. Cool and wet favorable in Indiana.—Of cool Aprils, the most beneficial appears to be those with an excess of precipitation, as following nine cool and wet Aprils the yield of wheat was above the normal seven times and below twice. For the state, 2° in temperature and 1.25 inch of precipitation, mark the average departures from the normal. Considering departures greater than this as abnormal, it is found that only one wheat crop out of seven has been below the average after an abnormally cool April, also only one crop out of five has been below the normal following an abnormally wet April.

450. A cool May also beneficial in Indiana.—Of fifteen cool Mays, the wheat crop was above the average twelve times, eight of the twelve following cool wet Mays.

451. In Missouri.—The following tabulations show the relation between weather and the yield of wheat in Missouri for the months indicated, covering a period of thirty-one years:

TABLE 30.—CORRELATION BETWEEN WEATHER AND YIELD OF WHEAT IN MISSOURI

		Years	
No. of years	*Weather*	*Yield above normal*	*Below normal*
	March		
8	warm and dry	6	2
7	cold and dry	1	6
8	warm and wet	3	5
8	cold and wet	4	4
	April		
10	warm and dry	5	5
10	cold and dry	4	6
4	warm and wet	1	3
7	cold and wet	4	3
	May		
7	warm and dry	4	3
6	cold and dry	4	2
9	warm and wet	2	7
9	cold and wet	4	5
	June		
11	warm and dry	6	5
6	cold and dry	3	3
5	warm and wet	1	4
9	cold and wet	3	6

452. May warm and dry most favorable in Missouri.—If only these years are considered when the mean temperature for May has varied 1.5° or more from the normal and the precipitation 1.50 inches or more from the normal, the following results:

TABLE 31.—CORRELATION BETWEEN WEATHER IN MAY AND YIELD OF WINTER WHEAT

	May	*Years with yield*	
Years	*Weather*	*Above normal*	*Below normal*
4	warm and dry	4	0
1	cold and dry	0	1
3	warm and wet	0	3
3	cold and wet	1	2

The average yield of wheat in Missouri is 13 bushels to the acre. If only those years are considered when the yields varied 2.5 bushels or more from the normal, the following results are obtained:

TABLE 32.—CORRELATION BETWEEN WEATHER AND YIELD OF WINTER WHEAT WHEN LATTER VARIED 2.5 BUSHELS OR MORE FROM NORMAL

	May	*Yield*	
Years	*Weather*	*Above normal*	*Below normal*
3	warm and dry	3	0
3	cold and dry	2	1
6	warm and wet	1	5
1	cold and wet	0	1

These data seem to indicate that relatively warm and dry weather in May is needed in Missouri for the best yields of winter wheat.

453. In Kansas.—Investigations at the Fort Hays Experiment Station, Kansas, indicated that in western Kansas moisture is the limiting factor in the production of winter wheat. In a four-year study, it was found that the yield of grain was in direct proportion to the supply of available moisture at seeding time.

454. Summer rain and yield of wheat in Kansas.—At the Fort Hays Station, which is not far from the center of the wheat area of the Plains districts, 75 per cent of the total annual rainfall is received between April 1 and September 30. At Wallace, Kansas, about 65 per cent of the annual fall comes in May, June, July, and August, while in Lincoln, Nebraska, nearly 60 per cent falls in these four months. It was learned at Fort Hays that if the methods of handling the soil are such as to allow for the maximum absorption of the summer rainfall, and to reduce the evaporation to a minimum, the yield of winter wheat will be affected to a marked degree.

455. Rainfall and temperature by months.—H. B. Lanning made a careful study (unpublished) of the effect of the weather on the yield of wheat over an area including thirty-seven counties in the important wheat district of central Kansas. Dot charts were prepared for both temperature and rainfall for each month and for groups of months from July preceding planting of wheat until the following June.

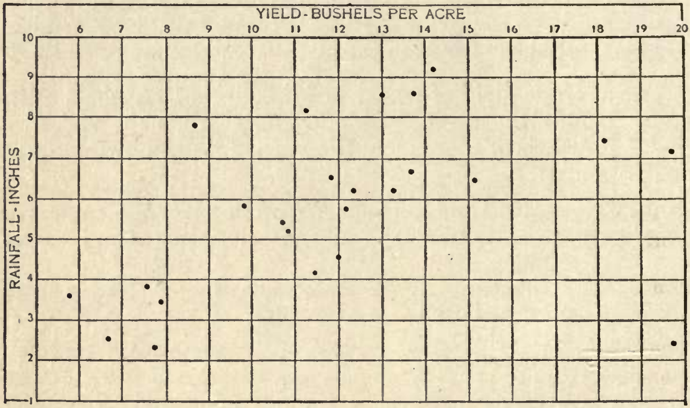


FIG. 63.—Relation between the rainfall for July of one year and for April of the following spring and the yield of wheat for that season, Kansas 1893–1917.

456. No temperature relation.—These charts showed no apparent relation between the mean temperature for any month and the wheat yield. In other words, the average temperature for any month does not vary enough from the normal to have its favorable or unfavorable effects shown in the harvest often enough to be of importance.

457. Rainfall and yield in Kansas.—No appreciable relation was found between the yield and the rainfall for any of the nomths except for July preceding planting and for April preceding harvesting, and in these months the relation is slight. The yield increases in a general way as the rainfall for the preceding July increases, until the rainfall reaches about 6 inches and the yield 13 bushels to the acre, but higher yields are always with less rainfall. The lowest and the highest yields of wheat in central Kansas have occurred when the rainfall of the preceding July for that district was about one inch. Charts showing the yield and the rainfall for July and August, and July, August, and September also indicate a fairly regular increase in yield with increasing rainfall until about 13 or 14 bushels to the acre, and then higher yields have always been with less rainfall.

458. July and April combined.—Fig. 63 shows the relation between the rainfall for July preceding and April of the year of harvest, and the yield of wheat in Kansas from 1893 to 1916–17. With three or four marked exceptions, there is a fairly close relation.

The following statements of weather conditions favorable or unfavorable for winter wheat in Kansas, by months, are from S. D. Flora, meteorologist of the Weather Bureau:

TABLE 33.—CONDITIONS FAVORABLE AND UNFAVORABLE TO WINTER WHEAT IN KANSAS

Month	*Condition favorable*	*Condition unfavorable*
January	Snow cover, abundance of moisture.	High winds, if dry. Freezing and thawing without snow cover.
February	Same as January.	
March	Cool and wet as it promotes stooling	Abnormally warm, especially with high winds; heaving.
April	Plenty of moisture and temperature near normal.	
May	Warm and sunshiny	Cold and wet favors black stem rust.
June	Warm and dry	Excessively high temperature which shrivels the grain.
July	Warm.	Wet delays harvest.
August	Dry for threshing, abundant moisture for preparing ground for next crop.	
September		Prolonged dry spell.
October	Abundant moisture.	
November December	Abundant moisture; snow cover.	A cold period without snow.

459. In Iowa.—February is a very critical month for winter wheat in Iowa. A correlation between the weather and the surviving winter wheat acreage for twenty years gives the following result:

TABLE 34.—CORRELATION BETWEEN WEATHER AND THE SURVIVING WINTER WHEAT IN IOWA

Weather	*February* *Correlation coefficient*	*Probable error*
Mean temperature	0.41	±0.12
Average rainfall	0.46	±0.12
Snowfall	0.36	±0.12

The mean temperature was above the normal in February in the southern third of Iowa eight times and the surviving wheat acreage was above the normal every time. A warm and wet February is decidedly favorable for winter wheat in Iowa.

460. In Wisconsin.—A correlation between weather and winter wheat in Wisconsin for the period from 1891 to 1917 shows the following:

TABLE 35.—CORRELATION BETWEEN WEATHER AND WINTER WHEAT IN WISCONSIN

Month	*Precipitation*		*Temperature*	
	Correlation coefficient	*Probable error*	*Correlation coefficient*	*Probable error*
April	−0.14	———	0.07	———
May	0.14	———	−0.12	———
June	−0.03	———	−0.42	±0.11

This indicates that a cool June is decidedly favorable for a good wheat yield in this state.

461. Winter-killing of grains.—Winter damage to fall-sown grains is usually grouped under four main heads: (1) heaving, (2) smothering, (3) direct effect of low temperatures on the plant tissue and protoplasm, and (4) physiological drought.

462. Heaving is one of the most common causes of damage especially on poorly drained, heavy soils. It occurs usually in the spring, and is due to alternate freezing and thawing. The plants are lifted from the soil when it expands, and as a result the roots are broken and exposed to the air. Heaving is a common cause of winter-killing in the eastern part of the United States.

463. Smothering is believed to be a frequent cause of injury when the ground is covered with an ice sheet; instances have been reported where smothering has resulted from a very deep snow-cover. The damaging ice-sheet more frequently results from melted snow, although injury is sometimes caused by a storm of sleet and rain, which freezes nearly as rapidly as it falls.

464. Freezing of plants.—There can be no doubt that plants are often killed by the direct effect of cold on the tissue, without heaving, smothering, or physiological drought taking place. The injury usually increases with the degree of cold and its duration. The effect of a sudden freeze following a warm period is sometimes damaging, especially in the latter part of the winter or early in the spring, when a sharp drop in temperature follows a period of unusual mildness.

465. Physiological drought causes injury during dry spells in winter. Differences in resistance of certain cereals may perhaps be explained by their ability to absorb a larger amount of water from the soil in proportion to that transpired.

466. Winter wheat in 1919.—Fig. 64 shows the varying temperature and rainfall in Kansas and Indiana from August, 1918, to May, 1919, and the condition of winter wheat on the 1st of December, April, May, and June. Exceptionally favorable weather for the growth of wheat prevailed in all sections of the central wheat-growing area throughout the entire season. The soil was in excellent condition during the late summer and fall of 1918 for the preparation of seed-beds, germination of seed, and early growth of the young plants, and consequently the crop entered the winter in excellent condition with the roots well established. The winter was mild, with sufficient soil-moisture available, and the spring months were uniformly favorable for growth. The condition of the crop was exceptionally high on the first of April, 1919.

467. Yield disappointing.—The yield of winter wheat, however, did not come up to expectations, especially in the central and eastern portions of the belt, as compared with the indications a short time before harvest. It was quite disap-

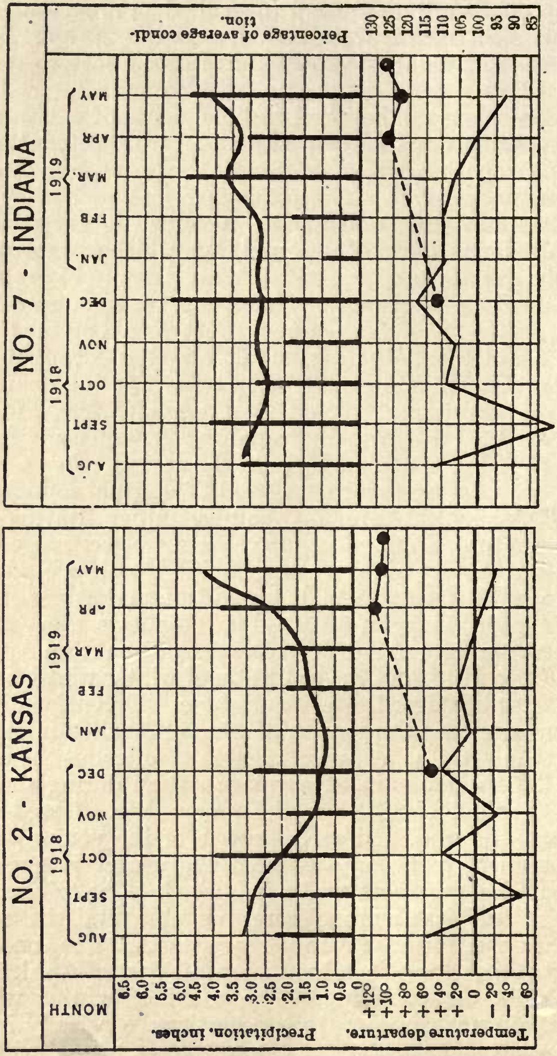


FIG. 64.—Diagrams showing the effect of the weather on the condition of winter wheat in 1917–1918.

pointing as to both quantity and quality. Under the influence of persistent favorable growing weather, there was too rank straw growth at the expense of grain in many localities. There was considerable lodging and this combined with warm dry weather when the grain was in the milk stage and while ripening, resulted in many poorly filled heads and much shriveled grain. As harvest approached there was an increase in disease, particularly scab and rust.

468. Weather and hessian fly damage.—A correlation between the weather in September and October and the damage done by the hessian fly the following year in two counties in Ohio, during the period from 1895 to 1913, is shown below:

TABLE 36.—CORRELATION BETWEEN WEATHER AND HESSIAN FLY DAMAGE

	Rainfall		*Temperature*	
	Correlation coefficient	*Probable error*	*Correlation coefficient*	*Probable error*
Adams Co.				
September	0.02	±0.15	0.24	±0.14
October	−0.13	±0.15	0.53	±0.11
Fulton Co.				
September	−0.23	±0.14	0.09	±0.14
October	0.36	±0.13	0.34	±0.14

The only correlation that is high enough to be considered is with temperature in October in Adams County. This shows that a warm October is favorable for the development of the fly.

469. Rainfall and yield of wheat in Australia.—The average yield of wheat in the state of Victoria for the twenty-five years from 1890 to 1914 was 9.1 bushels to the acre, while the average rainfall for the winter months, May to October, for 1890 to 1915 was 9.5 inches.

A. E. V. Richardson has prepared the following graph, Fig. 65, to show the relation between the rainfall and the yield of winter wheat in that state. He states that this graph shows that there has been an improvement in cultural methods since the serious drought of 1902; that the best yields have been with a rainfall for the six months of between 10 and 13 inches; that with each inch of rainfall during the first twelve years, a yield of 0.77 bushels was harvested, while during the second twelve years the yield for each inch of rainfall was 1.12 bushels to the acre; and that it seems possible to calculate the probable yield of wheat by the first of November.

He shows the improvement in farming methods by the fact that during the first twelve years the line of yield was always below the rainfall line and during the second period it was above with few exceptions. In the fall of 1914, he calculated a yield of 13.91 bushels to the acre while the actual yield was about 16 bushels to the acre.

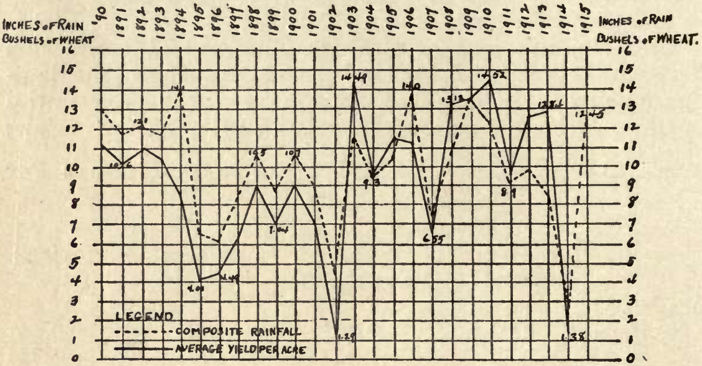


FIG. 65.—Graph giving relation between the winter rain and the yield of wheat in Australia, 1890 to 1915.

470. In Italy.—Girolamo Azzi has found in the province of Bologna, Italy, that there are two critical periods in wheat growth: (1) during the two decades preceding heading when wheat must have moisture; and (2), the two decades which follow the flowering stage (the period of the formation of the kernel), when violent rains and high winds will cause lodging and a resulting reduction in yield.

471. In England.—Studies by Gilbert and Lawes, Shaw and Hooker, show that a dry autumn (for the climate), a warm, dry winter, and a cool spring produce the best conditions for a good yield of winter wheat. Hooker states that "absence of rain during the flowering period and warmth at harvest time are wanted for good germinating seed."

472. Other factors should be studied.—It must be recognized that the effect of winter will depend on the condition of wheat when winter sets in; that particularly favorable or unfavorable weather in the spring and early summer may offset favorable or unfavorable winter conditions, and that there may be a short critical period during the formation of the heads.

LABORATORY EXERCISES

(1) The optimum and extreme temperature for the germination of the different grains should be determined. Available experiment station data should be supplemented by experiments.

(2) Crop yield and climatological data should be tabulated and correlations made, especially for short periods.

(3) Whenever practicable the character of the weather at about the heading time of grain should be recorded and its effect on the growing crop noted. It is believed that the most critical time for small grains is at about the blooming time but whether just before or just after has not been determined.

(4) A study is needed of the effect of the weather on grain sorghums in the lower Great Plains Region.

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CHAPTER IX

THE EFFECT OF WEATHER ON VEGETABLES AND MISCELLANEOUS CROPS

Vegetables are usually classified as "hardy" and "tender" but a better grouping would be as "cool" and "warm" weather crops. These groups might be further classified in regard to their varying need of moisture, sunshine, and temperature.

473. Warm-weather crops.—From a temperature point of view, warm-weather crops may be divided into two well-defined groups: (1) Those with a period of growth so short that they may be planted and harvested in the normal warm seasons; and (2) those with so long a period of growth that they must be started under glass in advance of the normal season to mature before fall frosts.

The following may be classified as warm-season crops as they make their best growth during warm weather and should not be planted or set out until the ground is warm and all danger of frost is over.

Cantaloupes also need frequent rains.

Cassava is very sensitive to frost and requires a growing season of about seven months. Its cultivation is not practicable outside the southern part of the Gulf states.

Castor beans are well suited to the climatic conditions of the arid southern valleys of Arizona where plants attain the size of small trees and live for many years. During frosty weather they are dormant or may be killed back somewhat, but resume growth with warm weather.

Cucumbers should not be planted until about a month after hard frost, when they will grow and produce throughout the summer. They need plenty of moisture.

Eggplants have a long growing season and must be started in hotbeds. After the plants are well established, they will stand dry and hot weather.

Gherkins are quite drought-resistant.

Muskmelons need plenty of moisture.

Okra may be planted about two weeks after average date of last killing frost. They are quite drought-resistant.

Peanuts are raised where the growing season is long and warm. They succeed best south of latitude 36 degrees; and are easily killed by frost.

Pepper plants must be started in hotbeds as they have a long growing season. They should not be transplanted until the ground is throughly warm.

Pumpkins will grow and mature during the warm season.

