STATE OF ILLINOIS DEPARTMENT OF REGISTRATION AND EDUCATION

DIVISION OF THE

NATURAL HISTORY SURVEY STEPHEN A. FORBES, Chief

Vol. XVIII.

BULLETIN

Article III.

Epidemic Diseases of Fruit Trees in Illinois 1922-1928

ΒY

L. R. TEHON AND GILBERT L. STOUT



PRINTED BY AUTHORITY OF THE STATE OF ILLINOIS

URBANA, ILLINOIS 1930

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STATE NATURAL HISTORY SURVEY DIVISION Stephen A. Forbes, Chief

H. C. OESTERLING, Editor

JOURNAL PRINTING COMPANY, Springfield, Illinois. 1930

(33069—2M)

Stephen Alfred Forhes

May 29, 1844-March 13, 1930

This article completes the Eighteenth Volume of the Bulletin of the Illinois State Natural History Survey published under the direction of Stephen Alfred Forbes. Volumes I to XII, inclusive, were issued under the title of the Bulletin of the Illinois State Laboratory of Natural History and Volume XIII to date as the Bulletin of the Illinois State Natural History Survey.

Stephen Alfred Forbes was the founder of the Illinois State Laboratory of Natural History and served as its Director from 1877 to 1917. He was appointed State Entomologist in 1882 and continued in this capacity until 1917, when he became Chief of the Illinois State Natural History Survey, a division of the State Department of Registration and Education, under the Civil Administrative Code merging the State Laboratory and the Office of the State Entomologist.

In addition to the Bulletin series there have been issued under his authorship or direction three *Final Reports on the Natural History Survey of Illinois,* two volumes dealing with birds and one with fishes; the last eighteen of the twenty-nine *Reports of the State Entomologist on the Noxious and Beneficial Insects of the State of Illinois;* and numerous miscellaneous papers dealing with various phases of natural science.

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EPIDEMIC DISEASES OF FRUIT TREES IN ILLINOIS 1922-1928

L. R. TEHON AND GILBERT L. STOUT

In a wide geographical sense the diseases of fruit-trees, like those of other crops, are distributed in strict accordance with climates; and in each climatic region the particular diseases which find conditions suitable for their existence exhibit notable yearly variations both in prevalence and in severity. It is well understood that these annual fluctuations occur simultaneously with, or in some cases subsequent to, certain kinds of variations in weather; and it is generally known also that the degree of success attending the application of sprays to control disease depends to a very high degree upon the prevailing weather conditions, partly because of the great influence they have upon the growth and development of the parasitic fungi which cause diseases and partly because they determine the seasonal progress in flowering, leafing, and fruiting of the trees upon which sprays are applied.

The plant pathologist who has dealt with fruit diseases in a limited region for a number of years is able to draw upon his experience to the extent that he can, upon the arrival of very unusual weather, foresee the kind of variation in disease that will occur. He may then recommend the modifications of spray-schedules and other control operations along lines likely to reduce the menace of a disease attack which would, under the usual program of control, be certain to result in excessive injury and loss to the season's crop. But it is a fact that forecasts of this kind, which now can be made only from long personal experience, are relatively rare and can be only relatively accurate.

The natural laws which govern both the major and minor variations of disease epidemics are as yet very poorly or not at all understood. No extensive studies have been made of diseases as they occur on fruit trees, except with such specific intentions as determining the effects of sprays or ascertaining the life histories of fungi. Knowledge of plant diseases and of their causes, apart from ancient superstitions and medieval theories, has been acquired so recently that there is no body of historical information available upon which either the investigator or the fruit grower can draw for dependable guidance in forecasting the extent or destructiveness of an impending epidemic. The efficient use of fungicides is limited by the same circumstances, the application of dusts and sprays being governed mainly by the phenomena exhibited by the fruit-tree which is to be protected rather than by those exhibited by the parasites which are to be destroyed. Nevertheless, the pressure exerted by the rapidly advancing demands of the modern agriculturalists who are engaged in the production of the fruit crops, as well as the industrialists who furnish the fungicides for the control processes, for more accurate directions and predictions, makes it necessary to have available a fund of concrete, accurate data from which to draw conclusions which, in older sciences, might be deduced from historically recorded experiences.

The practical results to be derived from the accumulation of a body of exact information on plant disease epidemics are at least two-fold. First, it is required that the manifestations of each disease shall be analyzed in such a way as to permit of measurement, with the natural consequence that there will be developed for the purpose accurate and uniform scales applicable to disease as a whole and not limited to those phases resulting in economic loss; and the present tendency to confuse crop loss with disease intensity will disappear. Second, the exactness of the accumulated data will make possible much finer comparisons than can now be made; and the effectiveness of fungicides will be increased, thereby, because of the certainty of their being applied more and more in accordance with the life-phenomena of the fungi they are intended to combat.

Since midsummer of 1921, the Natural History Survey has been engaged in studying the annual prevalence and intensity of diseases attacking the crops of Illinois. The purpose of the study has been to observe and record yearly the crop disease conditions, making the observations with such exactness and at the same time so extensively that the data and records obtained could be used subsequently to determine with accuracy the real relations existing between variations in weather and variations in plant disease epidemics. The diseases of cereals, of fruits, and of forage, vegetable, and other crops have been given time and attention each season, and two extensive reports—one on the distribution of diseases, the other on survey methods for diseases of cereal crops—have been prepared and printed.

It is our purpose, now, to present in some detail an account of the survey methods that have been developed and used in dealing with fruittree diseases and to state the results that have been obtained through their use. These methods are similar in certain respects to those described for cercal diseases in a former publication. Consequently this discussion has been made as brief as possible. For simpler and more detailed explanations of many of the processes used, the reader may refer to the more comprehensive discussion given in Article 1, Volume 17 of the Survey's Bulletin.

GENERAL METHODS

The aim of the fruit disease survey, as it has been conducted thus far, has been to "sample" the disease conditions prevailing in each of a considerable number of scattered localities each year and then, supposing these samples to be typical of the conditions prevailing in the regions from which they were taken, to subject them to arithmetical analysis and summarization in order to obtain numerical expressions of the general and special characteristics of each year's disease epidemics. In obtaining the samples, various numbers of observers have traveled the country roads of the State each year since 1921 and have examined small and large plantings of fruit trees in accordance with prepared instructions. In finding and selecting orchards for examination, the Farm Advisers of many County Farm Bureaus have given cordial assistance.

During the season of 1922, the four observers then employed were required to collect a specimen of each disease found in each orchard and to make certain specific notes regarding each disease. The specimens were intended primarily to serve as a means of confirming the observer's diagnoses, but they were expected also to serve both as substantiating records and as reference material from which additional facts could be obtained by subsequent examination.

For the convenience of the observers, but especially to assure reasonable uniformity in the making of the required notes, small mimeographed blanks were provided, one of which was to be filled out as completely as possible for each disease found in each orchard examined. These blanks, with their confirmatory specimens, have been held as a permanent record of the season's work. The following example shows the form of the blank, in Roman type, and, in italics, the notes secured in an unusually well completed instance.

Collector's No. 1220 Accession No. 15,635 Crop: Apple, Variety: Ben Davis, Developmental state: Disease: Scab. Cause: Venturia inacqualis. Type of injury: Fruit & leaves. Date: July 15, 1922. Town: Frederich. County: Schuyler. Date first observed: Late May. Source of infection: Control measures: Lime-sulphur. Calyx spray only. Size of field: 200 trees. Infection: in field, 100%; on plant: 60% of fruit.* Reduction of photosynthetic surface: Leaf specimen typical. Past prevalence: Present every year and usually severe. Usual damage: Considerable. Estimated damage: 5% of fruit ruined. Association with other diseases: Blotch, blight, frog-eye. Weather relations: Dry and hot. Additional notes: *Leaves show average of 7.5% of area occupied by scab lesions.

Although the topics of importance in a fruit disease survey are included in this blank, the small spaces do not provide sufficient room for definite detail in the notes and a larger blank had to be devised. After several trials, the form shown on the opposite page was developed. These note sheets, $8\frac{1}{2} \ge 11$ inches, are printed, and are gummed into pads of a hundred. They are carried by the observer, and one sheet is required to be filled out for each disease found in each orchard. As may be seen from the example, the information they give is essentially the same as

was required by the smaller blank first used; but the larger form has the two advantages of allowing fuller notes on most points and of permitting complete statements of counts made by the observer.

	1928
PLANT DI	SEASE RECORD BLANK
Crop Apple. County Cumberland.	Disease Scab (Endostigme inacqualis) Locality Ncoga.
Variety of crop Stayman's Win State of development Trees 20	ncsap. Size of field 1,000 trccs. 3 ycars old. Scason's fruit 2″ in diameter.
Control measures j Applied Not appli	$\begin{array}{ccc} X & \longrightarrow & \text{Spray.} \\ \text{ied} & & & \text{Kind used Oil (dormant) and} \\ & & \text{lime-sulphur.} \end{array}$
When used: Dormant spray; limc-sulphur. Thorough ap the leaves.	cluster-bud spray omitted; 4 applications of pplications with considerable spray burn on
INFECTION: Percentage of tre	ees diseased 100. Leaf infection 3.28% of area.
Data: Fruits examined 673	Scale classes: 0— 5—10—15—20—30—45— 60.
Fruits infected 146	Class frequency: 125+33+7+4+3+2+1+ 2=177.
Per cent, infected 21.7	01

Type of injury Abundant but light infection on fruit. Light infection on 29% of the leaves.

Class values:

Estimated damage (Not determinable at date of this report.)

Date first observed May 29th. Source of infection Probably old leaves.

Past history Orehard clean before 1927. Increased infection this year may be due in part to omission of cluster-bud spray.

Association with other diseases Black-rot, blotch, fire-blight, and rust also present in this orchard. See particular reports for each.

Additional notes (weather, phenology, etc.) Spring was cool, the month of June exceptionally wet, and July hot.

Date of observation August 1, 1928. Specimen No. 8-379; Acc. No. 21545.

Observer G. L. Stout.

0 + 165 + 70 + 60 + 60 + 60 + 45 + 120 = 580.

The blank is designed to record information regarding one disease only. This is seen to be practically a necessity when it is considered that a very considerable number of orchards may furnish data on each of several diseases in a given season and that, for convenience in study, the numerous records pertaining to one disease must be kept together. In addition to the geographical situation of the orchard, the pertinent facts

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given on each blank include a statement of the fruit variety, the number of trees in the plantation, their age, and the stage in seasonal development of the fruit or other structures at the time of examination, as well as information regarding the application of control measures, all of which may be essential in interpreting the data given in the other spaces.

The tree is taken as the unit of survey; and it is our custom, in examining large plantations, to prepare separate reports for each horticultural variety, thereby securing accurate information relating to the differences in predisposition to disease attack exhibited by the more common varieties of each kind of fruit grown in the State.

The data taken on the season's manifestation of disease is concerned particularly with two distinct phases: first, the *prevalence* of the disease, which we express as the percentage of trees suffering from attack in diseased orchards and second, the *intensity* of the attack, which we determine as (a) the percentage of fruits attacked; (b) the amount of woody growth diseased or destroyed; and (c) the destructive effect on leaves, expressed as destroyed or occupied leaf area. Some diseases do not, of course, exhibit all these phases, and from them the data which ean be acquired are limited to the types of disease they produce.

The observer, in all the processes of gathering data, must consider only the disease. The commercial effects of disease, seen as reductions in the grade of fruit or in lowered yields, are secondary things, well recognized by the fruit grower but quite apt to be misleading in a study of the epidemiology of disease.

In gathering these data, the observer is required first to determine the number of trees that have become diseased in the plantation in which he is working, and this determination he expresses as a percentage on the record sheet. When the disease is a prevalent one and the variety susceptible, this percentage, or prevalence "index," may be ascertained by a brief examination; but with rarer diseases, exceptionally good control, or resistant varieties, more care is required.

To determine the prevalence of fruit infection on the diseased trees, it has been found necessary to make a definite count of the observable fruit on each tree, as the tree is examined, and to distinguish between the fruits that are infected and those that are not infected, as the count is in progress. On the sample record, it is indicated that 673 apples were seen, of which 146 were seen to be infected by, and 527 free of. scab; and from these data it is considered that infection had occurred on 21.7 per cent of the fruit.

As the observer conducts his examination, he also gathers a random sample of leaves, which, to conclude his examination, he compares with a set of standard, measured diagrams, or scales, with which he is provided, and thereby secures an estimate of the amount of disease present on the leaves. The manner in which one such a diagram is used is described in the discussion of apple scab. The only explanation that needs to be made here is that, in obtaining the data shown in the sample record, 177 leaves were scaled, 125 of them being either free of infection or only very slightly diseased, while various numbers of the remaining 52 were diseased to the extent indicated by the scale classes under which the numbers are placed. The average amount of leaf area eccupied by scab lesions in this sample was 3.28 per cent. 'This figure we regard as an "index" expressing the intensity of the scab attack on leaves in the orchard.

When the record blanks have been completed, the collector sends them, often with substantiating specimens, to headquarters, where, as they accumulate, they are assorted by crops and by diseases, those for each disease of each crop being assigned a special folder for each year. The substantiating specimens are subjected to careful identification, often by microscopic examination and occasionally by culturing on artificial media, and then, designated by newly assigned accession numbers, they are preserved in the Natural History Survey's mycological collection for permanent reference.

ANALYSIS OF DATA

At the close of each season's work, it is necessary to analyze and summarize the accumulated records, and in order that the results obtained from data gathered in one season may be comparable with those of other seasons, this must be done in a uniform manner. In general, the process is the same as that outlined for cereal diseases in a previous article; but there are slight differences which require some explanation.

The current season's record sheets for each disease, already assorted, are now arranged alphabetically by counties and numbered in sequence, and the data which they furnish are assembled in a series of tabulations, only one of which has been used in preparing data for this discussion. It is made up in the manner illustrated by the very much abbreviated example shown in Table I.

One line across this table carries all the data on prevalence and intensity given by one record sheet and shows, besides, a number of simple computations made from them. The number of the record sheet appears in column 1 and serves as a reference to the place in the folder from which the data are taken. Column 2 shows the name of the county in which the examined orchard was located. As the record sheets have been assorted by counties, all the records for each county represented in the season's accumulation are grouped on consecutive lines, and column 3 then shows not only the number of trees represented by the examinations conducted in each county and in the state.

Column 4 shows the percentage of diseased trees in every infected orchard examined, as given by the individual records, and also gives weighted averages of these percentages for each county and for all records taken during the season. The weighted averages are obtained with the aid of the figures which appear in column 5, which we have termed "prevalence products." They are secured by multiplying each entry in column 3 by its corresponding entry in column 4. The purpose of this is to give a proper relative weight, in terms of the particular number of trees to which each percentage applies, to each of the prevalence percentages, so that when all the data obtained in one county, or in the State, are brought to an average, the observations made in small and possibly uncared-for orchards will not unduly influence those made in plantations of 500 to 1000 or more trees. As an example, suppose the short list of observed prevalence percentages given for Calhoun County in the sample table be added and divided by 4. The sum is 300.4 and the quotient is 75.1 per cent. But by weighting the prevalence percentages observed in each orchard in terms of the number of trees in each, the proper relative importance is given to each of the observations, and the prevalence index, equivalent to the previous quotient, is determined as 68.8 per cent. Since the difference between the apparent average of 75.1 per cent and the weighted average of 68.8 per cent amounts, in this one instance, to 6.3 per cent, it may

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EXCERPTS FROM THE SUMMARY OF FIELD NOTES ON THE PREVALENCE AND INTENSITY OF THE SCAB DISEASE OF APPLES IN 1928

			Prevale	nce Pro-	Intensity of disease attack					
Record	Country	Number of trees in	with i	nfection	Disea	sed fruit	Leaf	disease		
num- ber	County	orchards examined	Ob- served per- centage	Prev- alence product	Ob- served per- centage	Prev- alence intensity product	Ob- served per- centage	Prev- alence intensity product		
1	2 Calhaun	\$ 75	4	5 7 500	6	7 30_000	8	9		
23	Calhoun Calhoun	1,000	100.0	100,000 2,500	25.0 50.0	2,500,000	•T 1.00	2,500		
4	Calhoun	500	0.4	200	T	0	0	0		
	Total	1,600	68.8	110,200	16.6	2,655,000	0.01	2,500		
23 24	Clark.	180 80	100.0	18,000	18.0	324,000 16,000	T	0		
25 26	Clark Clark	200 85	100.0 100.0	20,000 8,500	0	0	6.71 3.87	134,200 32,895		
	Total	545	100.0	54,500		340,000	0.07	167,095		
64	Pike	352	100.0	35,200	0.24 4.0	140,800	0.30	10,560		
65 66	Pike	500	100.0	52,000	3.0	150,000	2.00	100,000		
67	Pike	1,600	100.0	160,000	10.0	1,000,000	1.18	100,000		
	Weighted averages	2,972	100.0	297,200	6.54	1,942,800	1.01	299,300		
	Total Weighted averages	5,117	90.27	461,900	9.65	4,937,800	0.92	468,955		

• The symbol T is used to indicate the presence of infection, when the actual amount is too small to measure. Its statistical value is considered to be 0.

readily be seen that the use of corrective weighting throughout the table assures a much more accurate final index.

The remaining columns of the table deal with the intensity of the disease, and the nature of the data used in them depends, of course, upon the types of manifestation characteristic of the disease. The disease illustrated in the sample table is apple scab, which in Illinois very rarely causes appreciable damage to either the blossoms or the woody parts of the tree; hence, the points of importance to be considered in determining the intensity of its attack are (a) the number of fruits infected and (b) the amount of leaf tissue destroyed. In the case of other diseases, such as fire-blight and blotch of apple, measure-

ment of seasonal intensity would include twig infection and perhaps blossom blight.

The observed percentages of diseased fruit recorded on the record sheets and entered in column 6 apply to diseased trees only. In order to secure an infection index for all trees, it is necessary to compute a "prevalence-intensity product" by multiplying each prevalence product in column 5 by its corresponding intensity percentage in column 6. This is entered in column 7. In effect it gives a proper relative weight to each recorded intensity observation, with the result that the intensity indexes for counties and for the entire set of data are considerably more accurate.

The observations on leaf intensity are entered in column 8. These figures, like those for fruit intensity, apply only to diseased trees, and prevalence-intensity products must be computed for them also, and in the manner just explained for the fruit intensity data.

When all the data given by the field-record sheets have been transferred to the table and the proper prevalence and prevalence-intensity products computed, indexes of prevalence and of intensity applicable to the entire set of observations can be secured by finding the totals of columns 3, 5, 7 and 9, and then dividing each of the three latter sums by the first.

The indexes which have been obtained by the completion of this table express concretely the prevalence of the disease and the intensity of each phase of its attack, as exemplified in the orchards subjected to examination in each county in which observations were made and in all the orchards in which data were taken.

If these orchards have been numerous enough and their distribution sufficiently wide and representative, the final indexes of the table will be statistical expressions of the average disease conditions prevailing in the orchards of the State for the year; but as it usually is impossible to examine so large a number of orchards carefully, additional treatment is needed in order to obtain satisfactory indexes from the data secured. The results computed from observations made in one county usually vary to a greater or less extent from those of an adjacent county; and this variation, though influenced by the number of orchards actually examined as well as by errors inevitable in random sampling, often expresses real differences in the disease epidemics, due to the predominant use of varieties differing in their predisposition to disease, to cultural practices, or to the extent to which effective control measures are employed. The disparity between indexes obtained for any two counties nevertheless applies directly to the majority of orchards of those counties; but since counties seldom have the same number of trees, the average disease condition for a two-county area is necessarily different from that shown either by the sum of the orehard examinations or by an average of the indexes of the two counties.

A proper adjustment of values may be obtained, however, by weighting the indexes for each of the counties in proportion to the number of trees in the respective counties. This process is, of course, necessary for all the counties in which data have been taken, and a separate tabulation with accompanying computations can be made. The number of trees per county, the most important item in this step, is not directly available and so must often be estimated. The agricultural reports of the Bureau of the Census give the number of trees only for the years 1919 and 1924. For the intervening years, the number of trees per county may be estimated closely by securing the difference between the given years, dividing this amount into 5 equal parts (unless there is reason for adjusting the years otherwise), and according as the change was either an increase or a decrease, adding or substracting one of the 5 parts for each year subsequent to 1919.

As an example, the number of apple trees in Bond County in 1919 is given in the Census Reports as 87,346. In 1924, this number had fallen to 59,483—a decrease of 27,863 trees. During this five-year period the average yearly decrease was 5572.6 trees, and the number of trees presumed to each year was: 81,773 in 1920, 76,200 in 1921, 70,628 in 1922, and 65,055 in 1923.

Subsequent to the 1925 agricultural census, data of this kind are not available and will not be again until the results of the 1930 census are made public.

The employment of data of this kind may be illustrated by using the indexes obtained in the foregoing sample table and weighting them in sample Table II, below, in terms of the total number of trees per county.

TABLE II

AN ILLUSTRATION OF THE ADJUSTMENT OF COUNTY PREVALENCE AND INTENSITY IN TERMS OF THE TOTAL NUMBER OF TREES EACH REPRESENTS

		Prevalence		Intensity of disease					
County	Trees per	0	Development	On	fruit	On	leaves		
	county	index	product	County index	Intensity product	County index	Intensity product		
1 Calhoun Clark Pike	2 777,154 6.219 251,286	3 68.8 100.0 100.0	$4 \\ 53,468,195 \\ 621,900 \\ 25.128,600$	$5 \\ 16.60 \\ 6.24 \\ 6.54$	$\begin{array}{c} 6\\12,900,756\\38,806\\1,643,410\end{array}$	7 0.01 3.07 1.01	8 7,771 19,092 253,798		
Total Averages	1,034,659	76.56	79,218,695	14.09	14,582,972	0.27	280,661		

The makeup of this table is essentially the same as that of Table I, except that the intensity indexes given in columns 5 and 7, having already been determined in Table I as applying to average trees, are used without reference to the prevalence index given in column 3. Hence, the "intensity products" of column 6 and 8 are products obtained directly by multiplying the number of trees per county given in column 2 by the intensity indexes given in column 5 and 7, respectively.

The final averages, or averaged indexes, derived from this sample calculation differ considerably from those obtained in Table I. The prevalence index has been reduced from 90.27 in Table I to 76.56 in Table II; the index for intensity of fruit attack has been raised from 9.65 to 14.09; and the index for intensity of leaf attack has been lowered from 0.92 to 0.27. These differences, though much greater in the two brief examples than in the actual extended tabulations, nevertheless serve to illustrate how desirable it is to take into account the entire number of trees per county, the disease condition of which is represented by the individual observations, or samples, tabulated from the field record-sheets. It is, of course, apparent that the indexes with which Table I closes apply only to the orchards which have furnished data, while in Table II the entire number of trees in the territory where sample orchards were examined is taken into account, with the result that the final indexes of Table II apply to all these trees, whether they are inside or outside of the sample orchards.