Squashes are less sensitive to cold than melons and some vatieties will not stand excessive heat.

Sweet potatoes have a long growing season and should not be transplanted from the hotbed for about a month after the last spring frost. The sweet potato is a subtropical vegetable and needs ample sunshine and high temperature for best growth. It is unable to stand cold weather and even at a temperature of 40° the growth is much retarded. Production in the United States is confined mostly to the southern and southeastern states where the growing season is from 150 to 175 days and the mean summer temperature over 72°. The plants make the best growth with frequent moderate rains during the late spring and early summer, but should have comparatively dry weather while maturing, otherwise it inclines the plants to excessive vine growth.

Tomato plants thrive best at a temperature of 75° to 85° during the day and about 60° at night. The fruit does not ripen well when the temperature is above 85°. Some studies in southwestern Ohio indicate that to produce the best yields in that region the month of May should be rather dry and cool; June, cloudy and wet; July, cool and wet, and September, clear and dry and not too warm. Tomato plants may safely be transplanted from the hotbed about two weeks earlier than eggplants or sweet potatoes. Bright sunshine, while tomatoes are in bloom, is favorable for a good setting of fruit, while cloudy and rainy weather is unfavorable.

Watermelons need plenty of moisture and will stand quite warm weather.

474. Cool-weather crops.—Some of these are the winter truck crops of the southern and Pacific Coast states and will endure temperatures below freezing without damage. Some varieties, however, are injured by frost and should not be planted until frost danger is over.

The cool-weather vegetables are divided into three general groups: (1) Short-season crops that cannot endure hot weather but will mature during the spring, and in some cases in the fall; (2) this group has a long growing season and must either be started under glass and transplanted as early as the ground can be worked; planted in the summer and allowed to make most of the growth in the fall; be grown as winter crops in the South, or as summer crops in the North where the season is cool; (3) relatively long season crops demanding cool moist weather during their early growth, but capable of enduring considerable heat after being well established. All of these crops need plenty of moisture.

Beans.—Although most varieties are very susceptible to frost damage and some thrive best in the continuously hot interior of California or in the dry districts of Arizona, most field and garden beans are best adapted to moderately cool moist climates. Yields are seriously decreased by especially hot dry periods when the plants are in bloom or when the seed-pods are setting. The lima bean grows to perfection in California only in the warm humid climate of the southern coast regions. The annual rainfall in this area is only 10 to 15 inches, but the ocean fogs are an important factor. In the interior valleys where it is hot and dry, the plants have given only a scant setting of pods. The small white or Navy bean, on the other hand, succeeds best in the cool humid climate of the coast region from San Francisco to Santa Barbara. There should be four full months of frost-free weather where beans are to be grown.

Beets.—Garden beets may be planted at about the average date of the last killing frost. This belongs to the third group mentioned above.

Cabbage is a winter crop in the South; an early spring or a fall crop in central districts, or a summer one in cool climates.

Carrots are an early crop that grows in warm weather also, but make the best growth late in the season in central districts.

Cauliflower cannot stand excessive heat. Early cauliflower should be set out about the date of the last average killing frost, and late varieties planted in summer for fall growth.

Celery is a winter crop in the South and a full season crop in the North where the summers are cool with a large amount of moisture.

Chard is capable of enduring considerable heat after the plants have become established.

Collards may be planted as early as the ground can be worked.

Kale is capable of withstanding considerable heat, but should be planted early.

Kohlrabi is an early planted short-season crop, and cannot endure great heat.

Lettuce heads best in cool weather. Head lettuce can be grown in greenhouses far better in eastern Massachusetts than in northern Ohio, possibly because of the greater amount of cloudy weather in northern Ohio in winter.

Mustard may be planted two weeks before the average last frost date. It is a short-season crop and cannot endure too hot weather.

Onion is one of the hardiest vegetables known. Well-established plants will endure temperatures of 12° to 14° and if given plenty of moisture will endure heat well. Onions require cool and moist weather in early growth but ripen better if it is drier.

Parsley should be planted about the average last killing frost date. It will endure heat if well established.

Parsnips need a long growing season and ripen properly only in cold weather.

Peas.—While heavy frost will kill the blossoms of most varieties, these plants will stand a temperature of 22° to 25° if not growing rapidly. The smooth peas are more hardy than the wrinkled variety. Hooker has found that in England the seed is greatly affected by the weather of the summer; it should be dry and cool.

Radishes are a short-season crop and may be grown in the spring, or in the fall if given plenty of moisture. They are of poor quality in hot weather and are of best quality when the soil is 90 per cent saturated; they make stunted poor plants when the saturation is 40 per cent, and a complete failure when only 10 per cent.

Rhubarb is a perennial crop that needs cool moist weather to make the most rapid tender growth.

Salsify and spinach are relatively long-season crops that should be planted about the average date of the last killing frost. They will endure considerable heat and drought after becoming established.

Turnips are a short-season crop. They will mature before hot weather if planted very early, or may be planted in summer and raised as a fall crop. Well-established plants are not severely injured by cold. Some varieties develop the best flavor only in the northern states where the nights are cool. They need cool and moist weather at seeding time.

475. Miscellaneous field and garden crops include those vegetables which cannot be regularly classed as warm- or cool-season crops.

Asparagus is cultivated under a wide range of temperature. It is resistant to extreme heat, endures drought, but will not endure extremely wet soil. It is one of the oldest vegetables known.

Hops require abundant moisture while making growth but sunny and moderately warm weather while the hops are developing and ripening.

Soybeans require about the same climate as corn. The pods may not fill well in hot weather in the extreme South.

Velvet beans grow well only when the weather is warm, and the young plants are very susceptible to frost. The higher the temperature when the seed is planted, the more rapid will be the growth and the shorter the time required to reach maturity.

476. Planting dates.—Fig. 66 shows the approximate dates for planting vegetables and may be followed with a reasonable degree of safety. The lines and zone areas are based on the last killing frost in the spring for the earliest planting, and on the average date of the first killing frost in the fall for the latest date.

FIG. 66.—Planting zones for vegetables in the eastern half of the United States. While these are the best dates, earlier and later plantings can be made with fair chance of success.

TABLE 37.—PLANTING DATES BY VEGETABLE GROUPS

Zone	*Group 1*	*Group 2*
A	Jan. 1 to Feb. 1	Feb. 1 to Feb. 15
B	Feb. 1 to Feb. 15	Feb. 15 to Mar. 1
C	Feb. 15 to Mar. 1	Mar. 1 to Mar. 15
D	Mar. 1 to Mar. 15	Mar. 15 to Apr. 15
E	Mar. 15 to Apr. 15	Apr. 15 to May 1
F[1]	Apr. 15 to May 1	May 1 to May 15
G[1]	May 1 to May 15	May 15 to June 1

Zone	*Group 3*	*Group 4*
A	Feb. 15 to Mar. 1	Mar. 1 to Mar. 15
B	Mar. 1 to Mar. 15	Mar. 15 to Apr. 1
C	Mar. 15 to Apr. 1	Apr. 1 to Apr. 15
D	Apr. 1 to May 1	May 1 to May 15
E	May 1 to May 15	May 15 to June 1
F[1]	May 15 to June 1	May 15 to June 15
G[1]	May 15 to June 15	(2)

Group 1. (May be planted two weeks before the average date of last killing frost.)—Early cabbage plants from hotbed or seed-box, radishes, collards, onion sets, early smooth peas, kale, early potatoes, turnips, and mustard.

Group 2. (May be planted about the average date of the last killing frost.)—Beets, parsnips, carrots, lettuce, salsify, spinach, wrinkled peas, cauliflower plants, celery seed, onion seed, parsley, sweet corn, and Chinese cabbage.

Group 3. (Should be planted two weeks after the average date of last killing frost.)—Snap beans, okra, and tomato plants.

Group 4. (Cannot be planted until ground is well warmed up; about a month after last hard frosts.)—Lima beans, pepper plants, eggplants, cucumbers, melons, squash, and sweet potatoes.

WHITE OR "IRISH" POTATOES

Potatoes rank first as a world food crop on the basis of actual pounds produced, although more people depend on rice as a staple article in the daily ration. Over 90 per cent of the world's production of potatoes is grown in Europe.

477. Range in the United States.—The potato is the most widely distributed crop in this country, although in 1916 about one-half of the crop was raised in eight states.

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[1] For the crops grown.

[2] Season too short for this group.

In the five years from 1913 to 1917, the states with the highest average production, in the order named, were New York, Michigan, Wisconsin, Minnesota, and Maine, each of which produced over 24,000,000 bushels.

478. Planting and harvesting.—Figs. 67 and 68 show the average date of the beginning of planting and harvesting of early potatoes. The number of days from planting to harvesting of the early crop varies from 80 to 100.

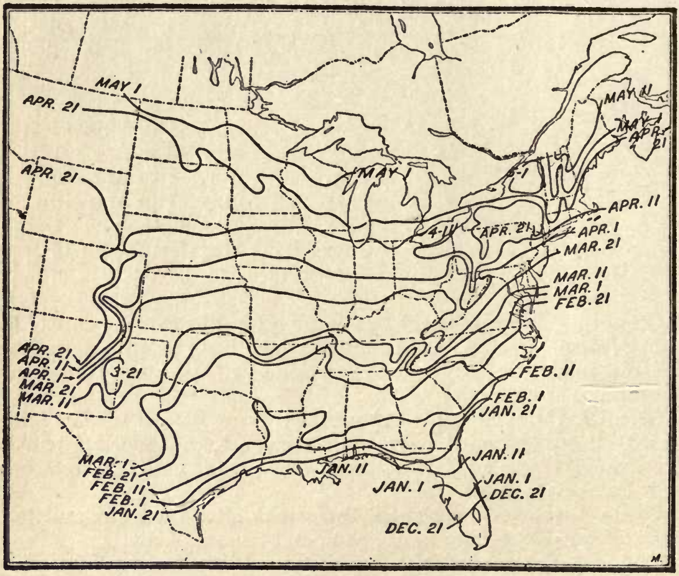

FIG. 67.—Average dates when the planting of early potatoes begins.

479. Temperature at beginning of planting.—The planting of early potatoes generally begins when the mean daily temperature in the spring rises to about 45°. The planting of early potatoes is nearly one month earlier than the average date of the last killing frost in the spring. As it takes less than one month for potatoes to come up, the crop is often subject to damage by late spring frosts.

480. Temperature requirements.—The white or "Irish" potato is a cool-weather crop. It originated in Peru, South

America, where the crop is grown at the present time at an elevation sufficiently high to make the average annual temperature about 52°. The mean temperature varies from about 48° in July to 54° in November. Regions in which the temperature rises to 85° or above for many successive days are not adapted to maximum yields.

FIG. 68.—The beginning of the harvest of early potatoes.

Potato production has made the greatest development in the United States where the mean annual temperature is between 40° and 50° and where the mean temperature of the warmest month is not over 70°. The greatest yields to the acre are in those states where the mean annual temperature is below 45° and where the mean of the warmest month is not far from 65°. In the southern states potatoes are a winter crop.

481. Water requirement.—At the Maine Experiment Station it was found that it takes about 425 tons of water to grow 1 ton of dry matter of potatoes and therefore that a crop of 200 bushels to the acre will require approximately 650 tons of water. Investigations in northeastern Colorado as well as in Utah determined that the weight of water absorbed during the growth of potatoes to the weight of dry matter produced was close to 450. The weight of water falling on 1 acre of land to the depth of 1 inch is 112.7 tons. Hence if the growing plants could use all of the water, it would require a rainfall between 5 and 6 inches between planting and harvesting to raise a 200-bushel crop.

The actual record of the rainfall in much of the country between planting and harvesting of the early potato crop is between 8 and 10 inches.

482. Distribution of water.—Experiments show that potatoes need a uniform distribution of water. A five-year test in Utah demonstrated that 1 inch of water weekly, or a total of 12.8 inches during the season gave a higher yield than any other treatment. When but one irrigation was given, the best results were obtained if applied when the potatoes were in full bloom.

483. Weather and potatoes in Ohio.—The following table shows the effect of rainfall or temperature on the yield of potatoes in Ohio:

TABLE 38.—CORRELATION BETWEEN THE RAINFALL AND TEMPERATURE AND THE YIELD OF POTATOES IN OHIO, 1860 TO 1914

Period	*Rainfall*		*Temperature*	
	Correlation coefficient	*Probable error*	*Correlation coefficient*	*Probable error*
April	−0.21	±0.09	———	———
May	0.06	±0.10	−0.10	±0.09
June	0.10	±0.09	−0.22	±0.09
July	0.33	±0.08	−0.51	±0.07
August	0.22	±0.09	−0.31	±0.08
September	−0.13	±0.09	−0.21	±0.09
October	0.07	±0.10	−0.11	±0.09
June, July comb.	———	———	−0.50	±0.07
July, August comb.	0.37	±0.08	−0.50	±0.07
June, July, Aug. comb.	———	———	−0.49	±0.07

484. Effect of varying rainfall.—Remembering that the correlation should be at least three times the probable error to indicate an appreciable effect and that if it is six times the probable error there is plainly considerable relation shown, it will be seen at once that the rainfall in Ohio is not a dominating factor in varying the yield of potatoes, when considered for calendar months. July and July and August combined show a fairly high relation, but this is not high enough to be important.

485. Effect of temperature.—The last two columns of Table 38, however, show that the yield is affected by the temperature variation and also that the summer should be cool.

486. July most important.—The highest correlation between the July temperature and potato yield is −0.51 for July and this is more than seven times the probable error. This indicates that July should be cooler than normal in Ohio for the best potato yields. Fig. 14 shows graphically the relation between the mean temperature in July and the yield of potatoes in Ohio. It makes plain that cool weather is most desirable, while a warm July is nearly always followed by a poor yield. If only those years are considered when the temperature variation is 1 degree or more from the normal it is found that when July is warm the probability of a good potato crop is only 12 per cent, and when July is cool the probability of the potato crop being greater than the average is 77 per cent.

487. Some temperature and yield comparisons.—By tabulating the years by variations in mean temperature for the month of July in Ohio, some interesting changes are shown in the yield figures, as indicated in the following table:

TABLE 39.—VARIATIONS IN YIELD OF POTATOES IN OHIO WITH VARYING AVERAGE TEMPERATURES IN JULY, 1860 TO 1914

July mean temperature (Deg. F.)		*Potato yield (bushels)*	
Groups	*Average*	*Years*	*Average*
Below 72.6	71.5	16	86.6
72.6 to 73.5	73.1	13	80.0
73.6 to 74.5	74.1	11	76.5
Above 74.5	76.3	15	67.7

This table shows an average decrease in the yield of potatoes in Ohio of 6.3 bushels to the acre with each increase of 1.6° in the average temperature for the month of July. Taking into account the acreage devoted to potatoes in this state and the average farm price during the past ten years, it is found that for every increase in the average temperature for the month of July of 1.6°, the value of the potato crop in Ohio has been reduced $4.03 an acre, or a total of 1,096,200 bushels, worth $701,568.

There were sixteen years during the period when the temperature averaged below 72.6°, and fifteen years when it averaged above 74.5°, and by tabulating the yield figures during these years an average variation in the yield of 18.9 bushels to the acre is found, or an average of 3,288,600 bushels, worth $2,104,704.

488. Combined effect of temperature and rain, Ohio.—In Fig. 69 the combined effect of the temperature and rainfall for the month of July is indicated. The diagram shows that there were thirteen years during the fifty-six when July in Ohio was warm and wet, and that in these years there were ten with a yield below the normal and three with a yield above the normal. This indicates that when July is warm and wet, the probability of a good potato yield in Ohio is only 23 per cent. When July is warm and dry, the diagram shows ten years with the yield below the normal and four with the yield above the normal. This indicates that when July is warm and dry, the probability of a potato yield above the normal is only 29 per cent. When July has been cool and dry, there have been seven years with a yield above the normal and seven years below the normal, indicating that the probability of a good potato crop with these conditions is just 50 per cent. When it has been cold and wet, however, the chart shows only three years with a yield below the normal and twelve with a yield better than the average. This indicates a probability of 80 per cent that the yield will be above the normal in Ohio if July is cool and wet.

489. In New Jersey.—In the state of New Jersey in the past thirty-three years the yield of potatoes has been below the normal every year but two, when the average temperature in July has been 1 degree or more above the normal. And when the mean temperature for July has been below the normal, the yield has been greater than the average every year but two. There have been eleven years when the temperature in July has averaged 1 degree or more above the normal and the average yield of potatoes for those years has been 12 bushels to the acre less than the normal. There have been twelve years when the temperature has averaged 1 degree or more lower than the normal and during these years the potato yield has averaged 13 bushels to the acre greater than the normal.

This makes an average difference of 25 bushels of potatoes to the acre in New Jersey depending on whether the month of July is appreciably warmer or cooler than the average.

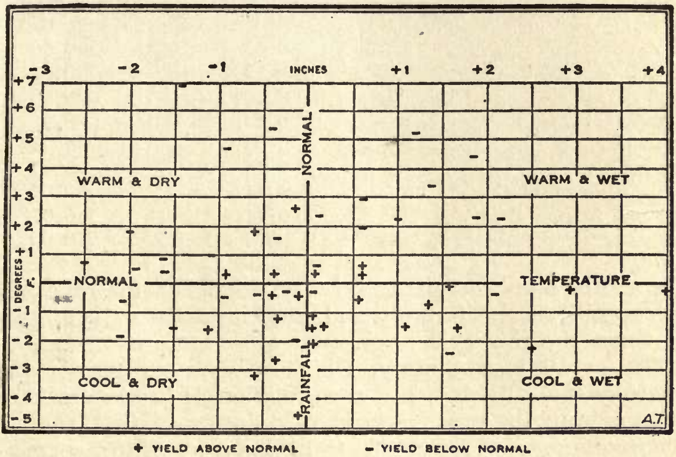

FIG. 69.—The combined effect of the July temperature and rainfall on the yield of potatoes in Ohio, 1860 to 1915.

Taking the figures for 1916 as a basis for calculation, this means a difference in the total potato yield of 2,125,000 bushels, worth $1,290,760. The average increase in the value of the potato crop an acre in New Jersey is thus close to $21, if July is cool over what it is when July is very warm.

490. In Wisconsin.—A correlation between the July temperature and the yield of potatoes in Wisconsin for twenty-seven years gives a correlation coefficient of −0.39, probable error ±0.11.