Geographically, cropping in Illinois follows rather well defined plans. This has been recognized in the preparation of agricultural statistics to the extent that nine districts have been delimited. A considerable inequality exists with respect to the number of trees in these statistical districts, but this may not be represented adequately in the field examinations. To overcome this discrepancy, as well as to counterbalance the high amount of disease usually found in small-orchard regions, where spraying is not so generally or carefully done, so that the data taken there do not outweigh data taken in regions of dense fruit-tree populations, where commercial production is the aim and sprays are applied with care and success, a third tabulation of data and computation of indexes is often necessary. For statistical purposes, the State is divided from north to south into four sections of about equal length, and through these sections run longitudinal lines separating the north section into two approximately equal portions, the next section into three portions, and each of the two southern sections into two portions. The lines of division have been made to conform to county boundaries. Observations made in any one of these districts, after having been properly weighted in Tables I and II, may be extended to apply statistically to the entire fruit tree population of the district, and the calculation of the weighted district values gives a series of indexes showing the prevalence of a disease and the intensity of its several types of infection throughout the State. This process of equalization, described fully in our account of cereal diseases, is essentially as illustrated in Table III.

As a matter of practice, we have not yet been able to make consistent use of Tables II and III for our Illinois data. The making of these analyses is, as is of course apparent, entirely dependent upon having complete agricultural statistics at hand; but these statistics, provided at present only by the Bureau of the Census, are not issued concurrently with the gathering of our data. They are made available once in five years, and it is only after they have been made available that the fruit disease data collected during the preceding five years can be considered in all ways. The result is that, since no new statistical reports of a suitable character have been at hand since 1925, the observations we have made during the last four years can be made to apply only to the particular orchards in which they were taken; and because the years of this period number more than half of the years included by our survey, all the data presented on subsequent pages have been made to conform to this limiting condition. TABLE III

TABULATION OF DATA, AFTER EVALUATION IN TABLES I AND II, TO OBTAIN INDEXES REPRESENTING THE PREVALENCE AND INTENSITY OF A DISEASE THROUGHOUT THE STATE

		L L	revalence					Inter	ısity		
Counties	Number of trees in				Number of trees in		On fruit			On leaves	
(grouped in districts)	each county	County product	District index	District prevalence product	each district	County product	District index	District intensity product	County product	District index	District intensity product
District 1 Carroll Henry JoDaviess JoDaviess Mercer Whiteside Total.	23,080 46,078 279,468 38,148 37,057 37,1417 37,057 38,3358 38,3358 38,3358 38,3358 478,558	$\begin{array}{c} 2,388,000\\ 2,388,000\\ 25,152,120\\ 25,152,120\\ 2,814,800\\ 3,635,700\\ 3,731,502\\ 3,432,200\\ 45,016,822\\ 45,016,822\\ \end{array}$	94.06	59, 895, 808	636,783	997,056 997,056 530,818 1,397,340 1,034,941 1,034,941 1,034,941 1,037,340 1,647,806 210,705 210,705 715,233 77,233,807 77,283,807	15.21 to Give the	9,685,409	$\begin{array}{c} 118, 631\\ 311, 026\\ 311, 026\\ 300, 620\\ 166, 410\\ 235, 543\\ 370, 120\\ 370, 120\\ 370, 120\\ 370, 120\\ 370, 120\\ 370, 120\\ 370, 120\\ 370, 120\\$	بر. بې بې	3,712,444
State totals and indexes			Index	Total	Total	5	Index	Total		Index	Total

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LIMITATIONS OF DATA

The data upon which the discussions in this paper are based have been taken during the growing seasons of the past seven years. No two of these seasons have been alike, either with respect to disease phenomena or with respect to the number, experience, and capabilities of the observers who gathered the data. It has been necessary, also, for us to conduct fruit-disease and cereal-disease surveys simultaneously; and there has been, as a consequence, a certain amount of interference by each of these surveys in accomplishing the objects of the other.

Up to the time the survey was undertaken, no similar investigation of crop diseases had ever been made. There were no methods of procedure at hand which could be adapted to our use, nor was there any adequate body of experience upon which to draw for guidance. It is true that limited surveys had been made in various places, but these were concerned with one disease of one crop, were made for an immediate purpose, and had in view the object of determining either the extent of distribution or, vaguely, the immediate threat of the disease. The experience of entomologists was pretty largely invalidated by the inherent differences in size, habits, and methods of reproduction that exist between insect pests and parasitic fungi.

We were therefore faced by the necessity of accomplishing simultaneously two tasks—developing methods and gathering data. Our first work was quite as crude as the methods first conceived; but with improvement in method the value and reliability of the data have improved also; and in this connection it has been an especially fortunate circumstance that during the first years abundant specimens were gathered and preserved as records to which we have since been able to turn for re-examination with great benefit to the quality of our early records.

The investigation of crop diseases in the open eventually resolves itself into a statistical problem, and in this respect the diseases of fruittrees present an especially difficult task. Practically all of the cereals and most of the vegetables come from herbs that are limited to one year of life, and their diseases, at least so far as seasonal epidemics are concerned, are limited in the main to some particular plant part, such as stem, leaf, flower, or seed. Fruit-trees, on the other hand, are woody perennials, and each of their serious diseases is able to attack several parts of the tree. The destructive effect of a cereal disease usually may be measured directly in terms of the one part of the plant that is attacked; but a fruit-tree disease, which may begin the season by destroving the blossoms and continue by killing the new growth, injuring the leaves, and marring or rotting the fruit, often exhibits seasonal variations in the intensity of each of these types of attack, the sum of which gives it its destructive effect. Each effect must therefore be measured separately. For certain diseases, one or more types of attack are so rare or do so little injury that they can be ignored, while certain other types of attack-notably injury to the fruit-vary so much in severity that it is impossible, in a general survey, to do more than to note the amount of diseased fruit.

Moreover, it is permissible to take cognizance only of the disease, as it is expressed in its effect on the tree. To attempt to express the disease attack in terms of a possible commercial loss alone is not within the province of such a survey, as the actual loss of fruit, or the reduction in commercial value as it affects the crop, may be greater in the year of a mild epidemic than in the year of a heavy epidemic, according to the time of the disease attack, the subsequent conditions of the market, or the prices offered.

There has been a very considerable yearly variation both in the manner in which we have collected data and in the amount of data secured. In the first season, that of 1922, four observers were active, and the largest quantity of data that we have been able to obtain in any one year was taken. The progress of the survey that season was materially advanced by the cooperation of the County Farm Advisers, who willingly helped in locating orchards and very often furnished transportation to the field men. In the seasons of 1923 and 1924 there were but two observers; in 1925 the number was reduced to one; and since then there have been two each season.

Coincident with the development of more painstaking and accurate methods of surveying, there has been a decrease in the number of orchards examined and in the amount of data taken in a season; but this is more than balanced by the increased dependability of the records.

FRUIT-TREE DISTRIBUTION

The number of fruit trees of various kinds grown in each of the several sections of Illinois has an important bearing upon the amount and kind of data that can be obtained from each section in the course of a survey such as ours; and the cultural and disease-prevention practices, which are naturally much more adequate where fruit production is a major interest, as well as the location of orchards with respect to the geographical range of one or more diseases, strongly influence the character of the data as well as its significance when subjected to statistical analysis.

As an aid in understanding the data presented on later pages, therefore, the reader should have in the background of his thoughts a general picture of the fruit-tree population of Illinois. The latest available figures' indicate a total of a little over 12,821,000 fruit trees, of which about 6,764,000 are apples, 4,139,000 are peaches, 767,000 pears, 754,000 cherries, and 395,000 plums and prunes.

The location of these trees is such as to permit a rough grouping of the counties of the State, as shown in Figure 1, into three divisions, in each of which the number of trees. and the consequent intensity of fruit production, is essentially uniform. Throughout the northern half of the State orcharding is a minor interest, and the orchards are, for the most part, small and scattered. The total number of trees in this section is about 2,799,000—approximately 22 per cent of those in the State—and the average density of the tree population is about 89 to the square mile. In the central section fruit growing is a more important interest; and though it is true that the orchards of this region are also mostly small and scattered, there is a scattering of large

¹ The 1925 agricultural census furnishes data for apples, peaches, pears, plums and prunes but the figures of the 1920 census have to be used for cherries.

orchards, and Calhoun County bears the distinction of being the most important apple-producing county in the State. The number of fruit trees in this middle section is a little over 3,764,000—about 29 per cent of those in the State—and the tree population, about 262 per square mile, is nearly three times as dense as in the northern section. In the southern section, fruit production is an important commercial occupation. Here the orchards are large and frequent, and generally they receive good eare. The number of trees in this section, a little over 6,268,-000, amounts to 49 per cent of all those in the State, and the tree population, which reaches the high average of 614 per square mile, is



FIG. 1. THE FRUIT-GROWING REGIONS OF ILLINOIS

In the northern half of the state fruit production is not generally carried on as a commercial enterprise. The apple is the most common tree; but with the exception of a few large plantations it and the other fruit trees are grown in small farm orchards. The southern half of the state has two fruit regions which are distinguished chiefly by the density of fruit tree population, but in both regions commercial production of apples and peaches is the common practice. Further discussion is given in the text.

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about seven times as dense as that of the northern section and 2.3 times as dense as that of the central section.

The order of importance in which the various kinds of fruits stand also varies from section to section, as may be seen in Figure 1. In the northern and central regions, apples rank first and peaches second, while in the southern section this order is reversed. In the north apples are generally the only trees planted for a commercial crop, while peach, cherry, plum, and pear trees, numbering in their aggregate only about four-fifths of the total of apple trees, are seldom found in extensive plantings.

In the central section, apples and peaches both furnish commercial crops, and there are occasional pear plantations. Plums and cherries, also, are of more importance than in the north, though the plantings are generally small and scattered.

In the south, there has recently been a very decided stimulation in the planting of peach trees, and they now outnumber the apple trees by more than 200,000. The most intensive pear-producing regions of the State are also in this section, notably in Marion. Union, and Pulaski counties, and plums and cherries together, which are only one-third as abundant as pears, constitute only 3 per cent of the entire number of fruit trees, although when the areas of the several sections are considered they are of nearly the same importance as in the central section and are even more important than in the north.

In addition to these general features, each section has, of course, certain particular characteristics. In the north, commercial apple and peach production has been developed especially in Peoria, Tazewell, Fulton, and Bureau counties. Similar regions of especially intense production include Adams, Pike, Calhoun, and Jersey counties in the central section and Marion, Jefferson, Johnson, Williamson, Union, Jackson, and Pulaski counties in the southern section. The other counties in each section are fairly uniform. From north to south, through the State as a whole, there is, however, a gradual but very evident increase in the number of fruit trees per county.

APPLE DISEASES

The diseases attacking apple trees in Illinois can be classified rather conveniently as being either annual or permanent in their nature. Those that are classed as annual appear on the trees season after season but leave the trees more or less free from infection during longer or shorter periods of each year, at least in the case of one or more of their modes of attack. They are, therefore, the diseases which properly may be called epidemic.

Permanent diseases, on the other hand, stay with the trees they attack and continue to enlarge their destructive effects from year to year, though they are. of course, quiescent during the winter season. Represented in Illinois by the nail-head, fire-blight, bitter-rot, blotch and black-rot cankers, they are diseases of the larger, older, woody parts of the tree; and in those parts they persist, unless adequately treated, from the time of infection to the ultimate death of the tree. It is probable that their injuriousness varies from year to year; but their effects are very difficult to measure and the results of such measurements so uncertain that in the main they are excluded from consideration at this time.

The annual, or epidemic, diseases, though in many instances resulting from the same fungi or bacteria as cause the permanent diseases, generally attack the leaves, the twigs, the flowers, or the fruits; and though they may arise directly from infective material furnished by their permanent forms, their effects are usually limited to a single growing season. Each year brings a new attack, which varies from the attacks of every other year both in prevalence and in severity.

APPLE SCAB

Caused by Endostigme inacqualis (Cke.) Sydow

The scab disease of apple, the most widely distributed and most serious apple disease in North America, occurs throughout Illinois. It may attack the blossoms, the young twigs, the leaves, and the fruit, though generally only the leaves and fruit are injured to an appreciable extent. In Illinois, all four of these types of infection are known to occur; but the twig and blossom infections are generally so mild that they need not be given consideration. Leaf and fruit infection is usually severe in all parts of the State; but as a rule the injury is greatest in the north and is replaced to a certain extent in the south by blotch injury.

The effect of scab upon either the fruit or the leaves depends to a considerable extent upon the time at which infection takes place. When it occurs on young apples it often results in the production of small, misshapen, badly scarred, or cracked fruit that is of little value. Certain varieties of apples, however, have the ability to resist scab attacks. and the crops taken from these varieties, even in bad scab years, usually show only a very small percentage of scabby fruit, much of which is of a salable grade due to the healing, or "corking over," of the scab spots during the growth of the fruit.

Our comparisons of the year-to-year fluctuation in the amount of fruit infected with scab has therefore been limited to estimates of the percentage of apples bearing scab spots, and no consideration has been given to the very apparent differences in the degree of commercial damage to infected fruit resulting from the size or number or age of the scab lesions. From the commercial point of view, this would be, of course, an improper procedure; but since the epidemiology of the disease is our primary concern, the results of infection when stated in commercial terms do not measure adequately the variations in disease, though such an expression would indicate the relative predisposition of apple varieties to disease or the efficacy of spray schedules in preventing or halting the advance of an epidemic.

A significant refinement of the method we have used would be to make a careful count of the yield at picking time, in order to determine the ultimate percentage of infected fruits; and if at the same time a further careful grading could be performed with the infected fruits, measuring the quantity and size of the lesions, a still more accurate index of fruit disease would be obtained. But to do this has been

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beyond our means, and we have had to limit our collection of fruitinfection data to the routine orchard examinations made while the fruit was still on the trees.

Seab on apple leaves may, under various conditions, result in a variety of types of injury to the tree, ranging from the mere discoloring of a few leaves to nearly complete defoliation. Such grossly visible evidences of the severity of the attack depend, however, to a very considerable degree upon the resistance of varieties, upon particular local conditions of soil and weather, and upon other factors that concern the tree as a whole more than the disease. Because of this, it is necessary in the measurement of a season's epidemic to ignore these very easily observed conditions and to place emphasis instead upon the actual extent of the leaf infection. Observations made with this limitation will serve in comparing the actual year-by-year success of the disease, and those influences which heighten the effect of the disease upon the tree will not enter into the problem.

For the purpose of making such leaf-infection measurements, we have developed the scales shown in Figures 2 and 3. From among a large number of infected leaves, readily distinguishable grades of disease have been selected, and careful measurements of them have been made by using an instrument called a planimeter, thus determining, first, the area of the entire leaf surface and, second, the exact area occupied by the scab infections. From these two measurements, the percentage of the area of each leaf occupied by scab lesions has been easily computed.

In finally selecting the examples chosen to make up the scale, it was desired, first, to have percentage values for each unit which could be handled by the observer with a minimum of trouble and, second, to have an interval between the increasing grades of infection sufficiently large to permit easy and certain separation of the leaves examined in the field into the grades represented by the standard.

If the reader were to measure each of the samples of the scale, he would find no one of them to be of exactly the value given in the diagram; but the variation in each case is small. If exactness of measurement had been the only aim in developing the scales, it would have been an easy task to make the standards conform exactly to the percentages given for them by making slight changes; but each of the standards is a careful tracing of an actual leaf with its actual infection, and this adds considerably to ease in usage, while the reproduction of the leaf in diagrammatic black and white masks its reality sufficiently to avoid confusion.

The two scales for measuring leaf infection by the scab disease are necessary in order to measure the two types of scab infection. For reasons which are not well understood, the fungus which causes the scab disease produces two distinct types of lesions on the leaves. These types, shown in Figure 4, are usually described as "diffuse" and "spot" infections. The latter is more commonly met with in Illinois, but the diffuse type is also abundant; and on a given leaf the lesions on the upper surface may be of one kind and those on the lower surface of the other kind. As may readily be seen in the illustration, the two are so different in appearance that a scale made for one would not fit the other.



FIG. 2. SCALE FOR ESTIMATING THE INTENSITY OF THE SPOT TYPE OF SCAB ATTACK ON APPLE LEAVES

For each of the sample leaves in this scale, the total area of the spots has been determined and expressed as a percentage of its respective leaf area. By comparing infected leaves with these measured examples, the average leaf area occupied by scab lesions may be computed. See the text for details.



FIG. 3. SCALE FOR ESTIMATING THE INTENSITY OF THE DIFFUSE TYPE OF SCAB ATTACK ON APPLE LEAVES

The shaded area shown on each of the leaf diagrams represents scab lesions of the diffuse type illustrated in Fig. 4. This scale was prepared in the same way as the spot scale shown in Fig. 2 and is used in the manner described in the text. In using these scales, the observer, walking from tree to tree in the orchard, is required to select a number of leaves at random from each tree, without regard to the presence or absence of infection, and to compare them, either then or immediately afterward, one by one with the standards of the scale. The results of one such comparison are shown on the sample field-record (page 418), but in practice the appearance of the record differs in that each leaf is recorded under its proper class by a penciled dot. In classifying the leaves, the rule is that a leaf is to be considered as belonging to the class of infection exemplified by the standard which it resembles most.

As an illustration, the data shown on the record sheet have been brought forward in the following:

Scale classes	0	5	10	15	20	30	45	60	Total
Class frequency, <i>i. e.</i> , number of examined leaves falling in each class	125	33	7	4	3	2	1	2	177
Class values	0	165	70	60	60	60	45	120	580

Of the 177 leaves examined, 125 were either not at all infected or else bore such small traces of disease that they could not be placed in any of the 7 measurable classes. There were also 33 leaves sufficiently diseased to be placed in the "5" class represented by the scale but still not infected heavily enough to merit placing in the "10" class. And in each of the succeeding higher classes of infection there were fewer leaves, as the table shows.

In determining the average amount of leaf infection shown by these observations, a series of items, labeled in the table above as "class values" have been computed by multiplying the percentage values of each of the classes by the frequency with which each class was represented in the sampling of leaves. The 125 leaves in the "0" class have a class-value, or infection value, of 0; those in the "5" class have a class value of 165; and those in the "10" class a value of 70. The sum of all the class values is 580; and this amount (which may be taken to represent the total percentage-area of scab-infected leaf surface shown by the entire leaf sample) is divided by 177 (the number of leaves in the sample) in order to obtain the average per cent. of scab-infected area per leaf. The result in this case is 3.28 per cent. This figure we assume to represent not only the leaves examined but also the average condition of all the leaves in the orchard, since those examined constituted a representative sample selected at random.

Data on Apple Scab

During the summers of each of the seven years beginning with 1922 and ending with 1928, data were secured which show both the prevalence and the intensity of the annual scab epidemics. A large number of apple plantations varying in size from single trees to extensive commercial orchards with thousands of trees were visited and 494 usable records were taken. The total number of trees represented by all the data collected, from the first year to the last, is 132.943; and the number of counties appearing annually in the records averages 23, though the actual number has been as low as 4 (in 1925) and as high as 50 (in 1924). The average number of usable records secured per year stands at 70 and the average number of trees represented annually by these records is 18,991.

As appears from Table IV, in which the yearly indexes for prevalence and intensity have been added and averaged for the seven year term, the average prevalence of scab during the period covered by our observations has been 76.68 per cent., while the average proportion of fruit infected by the disease has been 16.56 per cent. and the index of average intensity for the leaf attack has been 4.92.

TABLE IV

PREVALENCE AND INTENSITY OF APPLE SCAB

	Prevalence	Inte	nsity	Basis of data			
Year	Per- centage of trees having scab infec- tion	Per- centage of apples infected by scab	Per- centage of leaf surface occupied by scab lesions	Num- ber of records	Num- ber of trees repre- sented by the records	Num- ber of counties repre- sented in the records	
	00.00	07.45	0.10	0.49	10.007	10	
1922	$ 93.00 \\ 74.85$	$\begin{bmatrix} 37.45 \\ 27.92 \end{bmatrix}$	8.13	243	18,965	49	
1923 1024	63 08	01.20	6 65	40	48 865	50	
1924 1925	98.58	Trace	0.00	5	1 058	4	
1926	16.32	0.01	0.22	16	9.511	11	
1927	93.77	6.36	1.95	42	12,755	10	
1928	. 96.32	10.36	2.84	62	26,984	8	
Total				494	132,943	162	
Averages	. 76.68	16.56	4.92	70	18,991	23	

The variation from year to year in the scab epidemics is shown in Table IV by the annual indexes. Subject to the qualifications outlined briefly in the columns headed "Basis of data," these annual indexes, which represent both the prevalence of the disease and its intensity on fruit and on leaves, give comparable pictures of the disease as it occurred in each of the seven years.

In 1922 four observers secured 243 usable records, representing 18.965 trees. The analysis of these records indicate that 93 per cent, of the trees represented by them were infected by scab. As these records were drawn from apple plantations located in 49 counties well distributed over the State, this prevalence index may be considered as typifying the general prevalence of the disease that year throughout Illinois. Upon the infected trees, the scab lesions were, as the records show, mainly on the fruit and the leaves. The actual extent of these infections on the infected trees is not shown in Table IV, since the data have been evaluated in the manner illustrated in Table I so as to show the extent of these infections as averages for all trees, whether infected or not. Hence, the field records taken in 1922 show that 37.45 per cent. of all the fruit borne on all trees represented by the records were infected by scab. In the same way, the leaf attack is given the average index, for all leaves on all the recorded trees, of 8.13, which is a concrete statement



FIG. 4. DIFFUSE LESIONS AND SPOT LESIONS PRODUCED BY SCAB ATTACK ON APPLE LEAVES

The leaf at the left bears lesions of the diffuse type, that at the right has typical spot lesions. Diffuse scab is usually found along the veins of leaves, while spot lesions are scattered irregularly over the leaf surface. These two types of lesions are usually found on separate leaves but occasionally occur on opposite sides of the same leaf. Their dissimilarity of appearance requires the use of the two measuring scales shown in Figs. 2 and 3.

of the percentage of leaf surface occupied by scab lesions. Since the number of records, the number of trees, and the counties in which these intensity records were secured are the same as for the prevalence record, the intensity indexes also indicate the intensity of the scab epidemic throughout the State.