491. In Michigan.—The correlation coefficient between the July temperature and yield of potatoes in Michigan covering a period of twenty-eight years is −0.54 or five times the probable error.

492. In Licking County, Ohio.—The following tabulation gives the correlation between the temperature and the yield of potatoes in Licking County, Ohio, for the period from 1860 to 1913:

TABLE 40.—CORRELATION BETWEEN TEMPERATURE AND YIELD OF POTATOES IN LICKING COUNTY, OHIO

Period	*Correlation coefficient*	*Probable error*
April	−0.01	±0.09
May	+0.06	±0.09
June	−0.29	±0.08
July	−0.36	±0.08
August	−0.28	±0.09
September	−0.23	±0.09
October	−0.15	±0.09
June, July combined	−0.44	±0.07
July and August combined	−0.44	±0.07
August and September combined	−0.15	±0.09

It will be seen that the correlation coefficient for June and July combined and for July and August combined is almost six times the probable error.

493. In Portage County, Ohio.—This is an important potato-growing county, but a correlation of the weather of different months and the yield of potatoes in that county covering the period from 1860 to 1913 gives very low correlation coefficients. This is probably due to the fact that the blooming period comes about the middle of August and that warm weather is needed before blooming and cool after blooming; thus the effect is neutralized.

494. Critical period of growth.—The tables following give phenological dates and data in connection with the growth of potatoes at Wauseon, Ohio, kept by Thomas Mikesell.

Table 41.—Phenological Dates and Data for Growth of Early Potatoes at Wauseon, Ohio, 1883 to 1912, by Thomas Mikesell

(Lat., 41° 35′ N., long., 84° 07′ E.; alt., 780 feet A. M. S. L.)

Year	*Date planted*	*Date above ground*	*Date in bloom*	*Date ready for use*	*Date ripe*	*Per cent of good crop*	*Quality of crop*
1883[1]	April 12	May 8	June 10	June 30	Aug. 20	...	.....
1884	21	14	18	July 2	July 30	...	.....
1885	23	19	25	9	31	...	.....
1886	22	9	12	June 24	July 20	85	Good
1887	26	11	18	30	25	100	Good
1888	23	18	20	July 10	Aug. 8	70	Good
1889	22	11	21	June 27	15	95	Good
1890	25	13	14	22	July 28	50	Fair
1891	24	11	17	June 29	Aug. 7	95	Good
1892	28	14	20	July 1	15	90	Good
1893	24	15	16	5	1	60	Good
1894	17	1	8	June 25	1	60	Good
1895	27	7	17	July 10	20	60	Good
1896	May 1	12	14	June 19	8	100	Good
1897	6	20	25	July 10	July 28	60	Good
1898	21	30	29	30	Aug. 20	...	....
1899	April 26	6	10	June 20	5	80	Good
1900	28	......	......	......	......	...	.....
1901	17	......	June 20	......	....	...	.....
1902	21	......	8	June 23	....	...	.....
1903	....	......	May 28	......	....	...	.....
1904	May 5	May 17	June 20	......	Sept. 12	75	Good
1905	4	10	6	June 27	Aug. 25	80	Good
1906	April 24	10	11	July 3	Sept. 1	80	Good
1907	May 4	14	18	7	Aug. 20	45	Good
1908	April 22	10	8	12	1	50	Good
1909	May 5	12	8	3	5	60	Good
1910	April 8	8	18	10	20	85	Good
1911	May 4	25	24	8	July 28	40	Fair
1912	April 16	9	16	June 28	July 25	75	Good
Average	April 26	May 13	June 15	July 2	Aug. 9	72	.....

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[1] Data for the years 1883 to 1901, inclusive, apply to Mikesell's own farm; data for 1902 to 1912 apply to certain nearby fields the same field being used for the entire season.

TABLE 42.—CONSTANTS DURING THE GROWTH OF POTATOES AT WAUSEON, FULTON CO., OHIO, 1883 TO 1912

	Time					*Total effective temperature (above 43° F)*				*Total rainfall*			
	From planting to above ground	*From above ground to bloom*	*From above ground to ready for use*	*From bloom to ripe*	*From planting to ripe*	*From planting to above ground*	*From above ground to bloom*	*From bloom to ripe*	*From planting to ripe*	*From planting to above ground*	*From above ground to bloom*	*From bloom to ripe*	*From planting to ripe*
Year	*Ds.*	*Ds.*	*Ds.*	*Ds.*	*Ds.*	*F*	*F*	*F*	*F*	*In.*	*In.*	*In.*	*In.*
1883	26	33	53	71	130	215	502	1,737	2,454	1.0	6.7	10.8	18.5
1884	23	35	50	42	100	272	764	1,163	2,199	2.6	2.9	5.0	10.5
1885	26	37	51	36	99	244	836	1,090	2,170	3.4	6.9	3.2	13.5
1886	17	34	46	38	89	242	630	1,036	1,908	1.4	2.3	1.8	5.5
1887	15	38	50	37	90	243	906	1,311	2,460	1.3	4.7	4.4	10.4
1888	25	33	53	47	105	269	731	1,418	2,418	2.0	2.3	4.0	8.3
1889	19	41	47	55	115	273	707	1,455	2,435	0.1	11.4	6.8	18.3
1890	18	32	40	44	94	143	680	1,177	2,000	5.5	1.6	4.0	11.1
1891	17	37	49	51	105	200	720	1,349	2,269	0.8	3.2	4.4	8.4
1892	16	37	48	56	109	171	746	1,617	2,534	7.4	10.4	6.1	23.9
1893	21	32	51	46	99	153	675	1,378	2,206	5.2	3.9	5.2	14.3
1894	14	38	55	54	106	183	553	1,738	2,474	2.4	4.0	3.1	9.5
1895	10	41	64	64	115	240	868	1,976	3,084	1.2	1.8	2.5	5.5
1896	11	33	38	55	99	285	749	1,617	2,651	0.7	4.9	13.7	19.3
1897	14	36	51	33	83	234	678	1,031	1,943	2.0	3.3	4.6	9.9
1898	9	30	61	52	91	188	801	1,570	2,559	0.7	3.6	6.7	11.0
1899	11	35	45	56	102	275	729	1,653	2,647	1.0	4.1	5.2	10.3
1900–1903													
1904	12	34	..	83	129	148	687	2,075	2,910	0.6	3.3	8.0	11.9
1905	6	27	48	80	114	64	422	2,178	2,664	1.0	6.8	9.5	17.3
1906	16	32	54	82	130	151	718	2,280	3,149	0.9	3.0	10.2	14.1
1907	10	35	54	63	108	103	480	1,717	2,400	0.5	5.9	6.3	12.7
1908	18	29	63	54	101	124	665	1,507	2,296	1.8	4.9	7.7	14.4
1909	7	27	52	58	92	76	495	1,532	2,103	2.4	3.5	7.6	13.5
1910	30	41	63	63	134	202	593	1,841	2,636	5.8	2.6	6.4	14.8
1911	21	30	44	34	85	505	802	963	2,270	0.5	3.9	6.5	10.9
1912	23	38	50	39	100	223	723	1,062	2,008	1.7	6.1	1.7	9.5
Aver.	17	34	50	55	106	209	687	1,518	2,414	2.1	4.5	6.0	12.6

A correlation between the thermal constants and rainfall and the potato yield gives the following:

TABLE 43.—CORRELATION BETWEEN THERMAL CONSTANTS AND POTATO YIELD, WAUSEON, OHIO, 1883 TO 1912

Period	*Correlation coefficient*	*Probable error*
From date of planting to date above ground..	0.03	±0.12
From date above ground to date of bloom....	0.24	±0.12
From date of bloom to date ripe..........	0.16	±0.12
From date planted to date ripe..............	0.25	±0.11
For 10 days before blooming................	0.17	±0.12
For 10 days after blooming.................	−0.30	±0.11

TABLE 44.—CORRELATION BETWEEN RAINFALL AND POTATO YIELD, WAUSEON, OHIO, 1883 TO 1912

Period	*Correlation coefficient*	*Probable error*
For 10 days before planting.................	0.02	±0.12
From date planted to date above ground.....	−0.06	±0.12
From date above ground to date in bloom....	0.33	±0.11
From date in bloom to date ripe............	0.18	±0.12
For 10 days before blooming................	0.09	±0.12
For 10 days after blooming.................	−0.07	±0.12

From these tables it is evident that cool weather is desirable during the ten days after blooming and that it should be fairly wet before blooming.

495. Correlation for short periods.—A correlation of the temperature and rainfall with the potato yield in three counties in central Ohio for the period from 1891 to 1910 gives the following:

TABLE 45.—CORRELATION BETWEEN WEATHER FOR 10-DAY PERIODS AND THE YIELD OF POTATOES IN CENTRAL OHIO FOR THE YEARS 1891 TO 1910

Period	*Rainfall*		*Temperature*	
	Correlation coefficient	*Probable error*	*Correlation coefficient*	*Probable error*
June 1 to 10.....	0.29	±0.12	−0.12	±0.13
June 11 “ 20.....	0.32	±0.12	−0.17	±0.13
June 21 “ 30.....	0.16	±0.13	−0.28	±0.12
July 1 “ 10.....	0.48	±0.10	−0.44	±0.11
July 11 “ 20.....	−0.29	±0.12	−0.33	±0.12
July 21 “ 31.....	−0.12	±0.13	−0.33	±0.12
Aug. 1 “ 10.....	0.06	±0.13	−0.23	±0.13
Aug. 11 “ 20.....	0.37	±0.11	−0.36	±0.11
Aug. 21 “ 31.....	−0.26	±0.12	−0.38	±0.11

TABLE 46.—CORRELATION OF WEATHER FOR 20-DAY PERIODS WITH POTATO YIELD IN CENTRAL OHIO, 1891 TO 1910

Period	*Rainfall*		*Temperature*	
	Correlation coefficient	*Probable error*	*Correlation coefficient*	*Probable error*
June 1 to 20.....	0.48	±0.10	−0.19	±0.13
June 11 “ 30.....	0.30	±0.12	−0.27	±0.12
June 21 “ July 10.	0.44	±0.11	−0.61	±0.09
July 1 “ 20	0.03	±0.13	−0.54	±0.10
July 11 “ 31.....	−0.23	±0.12	−0.41	±0.11
July 21 “ Aug. 10.	−0.08	±0.13	−0.42	±0.11
Aug. 1 “ 20.....	0.29	±0.12	−0.36	±0.11
Aug. 11 “ 31.....	0.22	±0.12	−0.43	±0.11

TABLE 47.—CORRELATION OF WEATHER FOR 30-DAY PERIODS WITH POTATO YIELD IN CENTRAL OHIO, 1891 TO 1910

Period	*Rainfall*		*Temperature*	
	Correlation coefficient	*Probable error*	*Correlation coefficient*	*Probable error*
June 1 to 30.....	0.42	±0.11	−0.33	±0.12
June 11 “ July 10.	0.58	±0.09	−0.53	±0.10
June 21 “ July 20.	0.26	±0.12	−0.61	±0.09
July 1 “ 31.....	0.002	±0.13	−0.57	±0.09
July 11 “ Aug. 10.	−0.20	±0.13	−0.51	±0.10
July 21 “ Aug. 20.	0.19	±0.13	−0.49	±0.10
Aug. 1 “ 31.....	0.11	±0.13	−0.35	±0.11

TABLE 48.—CORRELATION OF WEATHER FOR 40-DAY PERIODS WITH POTATO YIELD IN CENTRAL OHIO, 1891 TO 1910

	Rainfall		*Temperature*	
Period	*Correlation coefficient*	*Probable error*	*Correlation coefficient*	*Probable error*
June 1 to July 10.	0.59	±0.09	−0.58	±0.09
June 11 " July 20.	0.35	±0.11	−0.58	±0.09
June 21 " July 31.	0.09	±0.13	−0.62	±0.09
July 1 " Aug. 10.	0.02	±0.13	−0.63	±0.09
July 11 " Aug. 20.	0.02	±0.13	−0.54	±0.10
July 21 " Aug. 31.	0.06	±0.13	−0.51	±0.10

TABLE 49.—CORRELATION OF WEATHER FOR 50-DAY PERIODS WITH POTATO YIELD IN CENTRAL OHIO, 1891 TO 1910

	Rainfall		*Temperature*	
Period	*Correlation coefficient*	*Probable error*	*Correlation coefficient*	*Probable error*
June 1 to July 20.	0.44	±0.11	−0.58	±0.09
June 11 " July 31.	0.20	±0.13	−0.54	±0.10
June 21 " Aug. 10.	0.09	±0.13	−0.65	±0.08
July 1 " Aug. 20.	0.17	±0.13	−0.67	±0.08
July 11 " Aug. 31.	−0.05	±0.13	−0.52	±0.10

These tables show that the period covering the first ten days in July is a critical one for potatoes in central Ohio when it should be cool and wet. The correlation coefficient for temperature is four times the probable error and for rainfall nearly five times the probable error.

The most critical twenty-day period is from June 21 to July 10; the most important thirty days from June 11 to July 10 for rainfall and June 21 to July 20 for temperature; the most important forty days from June 1 to July 10 for rainfall and from July 1 to August 10 for temperature; and the most important fifty days from June 1 to July 20 for rainfall and from July 1 to August 20 for temperature.

The temperature correlation emphasizes the previous determinations that relatively cool weather is needed for potatoes.

496. Diseases of potato plants.—The foliage of the potato plant is particularly subject to diseases which are affected by weather conditions to a marked degree. Early blight, and the Fusarium dry-rot are dry-weather diseases, while late blight develops in wet and cool weather in some districts and in wet and hot weather in others. Sun-scald occurs when bright and hot weather follows suddenly a moist and cloudy period.

Other diseases such as brown-rot, rosette, potato-wilt, and dry-end rot affect the foliage in particular sections of the country, and it seems probable that a further study of these will show that most of them are more or less severe under certain weather conditions.

497. Late blight.—The so-called "late blight" of potatoes is the most serious of all potato diseases and is due to the fungus *Phytopthora infestans.* The potato rot resulting from this disease caused very great loss in eastern North America in 1842, 1845, and 1874, and there was a general outbreak in New England and New York in 1901, 1902, and 1903. In 1845 the disease spread through Great Britain, Ireland, and Belgium, and the terrible Irish famine of that year was due to the almost total loss of the potato crop of Ireland from this disease during the preceding summer.

This disease is undoubtedly favored by moist weather. Rainfall apparently has much to do with the spread of the disease, particularly if heavy rain is followed by cloudy weather and still air, when the moisture will cling to the leaves for a long time. If the rainfall is followed by clear skies and sufficient wind to evaporate the moisture rapidly from the potato leaves, then the disease will be checked.

498. Effect of temperature on late blight.—Writers in some parts of the country state that late blight will develop with a spell of warm, moist, "muggy" weather, while in other sections it will be noted that a serious outbreak of late blight has followed a period of cool moist weather.

In Bulletin 245 of the United States Bureau of Plant Industry, the following statement is made as to the effect of temperature on *Phytopthora infestans:*

> Exposing test-tube cultures for 10 minutes at temperatures up to 40° C. did not prevent the later development of the fungus; beyond this temperature inhibition resulted. Where cultures were held at constant temperatures the best growths resulted between 16° and 19° C. (60.8° and 66.2° F.) Below 16° C., the growth was slower and below 5° C. (41.0° F.) it was wholly inhibited. At and above 23° C., (73.4° F.) the growth was inhibited, with no sporulation above 25° C. (77° F.) and no vegetative growth at or above 30° (86° F.).

A. D. Selby, in the "Ohio Naturalist" for February, 1907, quoting from Scribner says: "A temperature ranging from 65° to 75° F. produces conditions favorable for the disease;" and quoting from Galloway, "A daily mean or normal temperature of from 72° to 74° for any considerable time, accompanied by moist weather, furnishes the best conditions for the spread of the disease."

499. Most favorable temperatures.—It should be noted that while the authors quoted above do not agree as to the most favorable temperatures for the spread of late blight, in one instance the writer refers to tests made under constant temperatures while the other two refer to mean daily temperatures, when the temperature would be higher than the optimum in the daytime and lower in the night.

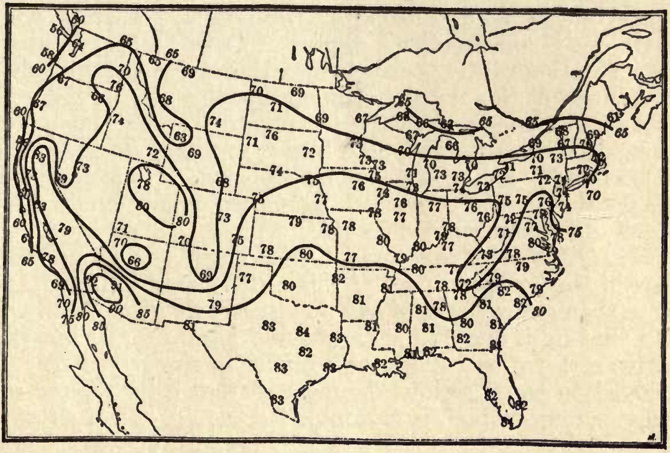

FIG. 70.—Average highest mean daily temperature during the warmest part of the season.

It is probable, therefore, that the most favorable open-air temperature condition is when the mean daily temperature is between 70° and 74°. Also that the development of the disease is checked if the mean daily temperature is above 75° for a few days, and that the spores are killed at a temperature of 77° to 80°.

500. Temperature terms relative.—In Fig. 70 there has been entered the highest mean daily temperature during the warmest part of the year at each of the Weather Bureau stations. Isothermal lines have been drawn for each 5 degrees. This chart shows that in extreme northern parts of the country and in the higher parts of the Rocky Mountain states, the mean summer temperature is generally too low for the best development of late blight in potatoes and that practically all of the central and southern districts are too warm for the disease to get a foothold. This makes plain also why in Maine late blight is a disease of "warm" moist weather, while in Ohio it is spoken of as a disease of "cool" moist summers. An inspection of the yearly temperature records would show that north of this normal temperature line of 70°, there are seasons or periods when the temperature is high enough to cause an outbreak of the late blight, and that even south of the line of 75° a season might be cool enough to cause loss to the potato crop. The critical district would be along the line of 70°, as shown on this chart.