The second year of the period, 1923, when 43 records representing 14,805 trees were secured in orchards located in 30 widely distributed counties, the prevalence index for scab stood at 74.85, the fruit intensity index at 37.23, and the leaf intensity index at 14.45. For the calculation

DISEASES OF FRUIT TREES, 1922-1928

of these indexes, there were available only about one-sixth as many records as in 1922, but the average number of apple trees represented in each record in 1923 was more than four times as great as in 1922. The reason for this difference is found in the fact that in the later year more orchards of commercial size were seen, and there is a reflection of this in the prevalence indexes shown for the two years, that of the second year, less by 18.15 than that of the first, being attributable in some



FIG. 5. TRENDS OF PREVALENCE AND INTENSITY SHOWN BY THE SCAB EPIDEMICS

The indexes of prevalence and intensity given in Table IV are plotted here by years against a logarithmic scale which makes the relative annual changes of each phase of the disease comparable with those of the other phases by the slope of the connecting lines. A discussion of this diagram is given in the text.

measure to the more general application of control measures in commercial plantations. The similarity in the intensity indexes for fruit for the two years appears, therefore, to indicate that 1923 was a worse scab year than 1922, and this finds considerable support in the very marked increase of the leaf intensity index from 8.13 in the former year to 14.45 in the latter.

The indexes both of prevalence and intensity for 1924, the third year of the survey, indicate a distinctly milder epidemic of scab than occurred in the two preceding years. Based upon 83 records representing 48,865 apple trees and typifying the scab conditions prevailing in 50 of the 102 counties in the State, this season's observations, averaging 588 trees per record, are the most reliable of any thus far obtained. The decreasing trend exhibited by the several indexes consequently may be taken as an indication that in 1924 the growing season was distinctly less favorable to the scab disease than was the case in either of the two preceding years.

The indexes given for 1925 are the least reliable in Table IV. Circumstances over which we had no control so influenced the season's work as to reduce the number of records to 5 and the number of counties represented to 4, while the entire number of trees entering into the computation of the indexes was only a few over a thousand. The prevalence of scab, computed to be 98.58 per cent., may be unreasonably high in view of the exceptionally low intensity indexes, which are given as a "trace" (meaning that the actual amount was too small to be determined) for the fruit and 0.22 for the leaves. Yet, these indexes, when compared with a report to the United States Department of Agriculture made co-operatively by two observing agencies in Illinois, in which the prevalence is placed at 100 per cent., the reduction in apple yield at 0.5 per cent., and the injury to the foliage as nil, are seen to be in rather close agreement with the generally observed condition for the year. Consequently, the fact that 1925 stands out in Table IV as marking a very abrupt fall in the intensity of scab from the high levels of the preceding years should be regarded as typifying conditions, though the absolute index values are open to doubt. What appears to be a marked increase in prevalence may, in fact, have been a fault due to too scant data; but the high prevalence mentioned above as given by other observers suggests that both the prevalence and the intensity phases of the disease need not have followed the same trend.

In 1926, 16 records representing 11 counties and comprising a total of about 9,500 trees, most of which were in commercial plantations, gave a prevalence index for scab of 16.32. This is a great decrease from the index of the previous year and may be regarded as reflecting in a measure the exceptionally low intensity indexes of 1925. Of the 1926 intensity indexes, that for fruit disease increased to a measurable amount, stated in the table as 0.01 per cent., while the leaf disease index remained at the same level as in the preceding year. Though the greatest difference between 1925 and 1926 is the decrease in prevalence, the slight increase in fruit intensity index, is indicative of the beginning of an increase in scab which ought, preventing circumstances being absent. to become more and more apparent in succeeding years.

In 1927, the prevalence of scab rose to 93.77 per cent., and this increase was accompanied by a distinct increase in the intensity of the attack, the fruit index reaching 6.36 and the leaf index 1.95. The 42 records entering into the computation of the indexes were taken in 10 counties located mainly in the central and southern fruit sections of the State, and a total of 12,755 trees, mostly in well-cared-for orchards, were represented in the data. A general increase over the previous year, both in prevalence and intensity, was decidedly apparent.

For the final year, 1928, the characters of the scab epidemic were shown by 62 records drawn from 8 central and southern counties, and in the computation of the indexes there was entered a total of 26.984 apple trees. The prevalence of scab, determined as 96.32 per cent., increased somewhat over 1927 and there was an accompanying but relatively greater increase in the intensity indexes, that for the fruit attack being 10.36 and that for the leaf attack being 2.84.

The trends of prevalence and intensity of the scab epidemics from year to year for the entire period of observation are shown graphically in Figure 5. The vertical scale in this graph is arranged in a manner such that the slant of the trend lines expresses the relative rate of increase or decrease of the prevalence and the intensity indexes, regardless of the actual numerical values they may have.

An examination of this diagram suggests that during the first three years scab was maintaining itself at a rather high level, possibly the highest it could attain under the climatic and cultural conditions prevailing in Illinois, and was not being subjected to circumstances resulting in great variation in the prevalence or intensity of its annual epidemics. How long this high level of disease had been maintained can not be determined from the data at hand; but, as the graph shows, it came to an abrupt end in 1925. Though the prevalence of scab increased in that year more than it had declined in the two preceding years, the intensity of the attack upon both fruit and leaves fell to exceedingly low levels. Their drop is so sharp as to outweigh by many times the relatively small increase in prevalence.

The effect of the great scab decline of 1925 remains apparent in 1926. Perhaps because the amount of infective materials produced in 1925 was very small, the prevalence of scab dropped in 1926 to the lowest point of which we have record. But the fact that the low levels of the fruit and leaf intensities reached in 1925 were at least maintained in 1926 probably is a rather definite indication that the conditions prevailing in 1926 tended to favor, rather than inhibit, the disease: otherwise, a further decline should have occurred. This view is also justified by the large increases in prevalence and intensity in the last two years shown on the graph. In 1927 all phases of the disease increased very greatly, but, except for prevalence, the indexes did not reach the high levels common before 1925. Though a much smaller increase occurred in 1928, it served to bring the scab indexes still nearer the level of the first years. The trend of scab since 1925 has been upward, and it is reasonable to suppose that it will continue upward until the usual levels are reached, unless another unfavorable year such as 1925 halts its advance.

APPLE BLOTCH

Caused by Phyllosticta solitaria E. & E.

Blotch of apples, in contrast with scab, is limited in its distribution practically to North America, and in Illinois it is confined, at least as a destructive disease, to the southern two-thirds of the State. Within this region it is often very serious. Fruit is attacked and defaced to such an extent as to be unmarketable; leaves are spotted more or less severely and the yielding abilities of the attacked trees lessened thereby year after year; and the young wood, particularly the twigs, is subject to infection, the resulting cankers remaining for three or more years to provide new infective material and to contribute to the decreasing ability of the trees to yield. There are, of course, other frequent types of infection, such as that on the bud scales, on the petioles of leaves, and on the stems of the fruit, but these are intrinsically of little significance, though it is true that the lesions on the lowest parts of the petioles often extend into the twigs and cause a large proportion of the cankers found at the nodes of twigs.

In the measurement of the annual blotch epidemics in Illinois, the prevalence of the disease and the intensity of its attack have, as with apple scab, been recognized as distinct phases. Prevalence has been determined by counting, in each plantation examined, the number of infected trees, regardless of the types or kinds of infection present on the trees, and expressing this number as a percentage of the entire number of trees in the plantation. Such a percentage, computed in the manner previously described and applying to all the blotch-infested orchards examined during a year, is regarded as an index of the general prevalence of blotch for the year. As such, it may be compared with similar indexes for other years.

The intensity of blotch attack cannot be measured as a single unit, because the variations in the epidemic from one year to another tend to emphasize sometimes one, sometimes another, of the various modes of attack: and there are also remarkable varietal differences among apples with respect to their susceptibility to one or more forms of the disease. Blotch injury on diseased trees is, however, most serious on the fruit, the leaves, and the twigs. In each of these types of attack a distinct form of intensity is represented, and each type must be measured separately. Thus far, we have gauged fruit infection only in terms of infected fruits; that is, the percentage of infected apples has been determined by careful counts, but no attempt has been made to record the number of blotch lesions per apple. Similarly, our measurement of the intensity of twig blotch has been limited to a determination of the percentage of infected twigs per tree, without attempting to specify either the number, the age, or the extent of the cankers.

For blotch on the leaves, however, a more accurate means of measurement has been employed. The diagram shown in Figure 6 constitutes a scale by which the intensity of leaf attack can be determined as the percentage of leaf area occupied by blotch lesions. In the construction of this scale, just as in the making of the scab scale, a large number of leaves showing various degrees of infection were placed in series and from among them representative samples were selected, which graded from light to heavy by readily distinguishable intervals. Careful tracings were made of these leaves, and of the spots borne by them, and the area of each of these standard leaves was determined carefully with a planimeter. To determine the area occupied by the blotch infections, it was necessary first to find the average area of a spot, since the individual spot is too small to be measured accurately. This average was obtained by tracing contiguously the magnified outlines of a large number of spots, measuring the area covered by them all, and dividing this area equally among them after reducing it to its actual, or unmagnified, size.

The percentage of the area of each of the leaves serving as standards in the scale occupied by the blotch spots could then be very closely approximated by first counting the number of infections on each leaf, multiplying the average spot area by these numbers, and dividing the



FIG. 6. SCALE FOR ESTIMATING THE INTENSITY OF THE ATTACK OF BLOTCH ON APPLE LEAVES

The figures given below each leaf diagram express the percentage of the area of each leaf occupied by blotch spots. The scale is used in the same way as the scab scales.

total spot areas so obtained for each leaf by the respective leaf areas. This process is, of course, subject to an error arising from a random sampling of spots in selecting the standard leaves, but even in the lesser grades of infection the number of spots is so large (it is exactly 100 in the first standard leaf) as to reduce this error to an insignificant point. For two of the grades used in the scale, two standard leaves have been supplied. The reason for this is that, with such small spots as those made by blotch and with the small percentage intervals that must be used to gauge blotch infection on leaves, the different appearance of large and small leaves with the same percentage of occupied area is often misleading to the eye, since the tendency in visual appraising is to emphasize the number, rather than the combined areas, of the spots. With light infections this danger is minimized by the fact that the intervals between the standards of the scale are smaller, while with heavy infections the greater intervals between standards, which is necessary for accurate classification, tend to lessen its occurrence.

The manner in which the leaf blotch scale is used in measuring the success of the blotch disease is similar in every respect to the method previously described in detail for the scab scale.

Data on Blotch

In determining the prevalence and intensity of the blotch disease of apples in Illinois, a total of 258 orchard records have been collected, and in securing them a total of 219,574 trees have been considered. Though the number of records, and the number of trees represented by them, has varied considerably from year to year, as may be seen in Table V, the average number of records per year was 36 and the average number of trees considered per year was 31,367. The extent of the territory in which the records were taken has varied also, the maximum number of counties represented in any one year being 38 in 1924 and the minimum number being 2 in 1925; but the average number of counties per year has been 18.

Table V shows the results of the survey of blotch. Over the 7 years of the survey term, the average prevalence of blotch is shown to be 72.33 per cent. while the average intensity of its attack is 18.09 per cent. for the fruit phase, 27.65 for the twig phase, and 1.19 for the leaf phase. These figures may be taken to mean that, year after year, the blotch disease attacks an average of 72 per cent. of the apple trees in the blotch infested orchards of Illinois, that in these same orchards it infects to an undetermined extent 18 per cent. of all the apples produced and 27 per cent. of all the young apple wood, and that the area occupied by its leaf lesions amounts to 1.2 per cent. of all the leaf area of all these trees.

The variations in all phases of the blotch epidemics, as they occurred from year to year, are also shown in Table V by the comparative sizes of the annual indexes given for each of the measured modes of attack. The indexes for 1922, computed from 68 records representing 17,781 trees distributed among 33 counties, give blotch a prevalence of 53.03 per cent., while the percentage of diseased fruit amounted to 41.36, the percentage of diseased twigs to 10.49, and the diseased leaf area 2.56 per cent.

In 1923, data computed from 54 records representing more than 75,000 trees located in 28 counties, showed a rise in blotch prevalence to 89.14 per cent., but this increase in prevalence was accompanied by a

fall in the intensity of the fruit attack to 32.15 per cent., a decrease of 9.21 from the index of the preceding year. The rise in prevalence was accompanied, however, by a rise in the intensity of twig attack to 81.29 per cent. and in the intensity of leaf attack to 3.89 per cent.

In 1924, blotch prevalence remained very high, the index of 87.68, which was computed from 54 records derived from 38 counties and representing 93,329 trees, being only 1.46 less than that for 1923. The intensity of the disease was, however, consistently low, the attack on fruit having an index of only 3.89, that on the twigs an index of 8.41, and that on the leaves an index too small to be recorded other than as a trace.

Blotch conditions in 1925 are represented by a very small number of records, which exemplify the attack on only 238 trees parceled be-

•	Prevalence		Intensity		Basis of data				
Year	Per- centage of trees having blotch infec- tion	Per- centage of apples infected by blotch	Pe centage of twigs infected by blotch	Per- centage of leaf area occupied by blotch lesions	Num- ber of records	Num- ber of trees repre- sented by the records	Num- ber of counties repre- sented in the records		
1922 1923 1924 1925 1926 1927 1928	$53.03 \\ 89.14 \\ 87.68 \\ 100.00 \\ 46.67 \\ 71.87 \\ 57.92$	$\begin{array}{c} 41.36\\ 32.15\\ 3.89\\ 9.09\\ 12.48\\ 18.34\\ 9.37\end{array}$	$ \begin{array}{r} 10.49\\ 81.29\\ 8.41\\ 54.54\\ \hline 7.59\\ 3.59\\ \hline \end{array} $	2.56 3.89 trace 1.93 0.01 trace trace	$ \begin{array}{r} 68 \\ 54 \\ 54 \\ 3 \\ 21 \\ 31 \\ 27 \\ \hline 258 \\ \end{array} $	17,781 75,625 93,329 238 11,622 11,207 9,772	33 28 38 28 14 10 7		
Total					258	219,574	132		
Averages	72.33	18.09	27.65	1.19	36	31,367	18		

TABLE V

PREVALENCE AND INTENSITY OF APPLE BLOTCH

tween two counties. The prevalence index for the disease, exactly 100 per cent., calculated from these records is undoubtedly too high and should therefore be regarded as an expression of a prevalence at most no greater than in previous years. The intensity indexes are also subject to the same limitations. Consequently the index of fruit attack, designated as 9.09 per cent., and of leaf disease, shown in Table V as 1.93 per cent., should be considered not as indicating increases over the preceding year but as showing a continuation of the former year's low values. The rather high index of twig attack, 54.54 per cent., possibly peculiar to the plantations from which the data were secured, serves only to illustrate the ability of blotch to perpetuate itself in this form for several years.

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In 1926 the indexes were computed from 21 records drawn from 14 counties and representing, in all, 11,622 trees. The prevalence indicated by these records is 46.67 per cent., which is probably somewhat of a decrease from 1925. The larger index for the fruit attack, 12.48 per cent., is undoubtedly an indication of blotch recrudescence following the two previous unfavorable years, though this is borne out only to a relatively slight extent by the leaf disease index of 0.01 per cent. Data on the twig attack are lacking for this year.

For 1927, 31 records made in 10 counties and representing 11,207 apple trees gave a prevalence of 71.87 per cent., which serves to indicate that blotch had regained much of the ground lost in 1924 and 1925; and an increase of the fruit intensity index to 18.34 per cent. bears out this indication. The value of the index for twig disease, 7.59 per cent., is, however, not greatly different from that of 1924.

In 1928 the prevalence of blotch, as indicated by 27 records obtained from 7 counties and representing 9,772 trees, fell to 57.92 per cent. In keeping with this are the noticeable decreases shown by the fruit and twig disease indexes, the former being 9.37 per cent. and the latter 3.59 per cent. The very small amount of leaf blotch is expressible, as in the previous year, only as a trace.

Subject to the limitations in data pointed out above, the trends of both the prevalence and the intensity of the apple blotch epidemics from year to year through the period covered by our survey are shown graphically in Figure 7. The general trend of the disease has been downward, and the changes from one year to another have, on the whole, been rather large. From a fairly high point in 1922, blotch increased considerably in 1923, and fell to a low point in 1924. The following year, 1925, it regained a considerable part of what it lost in 1924, and immediately thereafter, 1926, began a downward movement, interrupted by a slight rise in 1927, that furnished the low indexes of 1928. The course which the disease may follow in 1929 and later cannot be anticipated from the diagram, though the suggestion of the trends shown there is that it will continue downward.

By examining Figure 7 more closely, one may see that a rather striking parallel exists in the year to year trends exhibited by the various blotch indexes. The prevalence index stands at a relatively high point throughout, but its general level during the first four years was distinctly higher than during the last three years. The indexes for leaf and twig blotch appear to conform to this generalization; and it is worthy of note, in particular, that the upward trend in prevalence from 1922 to 1923 is reflected by similar though unequal trends in leaf and twig infection. The very slight decrease in prevalence from 1923 to 1924 appears also, in a greatly magnified degree, in the sharp decrease exhibited by the fruit, leaf, and twig infections, while the prevalence increase in 1925 is reflected also in the increased indexes of disease intensity. The fall in prevalence shown for 1926 was accompanied by a fall in the intensity of leaf disease and probably also of twig disease, though there is no adequate data to support the contention. For the slight rising and falling of blotch prevalence in 1927 and 1928, respectively, the fruit intensity index is seen to rise and fall, the twig intensity index to fall in 1928 to a point lower than it held in 1927, and the leaf intensity index to remain so low in both years as to be unmeasurable.

In general, it appears that the trend of prevalence exhibited by apple blotch from year to year is reflected in a distinctly magnified degree by the trends of each of the modes of blotch attack, but there is no lagging behind of any phase of the disease. It should be noted, how-



FIG. 7. TRENDS OF PREVALENCE AND INTENSITY SHOWN BY THE BLOTCH EPIDEMICS

The changes from year to year shown by the measured types of intensity are much greater than the changes in prevalence. Data for twig intensity in 1926 are lacking.

ever, that the intensity of blotch on the fruit, at least so far as it is expressed in our data, may at times move entirely independently of the other phases of the disease. Thus, in 1923, when the other trends had moved upward, the fruit infection trend was unmistakably downward; and in 1926, as the others moved sharply downward, that for fruit infection moved upward.

APPLE BLACK-ROT

Caused by Physalospora malorum (Pk.) Shear

The black-rot disease, known to occur widely in Europe, in South Africa, and in Canada, as well as throughout the United States, is one of the most common, though not usually the most serious, of apple diseases in Illinois. It ranges throughout the State and is found, in one or another of its forms, in practically every orchard. The most important injury resulting from it is the fruit-rot from which it is named. Generally, this rot is not of great importance, unless some predisposing factor such as codling moth injury provides unusually good conditions for its development. The canker form of black-rot does permanent damage to apple trees, but the fungus which causes the disease is known to be a weak parasite, able to gain access to the woody parts of the tree only through injuries already accomplished by more active diseases such as fire-blight.

Upon apple leaves, the black-rot disease appears as a spot which, because of its characteristically zonal markings, is commonly known as "frog-eye." After being killed by the black-rot fungus, the leaf tissues of these spots often are invaded by other fungi, and it has been our experience in Illinois that these secondary invaders are found in the lesions more often than the black-rot fungus. Hence, in measuring the extent of black-rot on leaves we have counted all "frog-eye" spotting as black-rot, regardless of the identity of the fungus actually found on the spots by microscopic examination.

In measuring black-rot epidemics, the statistical phases taken into consideration have been prevalence, intensity of fruit attack, the quantity of twigs and woody parts infected, and the percentage of leaf area occupied by the frog-eye spots. Prevalence, as with other diseases, is expressed as the percentage obtained by comparing the number of infected trees with the total number; and the intensity of both the fruit and twig infections is expressed as the percentage of these individual parts infected by the disease. No attempt has been made to measure further the severity of the infection on the individual apple or twig. With the fruit, however, it should be stated that only the apples on the trees have been counted, as the infection of fallen fruit, though one of the most common causes of decay, is nearly always secondary to injury by codling moth larvae.

In measuring the intensity of black-rot on leaves, we have used the scale shown in Figure 8. The units of the scale were selected and measured, and the scale itself has been used, in the manner already described in detail in the discussions of scab and blotch. The very small leaf-area values shown in Table VI and discussed in succeeding paragraphs seem inconsistent with the relatively large values shown by the standards in the scale, but it must be remembered in this connection that the scale itself serves only to measure the infected leaves, which often constitute only a small portion of a leaf sample, and that the total area occupied by lesions, which is obtained by using the scale, is parceled evenly among all the leaves of the sample.


FIG. 8. SCALE FOR ESTIMATING THE INTENSITY OF "FROG-EYE" SPOTS, THE MANIFESTATION OF BLACK-ROT ATTACK, ON APPLE LEAVES

This scale is used, in the manner described in detail in the discussion of apple scab.

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Data on Black-rot

A total of 311 records have been taken on black-rot during the course of our survey, and the data contained in these records present the state of the disease on 115,729 apple trees. As may be seen in Table VI, which gives the annual indexes of prevalence and intensity for black-rot, the number of records taken in any one year has ranged from a maximum of 99 in 1922 to a minimum of 2 in 1925, while the average number per year has been 44. The number of trees represented by the sets of annual records has varied also, ranging from a maximum of 26,452 in 1927 to a minimum of 198 in 1925, and the average yearly number has been a little over 16,500. The average number of counties represented in the yearly records is 15, but the actual number per year has ranged from a minimum of 1 in 1925 to a maximum of 32 in 1922.

TABLE VI

	Prevalence	Intensity			Basis of data			
Year	Per- centage of trees having black-rot infec- tion	Per- centage of apples infected by black-rot	Per- centage of twigs infected by black-rot	Percent- age of leaf area occupied by black-rot lesions	Num- ber of records	Num- ber of trees repre- sented by the records	Num- ber of counties repre- sented in the records	
1922 1923 1924 1925 1926 1927 1928	$\begin{array}{c} 65.64\\ 55.54\\ 82.65\\ 91.41\\ 91.57\\ 100.00\\ 100.00 \end{array}$	0.80 0.45 1.05 trace 0.17 0.01 0.01		$\begin{array}{c} 0.36\\ 0.18\\ 0.52\\ 1.09\\ 0.16\\ 0.15\\ 0.05\end{array}$	$99 \\ 13 \\ 36 \\ 2 \\ 54 \\ 63 \\ 44$	$7,893 \\11,059 \\25,281 \\198 \\20,717 \\26,452 \\24,129$	$\begin{array}{c} 32 \\ 10 \\ 28 \\ 1 \\ . 18 \\ 13 \\ 8 \end{array}$	
Total					311	115,729	110	
Averages	83.83	0.35	0.54	0.36	44	16.532	15	

PREVALENCE AND INTENSITY OF APPLE BLACK-ROT

The data obtained in the survey, as summarized in Table IV, show that during the period 1922–1928, the black-rot disease of apples has had the high average annual prevalence of 83.83 per cent., but that its intensity during this period, as measured by the occurrence of infection on fruit, on twigs, and on leaves, has been very light. The infected fruit has averaged but 0.35 per cent.; only 0.54 per cent. of the twigs have borne black-rot cankers, and the leaf area has been reduced only 0.36 per cent.