501. Time of development.—It must be remembered that in the southern part of this critical area it would take more than a few weeks of cool weather to develop the disease and that even one cool season would hardly do it; but that with a series of cool summers it might become sufficiently developed to cause serious damage, so that even with a cool moist summer which is favorable for the growth of potatoes there might result a very poor yield, due to loss by late blight. One warm and dry season, although unfavorable for the yield of potatoes, would kill out the Phytopthora so effectually that it would take another series of cool years for it to become again established.

HAY AND FORAGE CROPS

The acreage of hay and forage crops in the United States is second only to corn. Their distribution depends on a combination of climatic and economic factors. The area with the highest relative acreage lies from eastern Kansas, Nebraska, and South Dakota eastward to New England.

502. Climatic factors.—This region has a generous snowfall and generally a good snow-cover during cold winter weather, the summer rainfall is well distributed, and, in the northern part of the region, the summers are cool.

503. Weather and yield of hay.—A study made several years ago covering sixteen states in the northeastern part of the country showed that the rainfall for May had a large influence on the yield of hay. This and the further fact that the price of hay is influenced by the yield aided materially in a decision of the Inter-State Commerce Commissioners in a celebrated hay-rate case involving several million dollars. It has been stated that in order to produce a ton of dry hay on

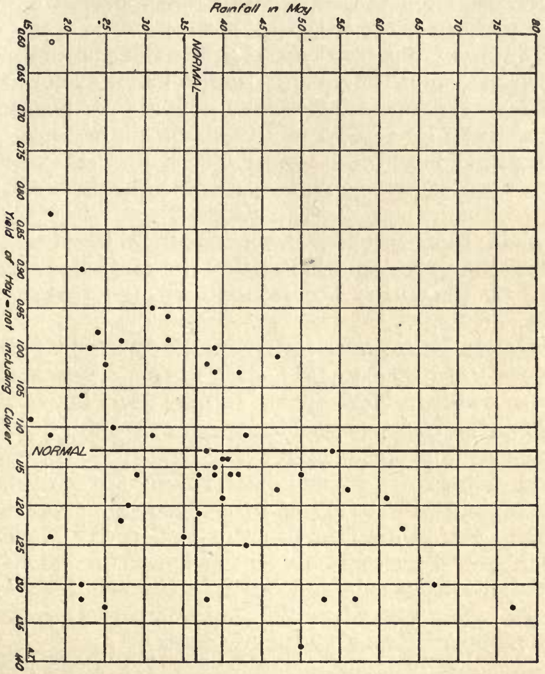

FIG. 71.—Relation between the rainfall in May and the yield of hay (not including clover) in Ohio, 1858 to 1909.

an acre of land, it is necessary that the growing grass pump up from that acre approximately 500 tons of water.

504. Hay in Ohio.—A comparison of the rainfall in May and the yield of hay in Ohio for the years from 1858 to 1909, gave a correlation of +0.49 with a probable error of ±0.07. The correlation for April and May was the next highest or +0.45, probable error ±0.07.

Fig. 71 gives a dot chart showing the relation between the rainfall in May and the yield of hay in Ohio. This indicates that a May rainfall of more than 1 inch above the normal, is always followed by a yield of hay above the normal. When the rainfall has been more than 1 inch below the normal, the yield has been below the normal eleven times and above five times.

It is plain, therefore, that other influences besides the May rain affect the yield, especially when the rainfall is light, as a large yield is frequently harvested following a comparatively dry May.

505. Hay in New York.—A recent study covering twenty-three years, from 1888 to 1911, showed that a normal rainfall is most favorable in New York. In nine years out of twenty-three when the rain was within 2 per cent of the normal, the yield was over 8 per cent above the average. That this crop does not appear to utilize much more than the normal amount of moisture is indicated by the fact that in seven years when the rainfall was 27 per cent above normal, the yield was only 5 per cent above the average. On the other hand, a slight deficiency resulted in a marked decline in the yield. In five years when the deficiency was marked, the yield was 32 per cent below the average.

506. Hay in Wisconsin.—The correlation between weather and the yield of hay in Wisconsin for twenty-seven years is indicated in the following:

TABLE 50.—CORRELATION BETWEEN WEATHER AND YIELD OF HAY IN WISCONSIN

	Rainfall		*Temperature*	
Month	*Correlation coefficient*	*Probable error*	*Correlation coefficient*	*Probable error*
April......	+0.05	———	−0.24	±0.12
May.......	+0.38	±0.11	−0.11	———
June.......	+0.25	±0.12	−0.58	±0.09

507. Hay in other states.—The following shows the correlation of the rainfall for April and May with the yield of hay for different states:

TABLE 51.—CORRELATION OF RAINFALL FOR APRIL AND MAY WITH YIELD OF HAY

		Rainfall			
		April		*May*	
State	*Years*	*Correlation coefficient*	*Probable error*	*Correlation coefficient*	*Probable error*
California	19	+0.12	±0.13	−0.017	±0.19
Iowa	26	+0.16	±0.13	+0.56	±0.09
Nebraska	40	+0.10	±0.11	+0.45	±0.09
New Mexico	24	+0.07	±0.13	+0.18	±0.13
New York	26	+0.44	±0.11	+0.003	———
North Dakota	24	+0.12	±0.13	+0.35	±0.12
Oklahoma	14	+0.85	±0.05	+0.28	±0.15
Tennessee	33	−0.18	±0.11	+0.32	±0.10
Washington	26	−0.58	±0.08	+0.07	±0.13
Wisconsin	25	−0.02	±0.13	+0.44	±0.11

508. June rain.—Charts of the relation between the June rain and the hay yield indicate that the later rain has considerable effect on the yield in North Dakota, but not in Wisconsin or any of the southern or western states given in the above table. In New Jersey and in more southern districts, it is probable that the April or even March weather may have a greater influence than that of later months.

509. Alfalfa requires more water than most crops, but the ability of the plant to send its roots to great depths makes it very drought-resistant and a valuable crop for semi-arid regions. It is found that alfalfa thrives best where the water-table is at a fairly uniform height.

510. Alfalfa and temperature.—Alfalfa is able to withstand high temperatures when the air is dry, but if accompanied by humid air high temperatures are injurious. If a hard freeze occurs soon after the plants come up, especially when the soil is damp, a large proportion may be killed. Alfalfa is liable to be winter-killed with freezing and thawing of the ground without snow-cover. An ice-sheet is very damaging.

511. Alfalfa in Nevada.—Alfalfa develops the highest food values when there is a high percentage of sunshine and the days are moderately warm and the nights cool. Enough moisture is needed to keep the soil in good condition, but too much cloudy weather is detrimental to the growth of slender stalks and a large number of leaves. Hot days and warm nights with much moisture cause the plant to develop a woody stock and fewer leaves. Plenty of sunshine, moderately warm days and cool nights cause alfalfa to develop more chlorophyll, which gives the plant more nutriment.

512. Curing alfalfa.—As this plant cures slowly, a good crop is frequently greatly damaged in harvesting in the humid sections of the country where rains are frequent. The importance of cutting during good weather has led to the establishment of an alfalfa fair weather warning service by the United States Weather Bureau. Forecasts of three or four days or more of fair weather are made and widely distributed in the principal alfalfa-growing districts during the harvesting season.

513. Alfalfa seed and frost.—Alfalfa seed ripens unevenly and the best plants, setting burrs heavily well down on the lower stems, will contain many green burrs, yellow burrs (turning ripe), and brown or ripe burrs at the same time. The yellow stage of the burr endures for about one week in Utah under ordinary conditions during which time the seed, if cut, will ripen from sustenance in the parent stem, if in good condition. The seed-growers estimate that near harvest time the crop increases in value about $5 an acre each twenty-four hours. For this reason it is desired that the crop be allowed to stand as long as unripe seeds remain. A light frost or a temperature of 31° or 32° in the alfalfa foliage is harmless to the brown burrs, but will injure the exposed yellow burrs and some of the green burrs. A temperature of 26° to 28° in the foliage will cause heavy damage to both yellow and green heads, the injury varying with the amount of leaf foliage and the proportion of these immature burrs. The effect of the frost is to blacken the seed, making it less salable and probably less viable.

514. Alfalfa seed warning service, Utah.—When the frost warning service is in operation, the seed is left standing until a warning is received. On receipt of the warning, as many mowers as are available are sent into the field and cutting is sometimes continued on moonlight nights well into the night. When cut, whether left flat or raked into windrows, comparatively little of the seed will be damaged. Tens of thousands of dollars worth of seed will be saved in this way on receipt of a frost warning.

515. Clover thrives best in a humid climate, and where the winter and summer temperatures are not extreme. It is said that white clover will withstand greater temperature extremes than either red or alsike. Crimson clover is less resistant to low temperatures than the other common clovers. Sweet clover thrives best in rather humid regions, but also grows well in semi-arid districts. This crop is adapted to a wide range in temperature.

516. Weather and clover.—A correlation between the weather and yield of clover in Ohio covering a period of twelve years gave the following:

TABLE 52.—CORRELATION BETWEEN WEATHER AND YIELD OF CLOVER IN OHIO

		Rain		*Temperature*	
District	*Period*	*Correlation coefficient*	*Probable error*	*Correlation coefficient*	*Probable error*
Franklin Co.	Winter	———	———	−0.43	±0.15
Ohio	"	———	———	−0.32	±0.17
Ohio	Jan.	———	———	−0.38	±0.16
Ohio	March	———	———	+0.75	±0.08
Franklin Co.	"	———	———	+0.14	———
Ohio	April	+0.50	±0.14	−0.51	±0.14
Franklin Co.	"	+0.12	———	−0.28	———
Ohio	May	———	———	−0.41	———
Franklin Co.	May	+0.38	±0.16	———	———

517. Clover in Ohio.—A more extensive study of weather and clover yield in Ohio for the period from 1864 to 1913 gave correlations as follows:

TABLE 53.—CORRELATION BETWEEN WEATHER AND YIELD OF CLOVER IN OHIO, 1864–1913

	Rainfall	
Period	*Correlation coefficient*	*Probable error*
April	+0.15	±0.09
May	+0.32	±0.09
June	−0.09	——
July	+0.08	——

It is probable that the weather during the winter has a greater effect on the yield of clover than the rainfall of the spring or summer.

518. Clover seed.—Dry weather is unfavorable for clover, but favorable for the seed crop because fertilization by bees can go on better. The pollen grains of red clover are particularly sensitive to moisture, hence there is little effective pollination when the flowers are wet. The time between pollination and fertilization varies with the temperature. In July it is about eighteen hours and in October, thirty-five to fifty hours.

519. Timothy thrives best in a moist cool climate. It is unable to endure hot and dry summer weather and is not grown south of latitude 36° except at high elevations. The greatest number of flowers bloom in the early morning hours, from about midnight until the time of or soon after sunrise. The number of flowers that bloom each day, and also to some extent the time of blooming, are affected by weather conditions, especially temperature. Clear weather and a minimum temperature of about 60° or above are most favorable. Timothy flowers have not been observed blooming when the temperature during the preceding twenty-four hours was as low as 50° F.

520. Millet needs a fairly large amount of rain and must have warm weather during the growing season. It was found in Russia that between the formation of the leaves and the appearance of the flowers, temperature is the most important factor and should not fall below 18° C. (64.4° F.). Severe cold delays the appearance of the blossoms. The period between the flowering and the ripening of the grain was most critical for rainfall. Millet has a comparatively shallow root system and therefore can well use light rains.

521. Sorgo has a much deeper root system than millet and can use water from a lower depth. This crop can cease to grow during a dry spell and when a good rain comes will revive and make a rapid growth. Both crops have a very low water requirement and mature quickly.

522. Cowpeas are adapted to those sections with warm summers.

523. Rape grows best under cool and moist conditions.

SUGAR PRODUCTS

In the United States, sugar is produced from sugar-cane and sugar-beets, and to a limited extent, from maple sap. Large quantities of sirup are made from maple sap in the northeastern states and from sweet sorghums in the central and southern states.

524. Sugar-cane is a tropical plant and requires high temperatures and a large and constant supply of moisture for its best development. The length of time from planting to tasseling (the end of growth) varies in Hawaii from eighteen months to two and one-half years. The plant is damaged by cold weather, hence in Louisiana cane must be harvested in an immature state, with the result that the yield of cane averages much less than in Hawaii.

525. Water requirements of sugar-cane.—The optimum rainfall for a crop in Louisiana is about 60 inches. In the West Indies the rainfall of July and August and September decides the crop of the next year, whenever the canes are in a healthy condition at the end of June. In the Barbadoes it is stated that each inch of rain corresponds to about 800 hogsheads in the resulting crop, or $^1/_{90}$ of a hogshead of sugar to the acre.

In Mauritius, it is said that the number of marriages depends on the rainfall because of its effect on the sugar crop. Sugar-cane should have comparatively dry weather during ripening and harvesting and dry weather facilitates grinding.

526. Temperature effects on sugar-cane.—The rate of growth of cane increases with the temperature. Freezing weather kills the buds, hence the seed cane must be cut and windrowed in Louisiana before the temperature falls much below freezing. As the cane is cut in an immature state in

Louisiana, the longer it can continue growing the higher the sugar-content; hence growers formerly suffered much loss from fall freezes. With the present excellent warning service, the cane is allowed to stand until a forecast of probable minimum temperature of 26° to 27° is issued by the Weather Bureau. A large force of men is then put into the fields and all the seed cane is windrowed and as much of the other cane as practicable. After the cane is frozen, windrowing is continued as long as it remains frozen or until only an amount sufficient for two weeks' grinding is left standing. The sirup in this standing cane which has been frozen will not spoil, unless it is too warm, for about two weeks, and grinding may be continued. The frozen cane that is windrowed and thaws out slowly receives no material damage. Sometimes a warning of damaging temperatures will result in windrowing of cane valued at $10,000,000 to $15,000,000.

527. Sugar-cane in the United States.—Sugar-cane can be raised in all of the Gulf states, but it is not grown commercially for sugar in any quantity outside the lower Mississippi Delta in Louisiana.

528. Sugar-beets.—The growing of beets for sugar is a comparatively recent practice, particularly in this country. The first factory in the United States was at Philadelphia in 1830. In 1880 there were four factories in operation, but in 1890 only two. In 1900 this number had increased to only thirty with an output of granulated sugar worth only a little over $5,500,000. By 1909 the number of factories in operation was about twice that in 1900, while the granulated sugar output was increased nearly ten times.

Sugar-beet factories have been built in regions where sugar-beets produce well, and later have had to discontinue operations because the sugar-content was found to be too low to make manufacturing financially successful.

529. Sugar-content of beets affected by temperature.—While the temperature and rainfall must be high enough for growth, it is found that moderate temperature and long hours of daylight are necessary to produce a high sugar-content. It must be cool during the ripening period especially, and there should be large diurnal variations in temperature.

It is found that the successful beet districts are in regions where the mean temperature during the growing months is

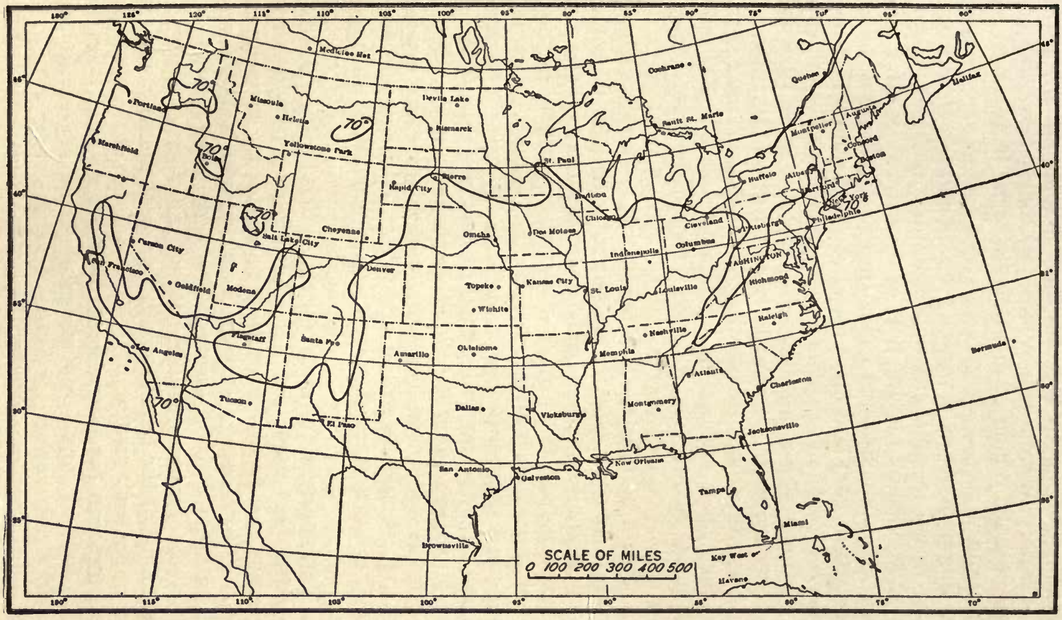

FIG. 72.—The region apparently best adapted for the cultivation of sugar-beets. The heavy line is the mean summer isotherm of 70° for the months of June, July and August.

not far from 70°. Fig. 72 shows the summer isotherm of 70° while a region on each side about 100 miles in width fairly well outlines the region of most of the sugar factories at the present time.

530. Sugar-beets as a winter crop.—Sugar-beets are successfully raised in southern California and parts of Arizona and New Mexico by making part of the growth in the winter months. The best fields in Colorado and Utah are at elevations between 4000 and 5000 feet. A great amount of heat is not necessary when the plants are growing, neither will they thrive if the weather is cold and damp just after planting. Sugar-beets are very sensitive to frost when young, although they can stand rather cold weather in the fall. A hard freeze just as the plants are coming up is almost fatal. The crop should have about five months without severe freezing weather.

531. Effects of rainfall on sugar-beets.—Heavy rains in the spring delay planting. Drought retards growth so that a uniform rainfall or supply of irrigation water is needed during the growing period. From a five-year experiment in Utah, it was found that when watered each week, 1 inch weekly gave a higher yield than any other quantity. It was determined in Indiana that the rainfall should be not less than 2 inches or over 4 inches a month. Experiments have shown that a heavy rainfall is followed for several days by a reduced sugar-content. It should be rather dry during ripening as heavy rains may cause continued growth and a lessening of the sugar values.