The same condition can be seen in the data given for individual years. In 1922, with prevalence at the relatively low point of 65.64, 0.8 per cent. of the fruit in the infested orchards examined was infected, 1.1 per cent. of the twigs were cankered, and the leaf area was reduced by frog-eye spots only to the extent of 0.36 per cent. In 1923, when the prevalence of black-rot, computed as 55.54 per cent., was at the lowest point observed by us, all forms of black-rot attack were low also, only 0.45 per cent. of both the fruit and twigs being diseased and 0.18 per cent. of the leaf area occupied by lesions.

The sudden rise of prevalence in 1924 to 82.65 per cent. was accompanied by increases in the indexes of all three types of attack, the computations made with the data for the year giving an average of 1.05 per cent. of black-rot infected fruit, 2.26 per cent. of cankered twigs, and 0.52 per cent. of leaf area occupied by frog-eye spots.



FIG. 9. TRENDS OF PREVALENCE AND INTENSITY SHOWN BY THE BLACK-ROT EPIDEMICS

Prior to 1925, prevalence and the three measured forms of intensity were high, and their changes from year to year were uniform in direction. In 1925, however, an upward movement in prevalence and leaf intensity was accompanied by sharp falls in both twig and fruit intensities. Subsequent to 1925, prevalence continued to increase, but there was a general falling off in all intensities.

This is in decided contrast with the conditions indicated by our relatively small amount of data for 1925. Though in this year the prevalence index rose to 91.41 per cent., the rise was accompanied by rather steep falls in two types of black-rot attack, the percentage of rot-infected fruit and cankered twigs sinking to amounts too small to estimate. There was, however, a rise in the leaf infection index to 1.09, the highest point in our record. Respecting the value of these indexes, it may be stated that though the number of observation, and of trees, upon which the indexes are based are very small, the relative state of the disease expressed by them is in accord with the conditions generally observed to have prevailed that year, although it is possible that the actual increase in black-rot leaf-spot is magnified somewhat in the index.

In 1926, the prevalence index rose very slightly to 91.57, and there were corresponding slight increases in the intensity indexes representing the black-rot attack on fruit and on twigs, the former being 0.17 and the latter 0.004. The index of leaf-attack, however, fell to the lowest point recorded in our observations up to that year.

Continuing the tendency to increase shown during three preceding years, the prevalence index rose in 1927 to 100 per cent.; but all the intensity indexes moved downward, that for fruit-rot to 0.01 per cent., that for twig cankers essentially to 0, and that for leaf spot to 0.15.

In 1928, the high prevalence of 1927 was maintained, and the downward movement of the intensity indexes was continued to 0.01 per cent. for fruit-rot, an inestimable trace for twig canker, and 0.05 per cent. for leaf spot.

The trends of prevalence and of the intensity of the three important forms of black-rot attack on apple are shown graphically in Figure 9. In this figure, the portion of the graph which would ordinarily be seen between the wavy lines has been omitted in order to bring the high prevalence line into closer comparison with the low intensity lines. From this graph, it may readily be seen that only from 1922 to 1923 and from 1923 to 1924 is there a complete parallelism among the prevalence and the three intensity curves. In 1923 all swing downward from the previous year, and in 1924 they swing upward. The rate of change is not, however, equal in any two cases. The upward trend of prevalence and leaf infection from 1924 to 1925 contrasts sharply with the steep fall of the twig and fruit infections; but the continued rise of prevalence from that year on is coupled with falling leaf intensity and low twig and fruit intensities.

APPLE FIRE-BLIGHT

Caused by Bacillus amylovorus (Burr.) Trev.

Fire-blight, like apple scab, occurs throughout Illinois; and just as scab is the most feared of apple diseases because of its ability to ruin a season's crop, so fire-blight furnishes the greatest threat to the continued existence and productivity of apple orchards. There is no part of an apple tree that cannot become blighted. With the appearance of the blossoms in early spring, fire-blight begins its destructive work, and as the season progresses new forms of attack may constantly be observed to appear. The year-round nature of the disease is well illustrated by the very generally recognized types of attack, commonly known as blossomblight, twig-blight, leaf-blight, fruit-blight, cankerous blight of the limbs and trunk, and collar-blight at the base of the tree. Seasonal phases of fire-blight, such as blossom-, twig-, and fruit-blight, constitute the epidemic aspects of the disease, and it is these which cause the annual reductions in yield, while the cankerous phases, represented by himb-, trunk-, and collar-blight, are permanent forms which constitute continual hazards in orchard maintenance.

In the measurement of epidemic fire-blight we have thus far limited ourselves to acquiring data on two phases only, prevalence and twig-blight. As a measure of the intensity of the annual blight epidemics an index of twig-blight serves as the best total statement obtainable, unless more exacting observations are made on individual phases than we have been able to undertake. Our twig-blight count includes fruit spurs which show evidence of blossom-blight, leaf-blight, or spur-blight, as well as the real twig-blight which commonly occurs a little later in the season. It is, therefore, a comprehensive measure of all epidemic phases of the disease; and the data presented below should be accepted in that sense.

Data on Fire-blight

In the course of our survey, 373 records have been made of the occurrence of fire-blight in apple plantations. These records typify the condition of the disease with respect to a total of 169,346 trees, or an average of 24,192 trees for each year's observations; and for the average year, the records show conditions prevailing in 23 counties. As may be seen in Table VII, the largest number of records secured in any one year was 105, in 1922, while the smallest number was 10, secured in 1927. The territory represented by these records has varied also, 41 counties furnishing the 1924 records and 7 counties the records for 1927; and the number of apple trees from which the recorded data was collected has varied from a maximum of 42,567 in 1924 to a minimum of 9,583 in 1927.

TABLE VII

•	Prevalence	Intensity		Basis of dat	a
Year	Percentage of trees having blight infection	Percentage of twigs infected by blight	Number of records	Number of trees represented by the records	Number of counties represented in the records
1000	10.01	1.00	105	12 000	20
1922	42.04	1.80	105	13,202	38
1923	(2.85	9.01	66	30,119	32
1924	65.41	10.69		42,507	41
1925	59.85	4.76	19	25,132	9
1926	58.89	4.49	60	25,919	28
1927	21.04	0.09	10	9,583	$\frac{7}{2}$
1928	81.01	3.05	44	16,824	9
Total			373	169,346	164
Averages	57.38	4.93	53	24,192	K 23

PREVALENCE AND INTENSITY OF APPLE BLIGHT

Variable as the quantity of the yearly records is, they are in the main representative of fire-blight conditions during the past seven years. The average prevalence of the disease, secured by giving each year's observations equal weight and dividing the sum of prevalence indexes for the period equally among the years, is shown in Table VII to be 57.38 per cent., and the average intensity of the fire-blight attack, expressed in terms of blighted twigs and spurs, is 4.93 per cent.

The individual years, however, often show considerable variations from the average. The prevalence of fire-blight in 1922, when 105 records were secured in 38 counties, was 42.64 per cent. in a total of 13,202 apple trees, less by 14.74 per cent. than the average, and the



FIG. 10. TRENDS OF PREVALENCE AND INTENSITY SHOWN BY THE RUST AND FIRE-BLIGHT EPIDEMICS

The annual fluctuations illustrated in this figure are discussed in the text. Data are lacking for the 1925 rust epidemic.

intensity of the attack, estimated at 1.86 per cent., was 3.07 per cent. less than the average.

In 1923, on the other hand, 58 records secured from apple-tree plantations distributed among 32 counties, showed a fire-blight prevalence of 72.85 per cent. among a total of 36,119 trees—15.47 points above the average condition—and an intensity of 9.61 per cent. for twig-

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blight, this intensity being higher by 4.68 per cent. than the average. In 1924, when 77 records taken in 41 counties showed a prevalence of 65.41 per cent. among 42,567 trees and an intensity of 10.69 per cent., the disease exceeded its average conditions by 8.03 and 5.76 per cent. respectively. This excessively high fire-blight condition was maintained to a lesser extent in 1925 when, on the basis of 19 records, the prevalence of the disease was shown to be 59.85 per cent. among 25,132 trees, or 2.47 points above the average; but in this year the intensity of fire-blight dropped to 4.76 per cent., or 0.17 point below the average. On the basis of 60 observations taken in 28 counties, the prevalence of blight in 1926 was shown to be 1.51 points above the average by the index for the year, which was computed to be 58.89 per cent. among 25.919 trees. The intensity of the attack, however, was 0.44 of a point less than the average, or 4.49 per cent.

The tendency of fire-blight to decrease, which was more or less apparent in the years from 1923 to 1926, appeared in its full extent in 1927. In that year 10 observations drawn from 7 counties indicated a prevalence of 21.04 per cent. among 9.583 trees and an accompanying intensity of 0.09 per cent. for twig-blight, these indexes being respectively 36.34 and 4.84 per cent. below the average conditions.

In 1928, there was a great recrudescence of blight, its prevalence, as indicated by 44 records made in 9 counties, being 81.01 per cent. among 16,824 trees; but the intensity of twig-blight, though it rose to 3.05 per cent., still remained at 1.88 points below the average.

The trends of prevalence and intensity of fire-blight are shown graphically in Figure 10 by the solid lines. The arrangement of the vertical scale of the graph is such as to make the changes from one year to another comparable in terms of the slope of the lines. It is readily seen that the intensity of blight attack has varied much more, proportionately, than its prevalence. With the single exception of the change from 1923 to 1924, when the prevalence trend fell and the intensity trend rose, the direction of both trend lines is the same for every year. And it is notable also that in every case the movement shown in the prevalence curve is magnified, in the intensity curve, to an extent accurately indicated by the relatively greater steepness of the year-to-year sections of the intensity curve.

APPLE RUST

Caused by Gymnosporangium juniperi-virginianae (Schw.) Sw.

Among the apple tree diseases occurring in Illinois, apple rust is distinctive because it is purely annual in occurrence on apple trees, and for this reason it is the only one of the apple diseases that can be classed as strictly epidemic. The destruction caused by it is limited to the fruit and leaves, and with the falling of the leaves and harvesting of the fruit it is entirely removed from the trees. The rust epidemic of any one year is, therefore, entirely separate from the epidemics of the preceding and following years. Since the fungus which causes the disease produces no permanent lesions upon the apple tree, it depends for its annual propagation upon its ability to accomplish a portion of its development upon another host, the cedar. So specialized are the habits of the fungus that the spores developed by it upon the apple tree are wholly unable to reinfect apple trees. They are, however, virulent on cedars, and the rust epidemics consequently develop anew each year from the infective material supplied by the "cedar-rust" phase of the disease.

Since it is annually dependent entirely upon cedar trees for its propagation apple rust is not so widely or generally distributed in Illinois as the other epidemic diseases of apples but is limited in its occurrence to regions in which cedars are relatively common and grow in close proximity with the orchards. Nevertheless, the extent of its range includes the entire state.

In measuring the annual rust epidemics, we have limited the accumulation of data to two phases of the disease. These are prevalence and the intensity of rust attack on the leaves, prevalence being, as with other diseases, expressed as the percentage of infected trees found in rustinfested orchards and leaf intensity as the approximate percentage of leaf area occupied by the rust spots as measured by the area-scale given previously for the spot type of scab, as this scale approximates with reasonable closeness the rust-spot condition.