532. Temperature for sugar-beets.—The limiting factors in successful beet-sugar production are too warm weather in the summer and too cold weather in winter for winter production. The difference between day and night temperatures should be large while ripening. The sugar-content will increase as the temperature decreases. In regions near the southern limit of the best production, a cool summer and fall produces the best results.

533. Sunshine for sugar-beets.—Sugar is made by the action of light on the green leaves when moisture and carbonic acid gas are present. Actual sunshine is not so important as long hours of daylight, hence the sugar-content increases with increases in latitude.

534. Correlation studies of sugar-beets.—The correlation coefficient between the average temperature for June, July, and August and the sugar-content of beets raised in 1901 to 1904 at five different places in the eastern part of the United States was −0.53 with a probable error of ±0.11. The correlation coefficient between the June average temperature and the tonnage in the United States was −0.67, probable error ±0.10. Curves showing the relation between the mean temperature for either June, July, or August, or these months combined, and the sugar yield in different states and the United States, gave in practically all cases a decreased yield with an increased temperature.

535. Weather and maple products.—A study of the effect of weather on the yield of maple products covering thirteen years in Portage County, Ohio, showed that February should be warm and that March must be cool for the best results. The curves for the March mean or maximum temperature and the yield have an opposite tendency. The correlation coefficient between the mean temperature for March and the yield was −0.69, probable error ±0.08. Out of the six years when March was cooler than the normal, the yield was above the average every year but one. That year the mean was only slightly above normal while the yield was only 0.1 pound a tree less than the average. There is a chance for a very profitable study in this connection.

536. Weather and honey.—There is opportunity also for a very interesting and valuable study of the relation between the weather and the yield of honey. Such studies in Iowa covering the period from 1885 to 1914 showed that an abundant but not excessive rainfall in May is desirable. June, which is the honey month, should be drier than normal for best yields. A rainy period is generally a time of decreased production. Clear days before a rain show a slightly greater increase than the days immediately following.

537. Temperature and honey.—A cold March is unfavorable for a good honey year. A record of the total yields of honey at different maximum temperatures for all single days recorded in 1885 to 1914, showed the following:

Maximum temperatures	*Percentage of honey production*
Less than 70°	1 per cent
70 to 800	8 " "
80 to 900	53 " "
90 to 100	37 " "
Over 100	1 " "

Considering all days for the months of June, July and August.

Temperatures	*Percentage of total honey produced*
All days less than 80°	17.3
" " 80 to 90	45.4
" " over 90	37.3

TOBACCO

Tobacco was used by the natives in North, Central, and South America when first visited by Europeans. There are three general classes of tobacco grown in this country, each of which is best developed under specific climatic and soil conditions.

538. In the United States.—The two most extensive districts of tobacco-culture in the United States are in northern and western Kentucky, including northwestern Tennessee, and southwestern Ohio, and in northern and eastern North Carolina and southern and central Virginia. Smaller though intensive areas are in southern Wisconsin, south-central Maryland, southeastern Pennsylvania, and north-central Connecticut, while a considerable amount is raised in northeastern South Carolina.

539. Climate and tobacco.—The distribution of the crop shows that it is extensively grown under quite wide variations of temperature and rainfall. The tobacco plants are very susceptible to frost; hence, the seed is planted in beds and the plants are set in the fields after all danger from frost is over. The beginning of transplanting varies from the latter part of March in northern Florida to the first part of June in Wisconsin and New York. The crop is generally ready to cut and house about three months after it is transplanted; hence, there is occasionally damage from fall frosts in the northern states.

540. Under shade.—Considerable tobacco is grown under cloth shade, particularly in the Connecticut Valley. The effect of the covering is to conserve the moisture of the soil, increase the temperature and relative humidity of the air, and reduce the wind velocity.

541. Weather and tobacco.—Tobacco is a weed and grows most rapidly with plenty of moisture and warm weather. In the shade experiments, it was found that the rate of growth increases with higher temperature and decreases with lower. If there is a decided drop in temperature, there is a decrease in the growth which continues for a day or two after the temperature has begun to rise. If the plants get a good start after transplanting, they will stand practically dormant during a drought and will then grow rapidly when rain comes.

542. In Kentucky.—A study of the weather and yield of tobacco in Kentucky covering a period of twenty years showed that June should be warm and wet to produce the best yields, although there were some marked exceptions to that rule. Neither the mean temperature nor the total rainfall for July was a determining factor in varying the yield. Rainfall in August was favorable, while the best yields followed a rather dry and cool May.

543. In Ohio.—A comparison of the yield of tobacco in Ohio with the temperature and rainfall departures from the normal for the state as a whole from 1881 to 1907 shows little relation, probably from the fact that tobacco is grown only in parts of the southern and western portions of the state.

544. Darke County, Ohio.—This is the most important tobacco-growing county in Ohio. Two independent studies have been made in this county covering the period from 1886 to 1909. Both investigators found that a wet August was desirable and that the months of June and July combined should be slightly cooler than the normal. No relation was observed between the yield and either the mean maximum or mean minimum temperatures, or the number of rainy days.

545. Montgomery County, Ohio, 1883 to 1908.—June should be warm, as a cool and dry month is decidedly unfavorable to the yield. Hot weather kills the cutworm. Too much rain in this month will force the plants into top. July should be cooler than normal, as the average temperature is a little too high unless the rainfall is above normal. If the rainfall is much above the average, it interferes too much with cultivation. August should be cool if it is dry, as hot and dry weather is decidedly unfavorable. Warm and wet weather is most favorable for growth, but is likely to develop rust.

546. Southwestern Ohio.—This study covered the counties of Darke, Miami, Preble, Montgomery, Warren, and Butler, from 1863 to 1913, inclusive. The following correlation table does not include 1875. That year the rainfall for June, July, and August totaled 22.7 inches or 7.8 inches above the normal, while the yield of tobacco was 470 pounds below, showing conclusively that the rainfall was too great for best yield.

TABLE 54.—CORRELATION BETWEEN WEATHER AND YIELD OF TOBACCO IN SOUTHWESTERN OHIO, 1863 TO 1913

	Rainfall		*Temperature*	
Period	*Correlation coefficient*	*Probable error*	*Correlation coefficient*	*Probable error*
July.......	+0.21	±0.09	+0.03	±0.10
August.....	+0.56	±0.06	−0.30	±0.09
July and August...	+0.43	±0.08	−0.21	±0.09

While this table shows that August is evidently the most critical month, possibly some other period could be found which has a more direct control on the yield. The student states that "A study of the original data indicates that the highest yield of tobacco is produced when the combined rainfall for July and August is about 3 to 4 inches above the normal. A greater excess is usually quite detrimental to a high yield. When the rainfall for August is about normal it seems that the July rainfall is the large controlling factor."

547. Summary.—The conclusions drawn from the above are that May should be moderately dry for a good seed-bed, and cool to harden the tobacco plants. June should be moderately warm and wet to insure growth when the plants are set out, unless the warm and wet weather develops bed-rot; July rainfall and temperature not far from normal, as too much rain interferes with cultivation; if dry, the temperature should be below the normal. .August should have rain enough to produce a good sized leaf after topping. Warm and wet weather makes the best growth but is more likely to cause the development of rust. Hot and dry weather is very detrimental; hence if the rainfall is less than normal the month should be cool. If the growing season is moderately wet with a uniform supply of moisture, the best growth will be with the temperature somewhat above normal. But if drought prevails or frequently occurs, the best results are obtained with the summer somewhat cooler than normal.

548. Tobacco root-rot.—While this disease is influenced by moisture and condition of the soil, the soil temperature is the most important factor affecting its extent. The most favorable soil temperatures for the development of the disease range from 62° to 74°. Below 59° the disease is less marked, while above 90° practically no infection occurs. June is the most favorable month for the development of tobacco root-rot, from a temperature standpoint. A heavy infection in June may be overcome by a very warm July.

SEEDS

549. Effect of weather on maturing seed.—It has been found in England by Hooker that the weather during the maturing of peas and beans has a very great effect on the yield of the crop from this seed. The ripening period must be dry. The lack of rainfall at harvesting time, making it by no means rare to gather and thrash a crop of seeds without its having been touched by a drop of water, is one of the reasons why beans and peas and short-season seeds raised in Idaho and other semi-arid states are in such demand.

550. Seeds from drier regions.—It is commonly better to use seed grown in a region of smaller rainfall during maturing, particularly in a comparatively dry district. Also instead of using seed that matured during wet weather, it is better to discard that and obtain seed from a drier region or even to use seed one year older if that was grown under the more favorable conditions of less rainfall and more sunshine.

551. Alfalfa seed.—The alfalfa crop that is saved for seed should have warm wet weather or ample storage moisture at the beginning of its growth, followed by fair and not too hot weather during blooming. A mean monthly temperature somewhere in the middle seventies is evidently favorable for the plant at the critical period of blooming. The season of growth and harvesting of seed must be quite free of frost.

552. Potato seed.—Immature potatoes or at least those not over-ripe are best for seed. Northern-grown potato seed is preferred not only because it may be less ripe when harvested, but is stored where it is kept dormant and solid. A temperature of 32° to 40° is best in storage in order to maintain the dormancy of the tubers.

553. Wheat seed.—Spring wheat seed obtained from farther north will ripen earlier and give a better yield and quality than seed from the same strain ripened farther south. Winter wheat seed, on the other hand, from points farther south will give better yields than northern-grown seed of the same variety.

554. Regions especially favorable for seed.—There are well-recognized localities especially favorable to the production of seeds of high quality. For example, alfalfa seed will mature well only in the dry climate of the semi-arid West.

Some of the common opinions about these matters have not been wholly verified, but they are so general and are so evidently a climatic matter that they are worth mentioning. Onions grown from California seed are different in keeping quality from those from Michigan seed; cabbage, cauliflower, and the like, head better from seed grown on Long Island or in the Puget Sound region than from any other section; tomato plants raised from seed produced in northern states are far superior to those from seed in the South.

555. Good "seed" weather.—It is probable that potatoes and turnips yield best when ripened in cool weather; that most of the cereals, clover, and most grain seeds are better ripened under warm conditions, while beans, peas, and some other legumes should be ripened under dry conditions.

PLANT DISEASES AND INSECT DAMAGE

There is a close relation between the weather and the damage done by plant disease and by insects. In many of these the kind of weather that favors the most rapid development of the disease or of the damaging insects is well known; in others it remains to be worked out, thus making it important that all farmers keep a careful record of the weather factors when disease or insect damage is prevalent and when this damage is checked.

556. Terms relative.—In the designation of "dry" or "wet" weather diseases and "warm" or "cold" weather diseases, it must be remembered that the writer is speaking in relative terms as compared with the average condition at the place of record. Plant diseases are not abundant in the tropics and yet various wilt and root diseases and many leaf troubles spread in Louisiana during the hottest weather there. On the other hand, many diseases common in the North are troublesome in Louisiana only in "cool" weather. The onion mildew and the bean anthracnose are well-marked examples.

557. Bitter-rot of apples is a common and destructive disease in the South but it is a botanical curiosity in New England. Apple-scab, on the other hand, is more prevalent in northern districts. Pear-blight is also a disease common only in warmer regions.

558. Late blight of potatoes.—In extreme northern districts this is spoken of as a "warm" moist weather disease, while in slightly more southern states it is known as a "cool" moist weather disease. It develops with greatest rapidity in moist weather, but the optimum temperature for its most rapid development is at about 72°.

Contrasted with the potato Phytopthora is the allied disease, cucurbits, the downy-mildew, which appears to flourish during hot seasons and to disappear in cool ones. In Wisconsin the summer of 1915 was cool and moist and the late blight caused immense damage to potatoes, but the cabbage crop was everywhere vigorous. In 1916 it was hot and dry and while there was practically no potato late blight, cabbages were "swept as if by fire" by the yellow disease *Fusarium conglutmans.*

559. Wet weather diseases.—It is agreed by all plant pathologists that the presence of water is necessary for the spread of bacterial diseases. All fungi are also favored by a large amount of moisture while some develop most rapidly under conditions cooler than normal and others are favored by temperatures higher than normal. An example of the last named condition is the "scab" or "black-spot" of cucumbers which sometimes causes much damage in the pickle-growing regions of Michigan, Indiana, and Wisconsin.

560. Dry weather diseases.—Some of the most well-defined dry weather diseases are the point-rot of tomatoes, the cabbage black-rot and the southern bacterial wilt of potatoes known as the "sleeping sickness."

561. Grain rusts.—Hot and humid weather at the ripening period favors a rapid development of rust and these conditions in many years limit the southern development of successful wheat-growing. In the spring wheat region of the Northwest, stem-rust often does great damage; in 1904 it was estimated that the loss from rust in North Dakota, South Dakota, and Minnesota amounted to $10,000,000. The conditions favorable for rust in that region are muggy, sultry, rather still, hot days with foggy cool nights at about the blossoming period. Just after the infection, cool, moist, slow-growing, showery weather may result in widespread damage.

562. Spread by the wind.—Bacteria being present in the leaf surface water film, are splashed up by the impact of falling raindrops, and these bacteria-laden drops are carried by the wind to a distance proportional to its velocity. The distance of the splash varies according to the size of the drop, depth of surface film, elevation and inclination of the surface of impact, and the velocity of the wind. Faulwetter found that with a wind of ten miles an hour a drop of rain 0.02 cc. in volume falling 16 feet the splash was carried in abundance 8 feet, in moderate quantities 12 feet, and in slight amount 16 feet, while a wind of thirty miles an hour carried the splash at least 50 feet.

563. Smuts.—It has been found that the soil temperature at the time of germination is an important factor in the development of the stinking-smut of wheat. The most favorable temperature is between 59° and 72° while a soil temperature above 72° or below 41° is decidedly unfavorable for the development of the disease. For this reason, winter wheat sown very early in warm soil or very late in cold, in the Pacific Northwest, is comparatively free from the disease. It has been found that the soil temperature is an important factor in the development of the Fusarium wilt of potatoes, as well as another Fusarium disease the "flax-wilt." In some experiments the flax developed normally when the soil temperature was held continuously below 59°, but if the temperature rose above 61° even for one day, infection occurred and wilt developed.

564. Insect damage.—It is well recognized that the activity of insects is affected by weather conditions, and that they cause more damage some seasons than others because of the characteristics of the weather.

565. Grasshoppers.—It is generally experienced in the middle and western states that when two dry summers occur in succession, the second one usually has a serious outbreak of grasshoppers. Dry weather favors the hatching of the eggs while in cool wet weather the grasshoppers often die in large numbers from disease.

566. Chinch-bugs.—Warm dry weather is favorable for an increase in chinch-bugs. A succession of dry summers, especially in May and the first part of June, and in August and the first of September, thus covering the two hatching periods, is very likely to cause an outbreak in a region subject to infection. The damage by chinch-bugs in thirty-eight counties in Illinois in 1914 was estimated at $6,400,000. The year was very dry, particularly in June, and there was a marked absence of heavy beating rains from May to August. This year was one of a series of rather dry summers in the region of infestation from 1910 to 1914. The next year the late spring and summer were cooler than normal and there was an abundance of heavy rain-storms which put an end to the destructive outbreak in one season.

567. Temperature and chinch-bug.—It was found in Illinois that the chinch-bug does not ordinarily begin its movements until the temperature reaches 74°, while on hot bright days its activities cease from 10 or 11 o'clock until 3 or 4 p. m. It was observed that they make little or no movement after twilight.

568. Effect of wind on insects.—The chinch-bug tends to move with the wind especially when on the wing. Warm days, with strong winds after rain or dull days, showed a rapid advance to the leeward. In New England it was found that the gipsy moth made a general progress of five miles a year toward the northeast, the direction of the prevailing winds, while the spread was only three miles a year toward the west.

569. Cutworms.—A study in Marion County, Ohio, showed that the weather during May exerted a strong influence on the damage done by cutworms. It was found that a cool and wet May was favorable to cutworm activity, while a warm and dry May was unfavorable. The correlation coefficient between temperature in May and the percentage of damage to corn in the county was −0.50, probable error ±0.11. It was +0.34, probable error ±0.14, between rainfall and damage.

570. White-grub.—It was found that the correlation coefficient between the temperature in May and the percentage of damage by the white-grub was −0.55, probable error ±0.11, and between rainfall and damage +0.51 and probable error ±0.11, showing that a cool and wet May was also favorable to the activities of this pest.

571. Hessian fly.—Augestine found that the highest correlation between weather and damage by the hessian fly was with a warm October and a dry April. The correlation coefficient between the October temperature and damage was +0.62, probable error, ±0.10, and between April rainfall and damage, −0.72, probable error ±0.08.

572. Insect pests and parasites.—The effect of the weather on parasites or fungous diseases of insects may be different from that on the insects themselves. For example, the oat aphis breeds and multiples at a temperature of about 40° or above, while the common parasite of this and many other aphids is not active at a temperature below 56°. Consequently, a mild winter and cool spring, when the temperature fluctuates between 40° and 56°, permits the aphis to multiply unchecked by the attacks of the common natural enemy. At a temperature of about 70°, however, the parasite will multiply about ten times as rapidly as its host, hence at that time the plant-lice are soon destroyed by the parasite.

573. Cattle-tick.—A study by Cotton and Voorhees showed that zero weather is fatal to the cattle-tick in all stages, unless the tick is on an animal or in a well-protected building. Adults were killed at a temperature of 14°, the seed ticks at 4°, and eggs at 2°, when exposed under conditions similar to grass in ordinary pastures. They found that the ticks will not permanently occupy a territory where zero temperatures occur, or where the mean relative humidity is below about 60 per cent.

LABORATORY EXERCISES

(1) A study of the effect of the weather during the ripening of seed on its viability and vigor is of much importance. Whenever germination records are available covering any considerable number of years, correlations may be made with the weather condition.

(2) Another problem that needs more study is the influence of different soil temperatures on germination: Time necessary and percentage of germination.

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CHAPTER X

WEATHER FORECASTS AND WARNINGS

The United States Weather Bureau issues regular forecasts of the weather twice each day, while special forecasts and warnings are put out whenever the conditions warrant.

574. Forecast centers.—District centers, at which forecasts are made for a district covering several states, are located at the Central Office in Washington, D. C., and at Chicago, Illinois, Denver, Colorado, New Orleans, Louisiana, and San Francisco, California.

575. A. M. forecasts.—The morning forecasts are made at about 9. a. m., eastern time, and cover the probable conditions thirty-six hours in advance. These forecasts are immediately telegraphed from the centers to about 1600 principal distributing points, whence they are further disseminated by telegraph, telephone, wireless, and mail. These are the forecasts that appear in the afternoon papers.

These forecasts reach nearly 100,000 addresses by mail, and are available to more than 5,500,000 telephone subscribers within an hour after the time of issue. Many thousands of persons never think of starting on a trip, or of taking up any important work that is affected by the weather without calling up the Weather Bureau Office or the nearest telephone exchange and asking for the official forecast for the next thirty-six hours.

576. Value of forecasts.—Shippers of perishable products must know the forecasts. Commission-men and other shippers of perishable products in most of the important cities always delay their morning shipments until they know from the forecasts what temperature to expect and how to prepare their goods for it during transit. The railway and transportation companies make continuous use of the forecasts in all their shipments. Often shipments of perishable goods are accelerated or protected against temperature extremes by icing or heating, as conditions may require. Bananas, for example, must be kept at a temperature of 58° to 65° during shipment, as a temperature below 55° chills the fruit sufficiently to cause a deterioration in quality, while a temperature above 65° inside the car will produce over-ripening. The shipment of live-stock by freight is avoided, if possible, when a hot wave is expected. High temperatures are hurtful to certain other shipments, such as fish and oysters, so that the question of the proper amount of ice to be used is intimately connected with the forecasts issued.

577. Special forecasts for agricultural interests.—Some of the special forecasts issued for and widely used by the agricultural interests are the following:

Alfalfa cutting.—Throughout the principal alfalfa-growing districts, special three or four day fair weather forecasts are issued at harvesting time.

Sheep shearing and lambing.—Special forecasts of snow or rain, especially with wind and low temperature, are widely distributed in the West at shearing and lambing time so that shearing may be delayed or if done sheep may be protected, and extra precautions taken to care for young lambs.

Spraying forecasts.—It has recently been necessary to have spraying experts in important apple and other fruit-growing districts and even to detail special weather forecasters to these regions so that spraying may be done before rainy periods to prevent the rapid dissemination of apple-scab and other diseases.

Raisin-drying.—In the raisin-growing districts of California, rain forecasts are of great value. The raisin crop while drying is extremely susceptible to injury from rains, and the forecasts enable the growers to stack and protect the drying trays. Rain forecasts are also utilized in the large fruit-growing districts to hasten picking before a rain, so that the fruit can be shipped while dry.

578. P. M. forecasts.—The evening forecasts are made at about 9 p. m. eastern time, and cover the two following days. These forecasts are sent throughout each district by the Press Association wire service. These appear in the morning newspapers.

579. Local forecasts.—The weather forecasts at district centers are for states or sections of states. At most of the other Weather Bureau Offices, the official in charge amplifies

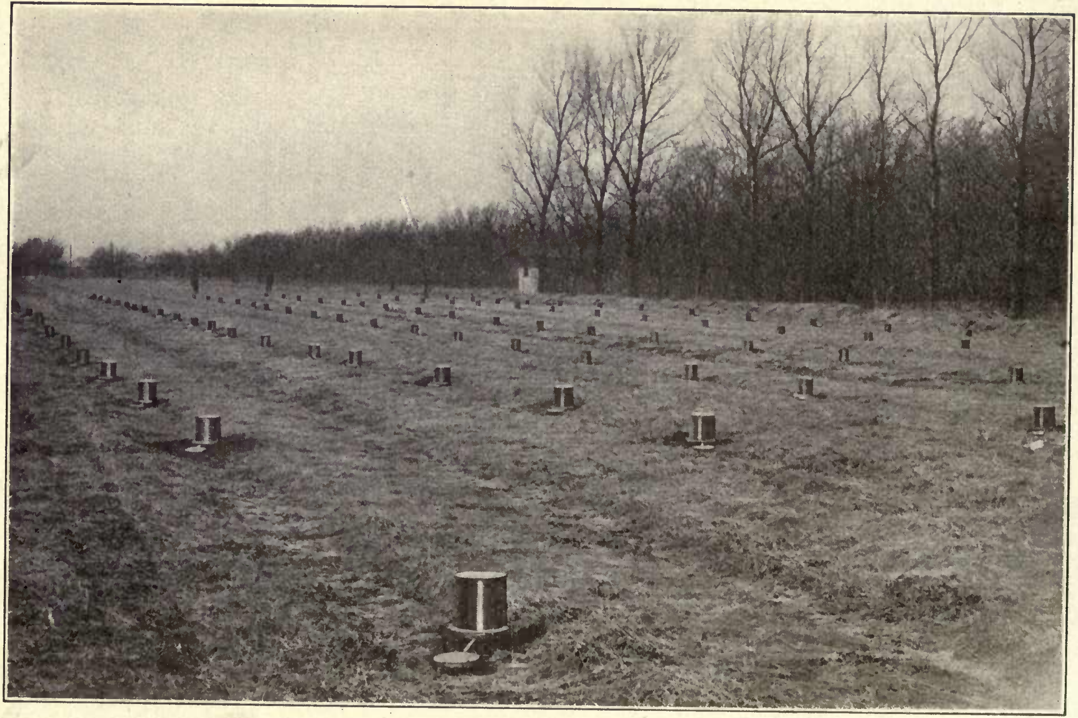

PLATE VII.—Heaters can be used successfully in protecting strawberries from frost damage.

or modifies these state forecasts to cover the probable condition in the particular city or vicinity where each office is located.

These forecasts are based on a knowledge of the weather that is prevailing throughout the country and certain well-defined laws of the weather.

580. Observations.—A record of the pressure, temperature, weather, wind, clouds, humidity, amount of rainfall, and extremes of temperature during the preceding twelve hours, and the like, is made by trained observers at about 200 different points at 8 a. m. and p. m , eastern time.

Within five minutes after these observations are made, a telegraphed message in code, giving all the essential weather facts, is filed at the local telegraph office and by an ingenious "circuit" system is placed in the hands of the Weather Bureau officials at Washingtion and at about 180 other stations in the country, within thirty minutes after the instruments are read.

581. Weather maps.—As fast as the telegrams reach the various offices, the data are charted by trained men on outline maps of the United States, so that by the time the last report is received the forecaster has a complete weather map before him.

When these maps are completed, each forecaster has before him an actual picture of the weather that prevailed throughout the country half an hour previously. He can see the pressure and temperature of the air, not only at his station, but at every other station. He knows where it is raining or snowing; the amount of precipitation that has fallen at each place during the preceding twelve hours, the wind direction and velocity, the kind, amount, and direction of movement of the clouds; where and when thunder-storms occurred and any other fact that is of importance regarding weather. Used in connection with a similar map of twelve, twenty-four, thirty-six, and forty-eight hours before, he can trace the movement of the various weather conditions from place to place.

582. Weather laws.—A study of the daily weather maps shows that the wind does not "blow where it listeth," but that there are well-defined laws that regulate the wind and the movement of storms and general weather conditions.

583. 1st law: weather moves eastward in temperate latitudes.—In the temperate latitudes in both the southern and northern hemispheres, the weather conditions move in a general easterly direction with a fair regularity of motion. This is the most important law of storms. The atmosphere near the surface of the earth moves in wave-like areas of high and low pressure. Fig. 73 shows the average paths over which these areas move in the United States, as well as the average distance traveled each twenty-four hours.

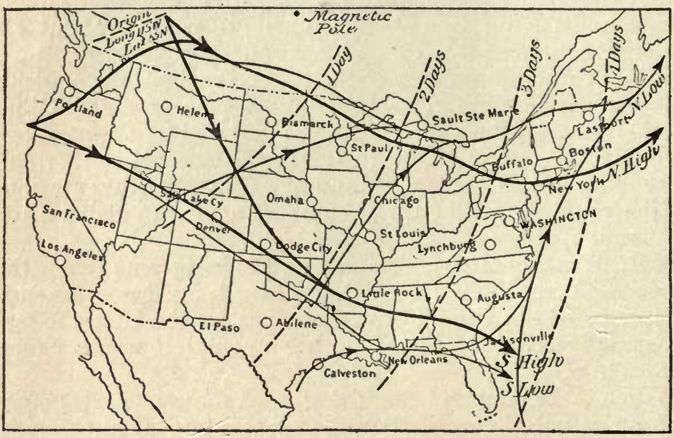

FIG. 73.—Average tracks of high and low pressure areas in the United States as they move from west to east. The broken lines running from northeast to southwest show the average distance traveled each twenty-four hours.

584. 2nd law: the direction of surface winds depends on the difference in pressure.—On the weather maps (see Figs. 74 and 75), the solid lines are those of equal barometric pressure or isobars.

The word "high" indicates the centers of the high pressure areas and the word "low" centers of low pressure. Arrows on the maps show the wind direction at the time the observations were made. The arrows fly with the wind, and it will be seen that the wind blows toward the center of the lows, and away from the center of the highs. This is the second important law of the weather.

A wind from the east on the Atlantic Coast is usually followed by a rain because the wind is blowing toward a storm that is approaching from the west. These low-pressure areas or storms are usually accompanied by rainy weather and rain begins to fall when the center gets near enough. After the storm center passes by, the wind shifts to westerly, as it still blows spirally toward the center, and fair weather usually follows.

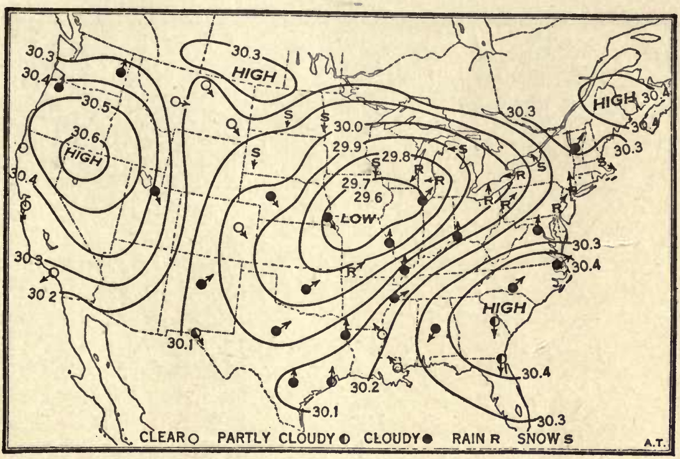

FIG. 74.—A typical winter storm Dec. 15, 1893, that is central over southern Iowa.

585. 3rd law: the temperature at any place is largely controlled by the wind direction.—The dotted or broken lines on the weather maps are lines of equal temperature or isotherms. It will be seen that these temperature lines curve to the north in front or to the east of the lows, where the winds are from the south, and curve toward the south to the west, or in the rear of the lows where the winds are from the north. It is warm in front of the low pressure areas because the winds are coming from a warmer region. North winds bring cooler weather because they are coming from a cooler region.

586. 4th law: pressure areas and weather.—Low-pressure areas are usually accompanied by cloudy weather with rain or snow, while high-pressure areas are more likely to be attended by clear skies and fair weather. As these areas move eastward, they carry along with them the weather, temperature, and wind variations described above.

587. Weather forecasts are made for any particular region by estimating the path and rate of movement of a low or high pressure area west of it, the probable weather that it will cause, how it will affect the wind direction, and through the wind direction the temperature.

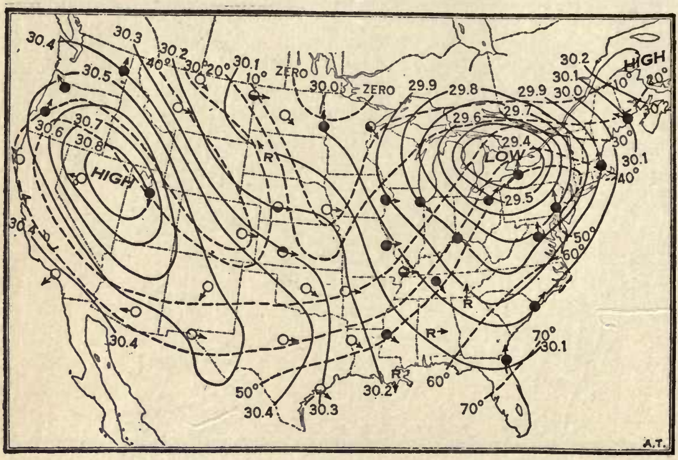

FIG. 75.—The same storm twenty-four hours later, Dec. 16, 1893. The temperature lines are shown on this chart. The arrows at each station show the wind direction; they fly with the wind.

588. Special warnings.—In addition to the regular twice-daily weather forecasts, special warnings are issued for peculiar conditions and interests. Some of the most important are given below.

Storm warnings.—Warnings of high winds and hurricanes influence the handling of the shipping all along the coasts.

Flood warnings.—Forecasts of the height of the water in the large rivers can be made very accurately, days and sometimes weeks in advance. Warnings of floods are made whenever it is expected that heavy rains will cause a sharp and continued rise in the streams. Some of the most fertile soil is in the river valleys and warnings of damaging waters are very valuable and can be obtained from the river district centers.

Cold wave warnings.—These warnings are utilized by many interests and millions of dollars worth of damage averted by their receipt.

Frost warnings are issued for truck-growers and orchardists in protecting crops from frost damage. (See Chapter XI.)

Warnings for stockmen.—Cold wave, high wind, and heavy snow warnings are issued for the benefit of stock-growers over the Great Plains and in the West.

Heavy snow warnings are issued for railroads and other transportation companies.

LOCAL WEATHER SIGNS

Certain local signs are valuable in anticipating the weather for a few hours in advance only. These relate largely to the relative humidity, clouds, and air pressure.

589. Humidity.—There is usually an increase in the humidity of the air before a rain because the latter is usually preceded by warm southerly winds that are taking up moisture as they flow northerly. Warm moist air attends a falling pressure, and under these conditions there is a feeling of physical and mental lassitude that is in striking contrast to the feeling of exhilaration that accompanies the cool, dry, electrically-charged westerly winds that come with a rising barometer. The lower animals and insects, as well as humans, are undoubtedly affected by these conditions.

590. Good rain-indicators.—Certain phenomena are brought about by increasing moisture and hence are good rain-indicators. Some of these are: sweating walls, sidewalks, metal plates, and dishes; tightening of ropes; increase in perfume of flowers; softening of moss; shortening of guitar strings; increase in odor from drains and ditches; tightening up of curls, and the like. The American Indians say: "When the locks turn damp in the scalp house, surely it will rain." Floors saturated with oil become very damp, salt increases in weight, and tobacco becomes moist before a rain.

Corn fodder is very sensitive to any increase of moisture in the atmosphere and becomes damp and limp before a rain. It is said that before a rain the leaves of many trees are turned up or twisted over so as to show more of the under side, and if this is true it is probably caused by the absorption of moisture from the atmosphere by the wood fibers in the stem.

591. Moisture in vapor form.

> When the stars begin to huddle,
> The earth will soon become a puddle.

"When the sky is full of stars, expect rain." When there is an increased amount of moisture in the atmosphere in the form of vapor, there is usually a greater homogeneity of the atmosphere, hence its transmissibility for both light and sound waves is increased. For this reason when the amount of water-vapor increases, stars that are usually visible only with a telescope may be seen with the naked eye. Under similar conditions, sound is carried more readily and the singing of birds and the calls of domestic fowl are plainer and more noticeable. This is why "parrots whistling indicates rain," and

> When the peacock loudly bawls,
> Soon we'll have both rain and squalls.

592. Pressure of the atmosphere.—The differences in air pressure are not great enough at any single point to be noticeable to man. It seems possible, however, that the difference in the supporting power of the air between high pressure (usually fair weather) and low pressure (usually stormy weather) condition makes some difference in the flight of birds, and has thus led to "Everything is lovely and the goose hangs (honks) high," and the saying that swallows and martins fly low just before a rain, and that bees remain in or near their hives just before stormy weather may be expected.

It has often been noticed that water will begin running in ditches that are fed by springs just before a rain, although they have been quite dry. This is undoubtedly due to the fact that the decreased weight of the atmosphere in a low pressure area allows the ground water-level to rise slightly.

593. Wind and pressure.—When the wind sets in from points between south and southeast and the barometer falls steadily, a storm is approaching from the west or northwest, and its center will pass near or to the north of the observer within twelve to twenty-four hours, with winds shifting to the northwest by way of southwest and west. When the wind sets in from points between east and northeast, and the barometer falls steadily, a storm is approaching from the south or southwest, and its center will pass near or to the south or east of the observer within twelve to twenty-four hours, with winds shifting to northwest by way of north. The rapidity of the storm's approach and its intensity will be indicated by the rate and the amount of the fall in the barometer.

594. Clouds.

> If clouds look like they had been scratched by a hen,
> Get ready to reef your topsails then.
>
> When ye see a cloud rise out of the west, straightway
> ye say "There cometh a shower"; and so it is.—Luke XII, 54.

The clouds are the "storm signals of the sky," and by watching them carefully very accurate prognostications can be made for a few hours in advance.

595. High clouds.—The high cirrus and cirri-stratus clouds are particularly valuable in this respect, especially if they are of the thin wispy type sometimes called "mare's tails." These clouds are composed of ice spicules and are formed by the condensation of moisture in high altitudes, that has been carried up in a storm area that perhaps is west of the observer and is moving toward him.

596. Halos, or large circles around the sun and moon, are formed by the refraction of light through these ice particles and are frequently indicative of stormy weather. If the high clouds are moving rapidly eastward and the sky below is partly covered with denser clouds moving westward, then the storm is approaching rapidly and will probably cause heavy rain and strong wind.

597. Low clouds.—Lower clouds are so closely connected with the rainfall that they are generally of little value in indicating the weather for any considerable time in advance. When the lower clouds begin to break up and enough clear sky can be seen "to patch a Dutchman's breeches," fair weather may be expected very soon.

598. Fog or mist.—"When Lookout Mountain has its cap on, it will rain in six hours." This is true in general with other mountains, but only "when the fog goes up the mountain you may go hunting, but when it comes down the mountain you may go fishing."

LONG-RANGE FORECASTS

Weather forecasts of a quite general nature are made for a week in advance by the Weather Bureau, by enlarging the observational field through daily reports by wireless and cable from different places in the northern hemisphere.

599. Seasonal forecast not yet possible.—It is not possible at the present time, however, to predict storms for a longer time than a week or ten days in advance, and the general weather of a month or season in advance cannot yet be determined. The officials of the Weather Bureau believe that the time will come when seasonal forecasts can be made, but it cannot be done at the present time with sufficient accuracy to warrant the attempt. Some of the most able scientific men of the century are at work on the problem, and sufficient has become known to be sure that it must be solved through a study of the solar energy alone and its effect on the atmosphere.

600. Planets have no known effect on the weather.—The planets have no effect whatever on the weather, and the effect of the moon is so slight as to be outside of consideration. No forecasts that pretend to predict the movements of storms for weeks in advance should be taken seriously, and all efforts to make predictions of the weather for months in advance, based on the movements of the planets, appear to be utterly unreliable.

601. Animals, birds, and plants.—In connection with the long-range forecasts, it may not be out of place to state also that animals, birds, and plants show by their condition the character of past weather and by their actions the influence of present weather, and possibly the character of weather changes that may occur within a few hours, but never the weather that may be expected during the coming winter or summer. Also that the weather of certain days, months, seasons, or years, affords no reliable indications of future weather, but show present abnormal conditions that the future may adjust.

LABORATORY EXERCISES

1. Paragraph 581. Practice should be given in making daily weather maps. The necessary data can be obtained from the published tables or from the nearest Weather Bureau Office.

2. Paragraph 582. A series of weather maps covering successive four to six day periods can be obtained from the Weather Bureau and from their use in the class the various "weather" laws can be demonstrated, and from them forecasts can be attempted.

The student will soon see that forecasting the weather is not so easy as it first seems and that there are marked exceptions to general rules.

3. Paragraphs 589 to 598. Forecasts should be regularly made from local weather signs. This will soon show that it cannot be done for any considerable time in advance.

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CHAPTER XI

FROST AND THE PROTECTION OF CROPS FROM FROST DAMAGE

The limiting factor in the successful cultivation of many crops is the usual date of the last killing frost in spring and the first frost in autumn; and in themselves, frosts are likely to set the bounds for much of the farm work. The relation of frost to crop-production may now be considered.

Fig. 76.—Average dates of last killing frost in the spring.

602. Average killing frost dates.—The average dates of the last killing frost in the spring and the first in the fall are shown respectively by Figs. 76 and 77 for the different sections of the country. Frost may be expected one year in two, on an average, on the dates indicated, while the dates when frost may be expected only one year in ten will be about two weeks later in the spring and two weeks earlier in the fall.

603. The growing season.—The potential growing season in any locality is usually considered to be the average number of days between the spring and fall killing frost dates. A map showing these days is given in Fig. 78.

For tender crops that are killed by frost, the possible growing season is less than indicated on the chart, because the killing frost dates are for the average when frost occurs one year in two. Killing frosts occur after the spring and before the fall date frequently enough to make the possible length of the growing or frost-free period frequently less than the average.

FIG. 77.—Average dates of the first killing frost in the fall.

Further, such crops as are not killed by temperatures at or somewhat below freezing, have a longer possible growing season than the frost-free dates. Winter grains and grass, for example, will continue to grow in the fall after a killing frost and will begin growing in the spring and winter long before the average spring killing frost date, if favorable temperatures prevail.

604. Vegetative periods.—The temperature at which most field and garden crops will begin to grow is probably close to 6° (C.) or 42.8° F. Hence the growing or "vegetative" period for the crops that are not killed by ordinary frosts may be considered as that between the date in the spring when the average daily temperature rises to 43°, and the date in the fall when the mean daily temperature falls to 43°.

605. Comparison of the vegetative with the frostless period.—The vegetative or potential growing period is longer than the frostless period in all parts of the United States, except over a small area along the north Pacific Coast, as shown by Fig. 79. This difference varies from less than twenty days in a few places in the northern part of the country to over 100 days in the northern part of the Gulf states.

FIG. 78.—Average number of days between killing frosts.

606. The true growing season.—The normal growing season, therefore, should be the average vegetative period and not the frost-free period, for the reasons given above.

607. Extending the growing period.—In those regions where the vegetative period usually begins a month or more before the last killing spring frost, and extends as long a time after the first fall frost, it has been profitable to protect tender crops from frost damage by artificial means, and thus

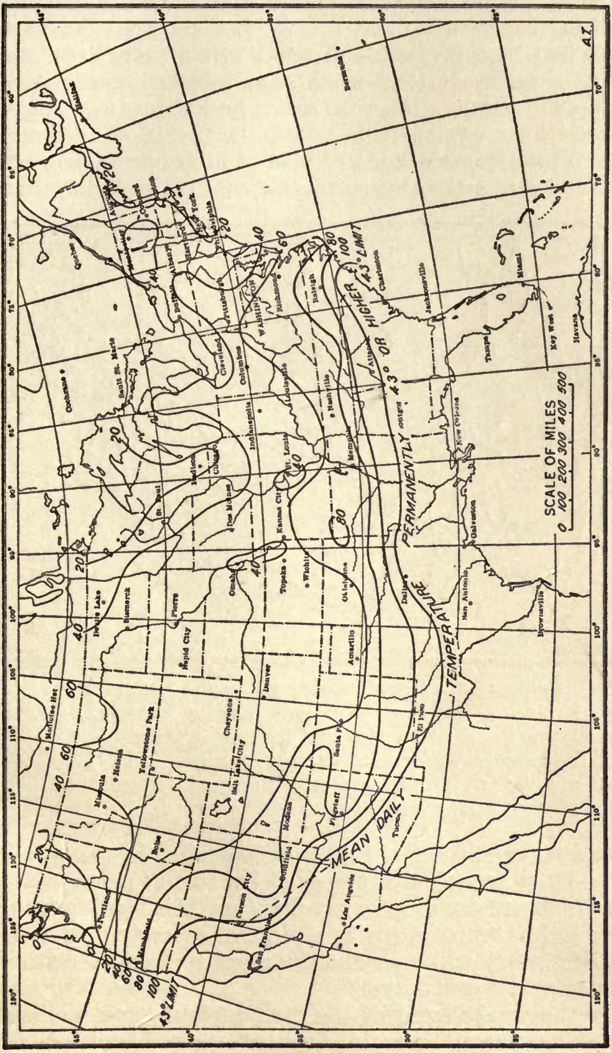

FIG. 79.—Average number of days that the frostless period is shorter than the vegetative period.

make their possible growth period agree more nearly with that of the hardy crops.

The protection of fruit and truck crops from frost is entirely practicable but whether economically profitable depends on the value of the crop saved and the expense of protection.

608. When frosts occur.—Areas of high barometric pressure spread across the United States from the west toward the east at an average rate of 400 to 600 miles in twenty-four hours. They are usually preceded by strong northwesterly winds which cause a drop in temperature; if it is in the winter and the fall in temperature is rapid and extreme it is termed a "cold wave," while in the summer the phenomenon is spoken of as a "cool wave."

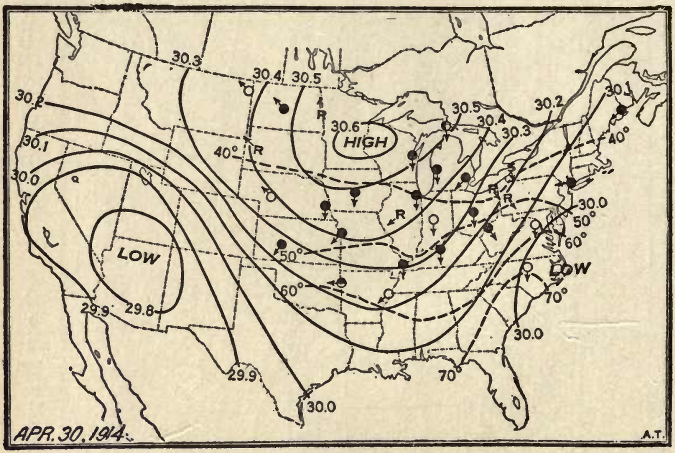

FIG. 80.—Daily weather map showing an area of high pressure with a cool wave in the Northwest that may be expected to overspread Ohio in the next forty-eight hours with general frosts. The solid lines are drawn for equal barometer pressure while the dotted lines are drawn through places with equal temperature. The arrows fly with the wind and show wind direction.

After the windy front of the high pressure area or "anticyclone" has passed by and the center of the high overspreads a district, it generally causes clear and comparatively quiet air. The air is so clean and clear that it may seem very warm in the sunshine, but continues keen and cool in the shade. At night the surface of the ground and objects upon it cool rapidly by radiation and in turn cool the lower layer of air by conduction, and, if it is in the spring or autumn, the temperature of the plants and of the air in contact with them may fall to the freezing point and frosts occur. Figs. 80, 81, and 82 show the movement of an area of high pressure across the Lakes and the Ohio Valley that was accompanied by general and widespread frosts.

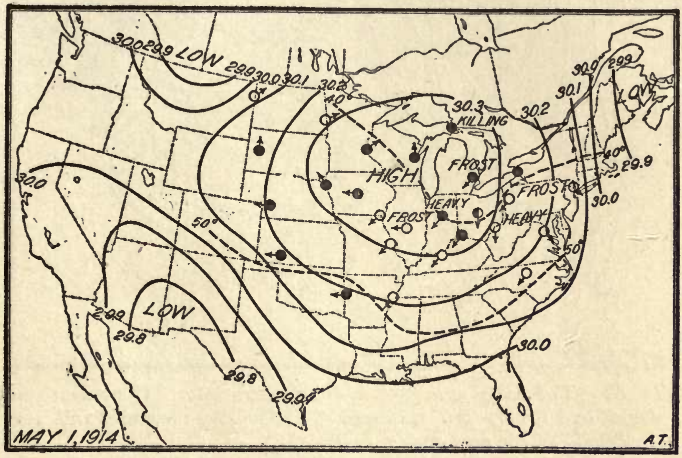

FIG. 81.—The high pressure area shown in Fig. 80 is spreading southeastward and is causing general frosts in Ohio. Light, heavy, and killing frosts are shown by appropriate words.

609. Local conditions favorable for frost.—The local conditions which indicate the central portion of an area of high pressure are clear and nearly still air with the temperature falling quite rapidly in the afternoon and early evening; with clear skies because the radiation of heat from the ground and plants is most rapid in clear weather; with nearly still air because under these conditions the air arranges itself in layers with the colder heavier air at the surface of the ground, especially in low places. This line of temperature variation is so well marked sometimes that the fruit on the lower part of a tree will be killed by frost while the upper part will escape damage and bear a good crop.

610. Principles of frost protection.—To prevent damage from frost, action must be taken to counteract, so far as possible, the conditions favorable for frost. Hence the following precautions should be taken:

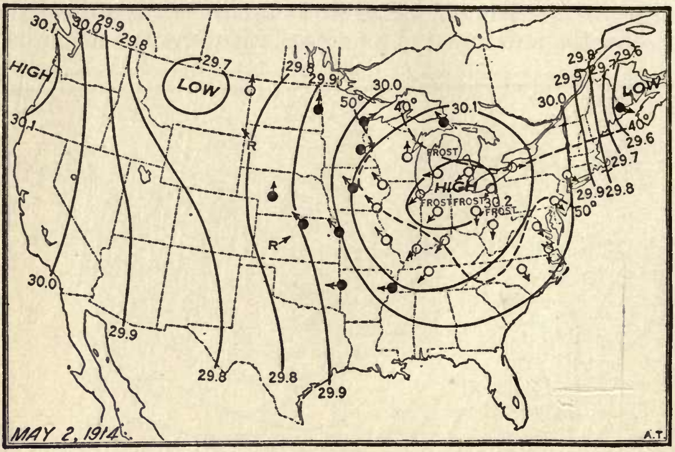

Fig. 82.—The same area twenty-four hours later. It overspreads Ohio and frosts are widespread. The temperature will rise gradually as the area moves eastward.

(1) Diminish the radiation of heat at night by covering with wood, paper, or cloth, or by building smudge fires that surround the trees or plants with artificial clouds of smoke.

(2) Locate orchards and early garden crops on the hillsides and not in low places, so that the air which has been cooled by conduction to the surface of the ground will slide slowly away into the valley and be replaced by the warmer horizontally moving air which overlies the colder air in the valleys when conditions of inversion prevail.

(3) By mixing the air so as to prevent its forming in layers.

(4) Adding heat to the air. It has been demonstrated that

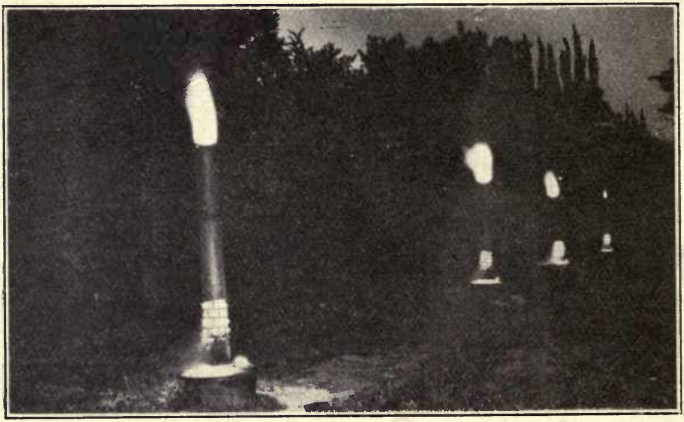

Plate VIII.—(Upper) The California short-stack oil heaters in place in an orange grove. (Lower) Improved tall-stack down-draft oil heaters burning at night. The lower portions of the stack are red hot and there is very little smoke.

by building a large number of small fires in the orchard or throughout the truck fields not only will heat be added, but the lower part of the atmosphere will be kept in circulation so that layers of cold air will not form.

611. Protection from frost damage by building fires.—The adding of dry heat to the air, thus warming up the cold lower layer and mixing the cold lower layer with the warmer layer immediately above has come to be the best accepted method for frost protection.

FIG. 83.—Lard-pail type of oil heater, and one of the first invented.

612. Kinds of fuel.—Fires may be made of oil, coal, wood, or any other material that will burn readily. The fuel to be used in any particular orchard will depend on its relative accessibility and the labor available.

613. Oil-heaters.—There are some ten to fifteen different types of oil-heaters on the market, varying from 1 to 6 gallons in capacity and costing from 20 cents to several dollars each. (Fig. 83 and Plates V to VIII.) The oil-heaters should be set at the rate of 80 to 120 to an acre. The temperature must be watched closely and when it has fallen nearly to the danger point, every third or fourth heater should be lighted and then the others as needed. The fires should be thicker on the outside edge, especially on the windward side, and also in low places.

614. Oil consumed.—The round heaters of the lard-pail type with the top about 7 inches in diameter will burn at a rate of about one quart an hour. With fifty pots of the one-gallon capacity burning to the acre, twelve and one-half gallons of oil will be consumed an hour for each acre. With heaters constructed so that the burning surface can be controlled, the intensity of the fires can be varied as the temperature conditions demand.

The number of hours that the heaters will be burned will vary with the season, crop, and location. If one stores 400 gallons of oil for each acre, it will allow for burning 100 one-gallon pots to the acre for twelve hours, which is sufficient for most seasons in the deciduous orchards. It is usually necessary to provide for longer burning periods and a much longer critical period in the citrus orchards.

615. Kind of oil.—The most desirable oil for fuel is a refinery product of about 20 to 26 degrees Baumé. Crude oil is used considerably, but it is likely to contain a small amount of water, and when such does exist the oil is liable to boil over after a short time, just when the fire is needed most. Oil with a parafine base burns much cleaner than that with an asphaltum base. Light gravity oil burns too readily, while too heavy oil does not burn clean and a large amount of soot is deposited on the trees.

616. Lighting heaters.—Special or home-made torches may be used in lighting the heaters. The time necessary depends on the type of heaters, kind of torches, the number of heaters lighted to the acre, and so on. Under very favorable conditions, one man can light over 500 fires in an hour, while 100 an hour would be a good number where the pots are scattered or do not light quickly.

617. Cost of equipment.—The initial investment for equipping a ten-acre orchard for oil-heating, including tank, cistern, heaters, and the like, under average conditions will not be far from $500, or $50 an acre. After the first year, the cost of heating including labor and fuel will approximate $3 to $5 an acre for each night.

618. Coal-heaters (see Fig. 84) cost more than the cheaper oil-heaters, but only about half as many are set to the acre. The best coal-burners hold 25 to 30 pounds of coal and will burn from four to six hours. It is considered that one ton of coal equals 100 gallons of oil in heating value. At one Ohio orchard in 1914, the temperature was kept 9 degrees higher within the orchard than was recorded outside the heated area with thirty-six coal fires to the acre. Oil-soaked waste and kindlings are placed in the bottom of the coal-heaters before they are filled. They are then lighted with a torch fully as fast as the oil-heaters. Coal is often placed in piles about the orchard, thus saving the cost of heaters. It must be remembered that a few large piles of coal to the acre will not furnish adequate protection, but that the more small piles the better.

FIG. 84.—A type of coal heater that will hold about 18 pounds of soft coal. They will burn seven or eight hours.

619. Wood fires.—Fires have been made of old rails, brush, and cordwood. In using cordwood, the sticks are piled with the ends dove-tailed together and as these ends burn off the sticks are pushed together. About six sticks of hardwood will burn four or five hours. Wood needs more attention than either coal or oil and the fires must be started earlier. (See Fig. 85.)

620. Great care needed.—Experience has shown that one must go about orchard-heating in a throughly businesslike manner. There must be plenty of fuel, men enough to keep the fires going and to make preparation for the next night's fight, and constant vigilance until the frost season is over. Care must be taken not to waste the fuel by lighting the fires too early or on nights when not needed.

Fig. 85.—Wood piled for orchard heating.

621. Critical temperature.—Thermometers should be distributed throughout the orchard and watched closely, and when the temperature approaches the danger point the lighting should be begun in the lowest part of the orchard. If the temperature is falling slowly, the fires need not be started until the temperature is very close to the danger point. This is especially true with oil-heaters as the effect of the burning oil is almost immediately noticed; it takes longer for the coal and wood to get started. If the temperature is falling rapidly, however, and the conditions seem to favor a low record, the fires must be lighted while the temperature is still several degrees above the danger point. (See Table 11 for data showing the critical point for many of the fruits.) Tender truck crops need to be protected from freezing temperatures also.

622. The lowest temperature just before sunrise.—Fig. 86 shows a thermograph record from May 11 to 18, 1914. It was quite warm on the 11th, the curve indicating a temperature of 80°. A cool wave reached the region of the station before noon of the 12th and there was a sharp drop in temperature. There was little variation on the 13th, but from the 14th to 17th typical radiation conditions prevailed. The temperature rose to between 60° and 70° during the daytime

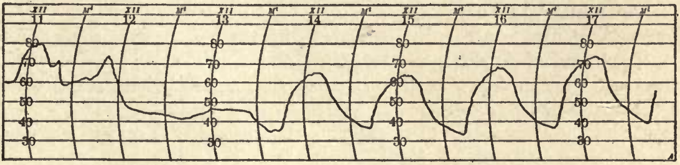

Fig. 86.—Record made by a self-recording thermometer May 11 to 18, 1914, at Delaware, Ohio.

under bright sunshine, but fell nearly or quite to freezing at night with free radiation. It is under conditions like those of the 14th to 17th that frosts are likely to occur and, as shown by the record, the lowest temperature will be reached just before sunrise.

623. Protection by heating possible.—Experience has conclusively proven that the temperature can be kept above the danger point by orchard-heating when otherwise it would fall low enough to cause damage to fruit and truck.

Arrangements can be made to receive frost warnings by writing the nearest Weather Bureau Office if an effort is made to protect fruit or truck from frost damage.

LABORATORY EXERCISES

1. Paragraph 603. Obtain daily mean temperature and killing frost data from the local Weather Bureau and compare the frostless and vegetative periods.

2. Paragraph 605. If the vegetative period is considerably longer than the frost-free period, what local crops might profitably be protected from early or late frosts?
3. Paragraphs 610 to 619. Carry out some tests of frost protection, particularly to truck or small-fruit crops, by covering or heating.
4. Paragraph 621. The influence of topography on night temperature should be ascertained by exposing thermometer at different elevations.

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CHAPTER XII

VALUE OF LIGHTNING-RODS

There was a time when lightning-rods were a fad and the lightning-rod agent flourished and waxed fat. But because he insisted on accumulating the good things of the land too rapidly there soon came a second period when shot-guns were kept loaded and standing beside the outside door because the lightning-rod agent became more to be feared than the lightning.

But the lightning-rod that had been put up stayed up and it began to be noticed that those which had been installed in an honest and workmanlike manner furnished protection, while all around buildings without such protection were being destroyed by lightning. This has led fire-protection agencies, appalled by the immense fire loss, to inquire more fully into the possible value of lightning-rods as a protection.

624. Thunder-storms.—All the features of thunder-storms point to their dependence on a convectional overturning of the atmosphere. Thunder-storms usually occur wherever there is a rapidly rising current of moisture-laden air. Condensation goes on rapidly in such a rising mass of air as soon as the dew-point temperature is reached and at such times electricity accumulates very rapidly. As clouds form, different clouds or parts of the same cloud may be charged with various kinds of electricity, negative or positive. Great changes in electrical potential are caused which may result in lightning.

625. Where thunder-storms occur.—Thunder-storms occur most frequently in warm regions and are commonest in spells of warm summer weather and in the afternoon shortly after the warmest part of the day.

In the United States the greatest number occur in the east Gulf states where the average days with thunder-showers each year will be close to sixty. In Missouri and eastern Kansas it will average over fifty, while in the whole central valley country from the Appalachian to the Rocky Mountains and from South Dakota and southern Minnesota and Wisconsin to the Gulf the average number each year is over thirty.

In New England, upper Michigan, and practically all of the region in and west of the Rocky Mountains, except in New Mexico and Arizona, the average annual number of thunder-storm days is less than twenty. In the Pacific Coast states they are very rare.

626. Nature of lightning.—Lightning is an electric spark on a tremendous scale. It occurs between clouds more frequently than between cloud and earth. The length of the flash between the cloud and the earth is usually not more than one mile in length, while within clouds it may be twenty miles in length. Lightning flashes usually consist of a number of successive discharges which follow each other with a very short interval between. In one case of a flash consisting of five successive discharges, the total time from the first to the last was found to be 0.2447 second, while the intervals between the successive discharges were found to be 0.0360, 0.0364, 0.0283, and 0.1440 second, respectively. One photograph showed forty distinct discharges in a single flash.

627. Damage by lightning.—Damage by lightning is mechanical as well as thermal. Not only is the damage caused by main discharges, but currents are induced in nearby metal objects and conductors and these often produce additional damage. It is probable that most of the unusual results in a lightning flash are due to these induction effects. This will be shown by a fire being started in inflammable material between two nearly parallel wires or rods.

One example reported is of a fire in a flour-mill where it was evident a fire started on a separator between the fan-shaft and the drive shaft bearings. In this case the mill had a metal roof and was iron-clad, a protection that is considered to be absolute as far as any damage to the exterior of the building is concerned. This same writer believes that these induction effects between the wires on baled hay are responsible for many otherwise unexplainable fires in properly protected barns or warehouses.

Another writer, secretary of a company carrying risks in farm property of fully $42,000,000, states that all of the losses and damages by lightning which they have had on rodded buildings have been traced to some metal parts, which were not connected to the lightning-rod. They find that the telephone line in houses is the most dangerous thing with which they have to contend. He states that they find lightning will jump ten, twelve, and fifteen feet from the lightning-rod to the telephone wire and the same from the telephone line to the lightning-rod. They now advocate placing the ground rod on the house as near as possible to the telephone wire without touching it.

628. Loss by lightning greatest in rural districts.—The property loss by lightning in the entire country averages approximately $8,000,000 each year, the greater part of which occurs in rural districts. In the central part of the country, the loss and damage by lightning is far greater in the country than in the cities. The Indiana Fire Marshal states that 75 per cent of all lightning losses occur in the rural districts which contain but 47 per cent of the population. He states further that in 1913, 92 per cent of all barns damaged by lightning were in the country and that 69 per cent of all barn losses were total. In the case of dwellings, 52 per cent damaged or burned by lightning were in the country and 48 per cent in the city.

It is stated on good authority that about four times as many barns are fired by lightning as houses.

629. Office of the lightning-rod.—There is a nearly constant interchange between the electricity in the earth and that in the atmosphere and one of the offices of the lightning-rod is to furnish a path for the quiet discharge or interchange of this electric current. The second office of the rod is to furnish a path for the disruptive discharge between the clouds and the earth when the potential reaches the breaking point.

630. Value of lightning-rods.—In 1914 the author sent letters of inquiry to over 1100 Mutual Fire Insurance Companies doing business in forty-four different states mostly in the rural districts. They were requested to report in detail the actual records from their books.

Replies from 130 different companies doing business in fifteen states showed that they had kept their records in such detail that full information could be given. These companies had about 350,000 farm buildings insured, valued at close to $300,000,000. These reports were tabulated and are summarized in the table following.

TABLE 55.—SUMMARY OF DATA COLLECTED FROM MUTUAL FIRE INSURANCE COMPANIES IN THE CENTRAL PART OF THE UNITED STATES

Period	*Number of insurance companies reporting*	*Number of farm buildings insured*	*Number of buildings burned from any cause*	*Number of buildings struck by lightning*	*Number struck, only damaged*	*Number struck and burned*	*Number struck that had lightning-rods*	*Number with lightning-rods struck and damaged*	*Number with lightning-rods struck and burned*	*Total risks on farm buildings*	*Total claims paid from all fire loss on farm buildings*	*Total claims paid due to lightning*	*Total claims paid due to lightning on rodded buildings*	*Percentage of buildings rodded*
1912.....	92	191,009	469	756	588	154	24	14	3	$173,343,000	$362,009	$137,590	$8,104	31%
1913.....	121	328,565	1,174	1,089	809	252	43	33	6	249,883,000	572,344	198,581	4,684	31
5 years...	51	94,797	465	660	456	155	21	11	1	63,026,000	185,963	71,442	270	34
Misc.....[1]		18,155	591	495	245	71	0	0	0	6,771,000	159,920	48,252	0	55

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[1] Summary from five different companies covering a term of years, the shortest being thirteen and the longest twenty-five years.

631. Lightning-rods as a protection to buildings.—This table shows that the total number of buildings struck by lightning in 1912 and 1913 was 1845. Inquiry developed the fact that close to 31 per cent of all of the buildings insured by these companies are equipped with lightning-rods. Hence, if rodded buildings were just as likely to be struck by lightning as unrodded ones, there would be 31 per cent of the 1845 buildings that were struck by lightning that would have rods on them. As a matter of fact, however, only sixty-seven of the buildings struck had rods of any kind. The number of rodded buildings that were struck, therefore, was only 10 per cent of the expected number, demonstrating the fact that the efficacy of the lightning-rod in actually preventing damaging lightning strokes is 90 per cent.

In a report covering the past five years, fifty-one different companies having nearly 95,000 buildings insured, had 660 buildings struck by lightning, only twenty-one of which had lightning-rods on them. As fully 34 per cent of their buildings are rodded, the expectation would be that 34 per cent of 660 or 224 would be rodded. But as only twenty-one were rodded instead of 224, or only 9 per cent, it shows that one may expect that out of every 100 farm buildings struck by lightning nine of them will be equipped with lightning-rods and ninety-one will not have rods. A table made up from sixty-seven different companies in Missouri, Illinois, and Ohio showed practically the same efficiency.

Five companies doing business in Illinois, Missouri, and Nebraska with over 18,000 buildings insured, made reports covering a longer period of years, the shortest being thirteen years and the longest twenty-five years. They have had no building burned or even materially damaged by lightning that was equipped with rods, and they report over 50 per cent of their buildings rodded. This is an efficiency of 100 per cent.

This finding of the efficacy of the lightning-rod in preventing damaging lightning strokes is substantiated by the results of an inquiry by W. H. Day of the Ontario Agricultural College. His inquiry covered Ontario, Iowa, and Michigan and included several years. He found the efficacy of the lightning-rod in preventing lightning strokes to be from 92 to 99.9 per cent.

632. Damage to rodded buildings.—Occasionally a rodded building is struck by lightning, but the properly installed lightning-rod is of very great value in preventing damage.

The table shows that the total claims paid on farm buildings due to lightning, in 1912 and 1913, was $336,171. Inasmuch as 31 per cent of these buildings insured by these companies were rodded, a loss would be expected on rodded buildings of 31 per cent of $336,171 or $104,213, but in fact the total claims paid for lightning damage on rodded buildings during the two years was only $13,053. In other words, the actual loss was only 12 per cent of what would have occurred if the lightning-rods did not serve as a protection.

The total number of buildings burned by lightning in 1912 and 1913 as reported by these companies was 407, and of these only nine were equipped with lightning-rods, or only 2 per cent. Of those struck that had rods, only 5 per cent were burned and the other 95 per cent simply damaged: thus showing that the danger of a building being burned by lightning that is equipped with lightning-rods is exceedingly slight.

A further study of the reports shows that when struck and damaged by lightning but not burned down, the average damage to a building was less than $10 on those equipped with rods and very nearly $200 when not so equipped.

633. Material for lightning-rods.—Lightning-rods may be of iron, copper, or aluminum and either will be satisfactory as a conductor. As iron is not so good a conductor as copper, it is thought to carry a lightning flash more safely, and besides it has the advantage of having a higher fusing point. Iron rods must be heavily galvanized and kept painted frequently and for this reason should not be used in locations difficult of access.

If single-strand iron rods are used, they should be No. 2, No. 3, or No. 4 (B. and S. gage) depending on the size of the building; No. 2 is 0.257 inch in diameter or about twice the size of an ordinary telegraph wire which is No. 9; No. 3 is 0.244 inch and No. 4 is 0.225 inch in diameter. Star section rods are preferred by many.

The Michigan Agricultural Experiment Station recommends the use of 3/8-inch seven-strand iron cable as being easy to handle, inexpensive, and wholly satisfactory. The important thing seems to be to have it heavily galvanized and kept painted.

634. Copper rods.—The best type of a copper rod is said to consist of bundles of small wires twisted tightly together. A steady electric current flows through every part of a conductor, but when the current is variable and exceedingly rapid the flow may be confined to a film very near the surface. To carry a lightning discharge, therefore, the rod should have as large a surface as possible. A twisted rod with thirty wires each 0.0425 inch in diameter has about five and one-half times the surface of a round solid rod with the same amount of material.

The National Board of Fire Underwriters recommends that on residences, barns, stables, stores, and similar buildings where the maximum height of any point does not exceed 60 feet, copper cable be used, weighing not less than 3 ounces a foot and no single wire being less than 0.046 inch in diameter. In the case of taller and larger buildings, they recommend the cable to weigh not less than 6 ounces a foot.

635. A continuous conductor necessary.—The all-important thing seems to be to have a continuous conductor from the highest points on the building to permanently moist earth beneath. The kind of material and the size of the rod does not seem to be so important as frequent inspection, good groundings, and constant care to see that there are no poor or broken joints or rusted and broken connections.

636. Points above all projections.—Points should extend above all chimneys or other roof projections and should be placed at each gable end and at intervals of 25 to 30 feet along the ridge. There should be two grounds to all rod systems and if the buildings are 100 feet or more in length, three or more down rods. All cables should be connected in one system. Insulators should not be used but the rod fastened directly to the sides of the building. All heavy masses of metal in the building should be connected to the rod, but the rods should be kept as far away as possible from gas-pipes or lead water-pipes.

637. Grounding the rods.—The earth connection may be a square sheet of copper 1/16 inch in thickness and not less than 3 feet square. This must be buried in moist earth even if one has to go down 10 or 12 feet. Probably the most economical and at the same time satisfactory grounding is made with cast iron or copper rods extending into the earth from 6 to 10 or more feet, or to a point well below the foundation walls of the building to be protected.

Farmers' Bulletin 842 illustrates satisfactory methods for grounding wires, connecting exterior and interior metal work, erection of roof points, and the like, in a very complete manner. (Figs. 87, 88.)

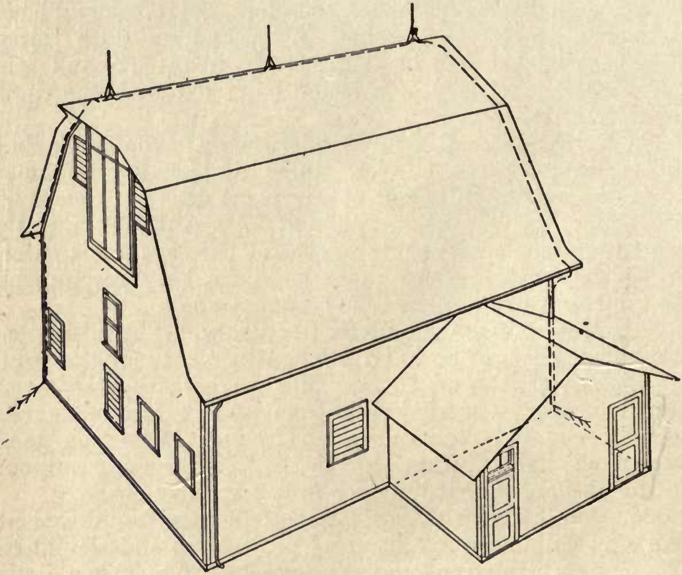

Fig. 87.—Lightning-rod on a small general barn.

638. How spliced.—When splices are necessary, the ends must be fastened solidly together and if possible riveted and soldered. When there is an imperfect connection, the electrical resistance will be so great that the electricity is likely to leave the rod and damage the building. Metal-covered roofs should be connected with ground wires from at least two corners by riveting and soldering and then run to moist earth.

639. Care in installing.—While lightning-rods must be put up in a workmanlike manner, their installation involves no more wonderful or mysterious processes than building a fence or digging a well.

The statement by some lightning-rod agents that no one but special scientists versed in all of the laws of electricity should do the work of putting up lightning conductors is about as sensible as to say that no one but a professor of geometry should be allowed to lay brick. And not only that but any professional in the lightning-rod business who advocates that his system is the only one scientifically correct and reliable, while all others are worthless and dangerous, invites the suspicion that he is himself a fakir.

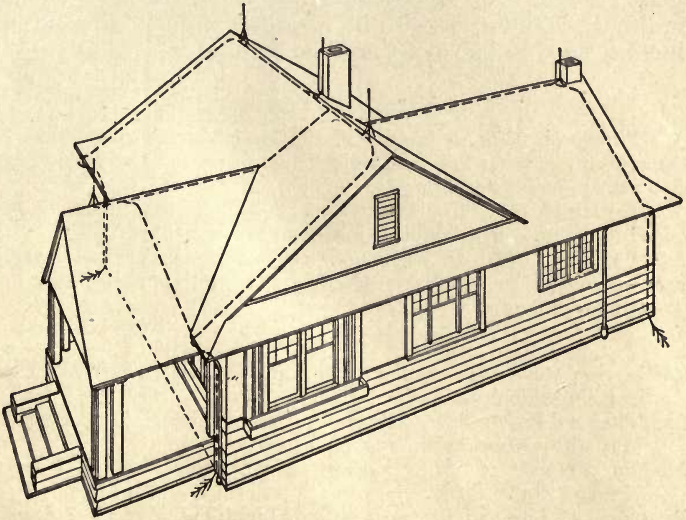

Fig. 88.—Method of placing points and connecting rods on a farmhouse to protect from lightning.

The installation of a proper rod is not and need not be excessively expensive. By the exercise of ordinary common sense and with the knowledge that electricity demands a continuous path to the moist earth, a satisfactory rod can be put up without serious trouble.

640. Loss of live-stock.—The loss of live-stock near wire fences is very great. It may be reduced by grounding wire fences by means of galvanized iron pipes or posts at intervals of about 100 yards or by attaching wires to the posts at about the same distances and letting them extend well into the ground. Care must be taken to see that these ground wires are in contact with each fence wire, and that they go into moist ground. The electrical continuity of the fence should be broken at intervals also by inserting sections of non-conducting wood in place of the fence wire.

LABORATORY EXERCISES

1. Paragraph 630. An inquiry of the local Mutual Fire Insurance Companies regarding losses on rodded and unrodded buildings would give some valuable data.
2. Paragraph 637. Copies of Farmers' Bulletin 842 should be obtained for detailed instruction in installing lightning-rods.
3. Paragraph 640. An inquiry of local stock-growers would develop some interesting and valuable data regarding loss of stock near ungrounded wire fences.

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