Data on Apple Rust

Satisfactory data on apple rust were secured for each of the years except 1925 included in the period of our survey. The less extensive distribution of the disease is seen in the fact that the total number of records of the disease is just 116, whereas 494 scab records were secured in the same period. The total number of trees from which these rust records were derived is 53,377. The average number of records per year was 19, and the average number of trees per year was 8,896, the data for each year representing, on an average, the rust conditions in 11 counties.

As is shown in Table VIII, the computations made with the accumulated apple rust data indicate that in rust infested orchards the average yearly prevalence has been 61.96 per cent., while the severity of the attack has been equivalent to a rust occupation of 3.38 per cent. of the leaf area produced by all trees in the orchards.

The exact condition of each year with respect to the rust attack is also shown in Table VIII. For 1922, 16 records derived from 14 counties indicate a rust prevalence of 26.29 per cent. among 3,503 apple trees, with an accompanying intensity of foliage disease amounting to 1.57 per cent. of leaf arca. In 1923, when 14 records were obtained in 8 counties, the prevalence of rust was 57.29 per cent. in 6,210 trees, and the intensity of the leaf attack amounted to 3.7 per cent. of the leaf areas of these trees. In 1924, the 29 records secured in 23 counties indicated the prevalence of rust to be 38.77 per cent. in 23,056 trees, with a leaf-area occupation of 0.25 per cent. Data were not secured for 1925, but in 1926 the prevalence of rust, as shown by 12 records taken in 9 counties, amounted to 72.51 per cent. among 2,445 trees, while the intensity of the leaf attack is given the astonishingly high index of 14.63. In 1927, the prevalence of rust rose still further, the 23 records taken that year giving a prevalence index of 81.22 per cent. among

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6,998 trees; but the intensity index dropped to 0.06 per cent., the lowest among our records. Again in 1928, prevalence increased, the index derived from 22 records taken in 7 counties being 95.72 per cent. for 11,165 trees; but the intensity of the rust attack was, nevertheless, quite light, the index of leaf-area occupation by rust spots being only 0.1 per cent.

The trends of rust prevalence and intensity from year to year are shown by dotted lines in Figure 10. From 1922 to 1923 the trend of apple rust, both in prevalence and in intensity, was upward, and the relative increase was nearly equal for the two aspects of the disease. From 1923 to 1924 both trends were downward, the intensity of the attack decreasing much more rapidly than prevalence. Between 1924 and 1926 no record is available; and the trends from 1924 to 1925 and

TABLE	VIII
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PREVALENCE AND INTENSITY OF APPLE RUST

	Prevalence	Intensity		Basis of data	a
Year	Percentage of trees having rust infection	Percentage of leaf area infected by rust	Number of records	Number of trees represented by the records	Number of counties represented in the records
1922	$26.29 \\ 57.29 \\ 38.77 \\ 72.51 \\ 81.22 \\ 95.72$	$1.57 \\ 3.70 \\ 0.25 \\ 14.63 \\ 0.06 \\ 0.10$	$ \begin{array}{r} 16 \\ 14 \\ 29 \\ 12 \\ 23 \\ 22 \end{array} $	$\begin{array}{c} 3,503\\ 6,210\\ 23,056\\ 2,445\\ 6,998\\ 11,165\end{array}$	$ \begin{array}{r} 14 \\ 8 \\ 23 \\ 9 \\ 9 \\ 9 \\ 7 \\ 7 \end{array} $
Total			116	53,377	70
Averages	61.96	3.38	19	8,896	11

from 1925 to 1926 cannot be indicated. Hence, the light line on the graph serves only to connect the actual data points.

In 1926, prevalence and intensity were both very high; and in the following year, 1927, we have the remarkable phenomenon of a still further increase in prevalence contrasted with a very rapid decline in intensity. In 1928 prevalence increased still further, and by referring to Table VIII, it may be seen that there was an accompanying increase in intensity, though it was too slight to be shown on the graph. It appears that throughout our period of observation, the trend of apple rust has been to increase rather steadily in prevalence; but the intensity of the attack has varied greatly from year to year and has shown a considerable degree of independence in its trends as compared with prevalence.

ILLINOIS NATURAL HISTORY SURVEY BULLETIN

SUMMARY OF APPLE DISEASE DATA

The observations given in the preceding pages have dealt with the individual diseases, and no comparisons have been made between diseases, as regards either their prevalence or their intensities. It will be of some interest, therefore, to compare changes in prevalence from year to year, and changes in the intensity of various types of attack of all diseases, and to determine the total effects of all over a period of years as exemplified in the years covered by our survey.

Prevalence of Apple Diseases

In Table IX, the prevalence indexes for all apple diseases are brought together so that the prevalence of each disease each year may be compared with the prevalence of every other disease.

TABLE IX

Disease	1922	1923	1924	1925	1926	1927	1928
Scab Black-rot Blotch Fire-blight Rust	$\begin{array}{r} 93.00 \\ 65.64 \\ 53.03 \\ 42.64 \\ 26.29 \end{array}$	$74.85 \\ 55.54 \\ 89.14 \\ 72.85 \\ 57.29$	$\begin{array}{c} 63.98\\ 82.65\\ 87.68\\ 65.41\\ 38.77 \end{array}$	$98.58 \\ 91.41 \\ 100.00 \\ 59.85$	$16.32 \\ 91.57 \\ 46.67 \\ 58.89 \\ 72.51$	$\begin{array}{c} 93.77 \\ 100.00 \\ 71.87 \\ 21.04 \\ 81.22 \end{array}$	$93.32 \\ 100.00 \\ 57.91 \\ 81.01 \\ 95.72$
Average incidence of disease per tree	2.81	3.50	3.38	3.50	2.86	3.68	4.27

SUMMARY OF PREVALENCE OF APPLE DISEASES

As this table shows, in 1922 scab was the most prevalent disease and rust the least prevalent, with black-rot, blotch, and fire-blight intervening and ranking in prevalence in the order in which they are named. In 1923, blotch became the most prevalent disease, with scab second, and fire-blight, rust, and black-rot following in order. In 1924, blotch continued to maintain the lead in prevalence, but black-rot rose again to second place, while fire-blight, scab, and rust occupied the places of lesser importance, and in 1925 blotch again held the highest prevalence position, with scab in a very high second place, black-rot also very high, and fire-blight last. Without noticeably increasing its prevalence, black-rot occupied the first place in 1926, with rust second, fireblight third, blotch and scab in fourth and fifth places; and in 1927 it still held the lead with a prevalence index of 100 per cent., while the order of prevalence for the other apple diseases was rearranged to give scab second place, rust third place, and blotch and fire-blight fourth and fifth respectively. In the final year, 1928, black-rot, with its prevalence index again at 100 per cent., continued to hold first place, with rust and scab second and third, and fire-blight and blotch in the fourth and fifth places.

If the annual prevalence indexes for these five epidemic diseases were added, each yearly total would be greater than 100. Although it is self-evident that the percentage of diseased apple trees can not be actually in excess of 100 per cent., these totals of the prevalence indexes would serve to express, for the purpose of comparison, the relative success these apple, tree diseases attain annually. The total of the prevalence indexes for 1922 is 281, while for 1923 it is 350. As numerical averages, these figures indicate that in the first year the incidence of apple diseases, as is shown in Table IX, was 2.81 per tree and in the second year 3.5 per tree. Ranking the years included in our survey according to the incidence of diseases per tree, they stand in the order shown by Table X.

TABLE X

Rank	Year	Incidence of diseases
1	1928	4 27
2	1927	3.68
3	1925	3.50
4	1923	3.50
5	1924	3.38
6	1926	2.86
7	1922	2.81

YEARS RANKED ACCORDING TO THE AVERAGE INCIDENCE OF DISEASES PER APPLE TREE

As was indicated in Table X, the average incidence of diseases per tree in any one year differs to a considerable extent from that in other years. This is due both to annual fluctuations in total incidence and to fluctuations from year to year by each disease. The prevalence trend of each disease throughout the survey period is shown graphically by the lines in the lower part of Figure 11, and these may be compared with the trend of average incidence per tree shown by the line in the upper portion of the same figure.

Outstanding in this diagram is the reduction in average incidence of diseases per tree in 1926. This is a reflection of the distinct drop, in the same year, of the prevalence of both scab and blotch. The rise in average incidence from 1922 to 1923 was the result of a rise in the prevalence of blotch, fire-blight, and rust, which was only partly counterbalanced by the decreased prevalence of scab and black-rot. In 1924 the prevalence of scab continued to decrease, and all other diseases except black-rot decreased more or less noticeably; and these conditions are reflected in the slight drop shown for 1924 in the average incidence curve at the top of Figure 11. In the following year, 1925, the prevalence of scab, blotch, and black-rot rose to very high points, while fire-blight fell off somewhat from its previous position. The absence of rust data undoubtedly influenced the situation also, but to what extent can not, of course, be determined. The result of the movement of the known prevalence indexes was, nevertheless, to bring about a rise in the disease incidence curve to approximately the height of 1923.

In 1926, three diseases fell eff in prevalence, scab very sharply, blotch quite sharply also, and fire-blight only slightly, while of the other two diseases, black-rot increased somewhat in prevalence and rust rose to the highest point recorded up to that time. The net result of these changes was to drop the disease incidence curve to a point only slightly higher than it occupied in 1922.



FIG. 11. COMPARISON OF THE PREVALENCE TRENDS OF APPLE DISEASES AND OF THE AVERAGE INCIDENCE OF DISEASE PER TREE. SEE TEXT FOR DISCUSSION

The general retrogression of disease prevalence in 1926 was compensated during the 1927 season by a rise in prevalence of all diseases except fire-blight, which fell to its lowest point in our series of records, and the result was to raise the disease incidence curve to the highest point recorded up to that time.

This general increase was continued into 1928. Fire-blight rose very sharply to a high degree of prevalence, black-rot, rust, and scab maintained or increased their former high indexes, and blotch alone decreased, with the net result that the average incidence of diseases per tree rose, as the upper curve shows, to the high point of 4.31.

AVERAGE ANNUAL PREVALENCE

Our records, covering as they do the changes in disease prevalence exemplified by seven growing seasons, during which each disease encountered at one time or another conditions that were favorable or unfavorable to its propagation, may be held to represent to a rather exact degree the average prevalence of each of the epidemic diseases which the orchardist may expect to have to meet over a period of years under Illinois conditions. This expectation, which may be expressed as the average annual prevalence computed for each disease from the indexes given in Table IX, is shown graphically in Figure 12. Fire-blight may be expected to be least prevalent, with rust, blotch, scab, and black-rot increasingly prevalent in the order named. And the individual tree, as indicated by the uppermost block in Figure 12, may be expected to encounter an average incidence of 3.4 diseases per year.



FIG. 12. AVERAGE PREVALENCE OF APPLE DISEASES

The blocks illustrating the prevalence of each disease show, by their length, the average number in every 100 trees attacked by each disease, and the small block representing average incidence, indicates the average number of diseases present on each tree.

Intensity of Apple Diseases

In the discussions given to the individual apple diseases on previous pages, the measurement of the intensity of disease has been concerned with three distinct phases: the prevalence of the disease on fruit, the quantity of twigs or young growth attacked, and the amount of leaf area occupied by lesions. It will be of some interest to consider each of these phases as they are affected by all five of the epidemic diseases and to see whether or not there is any relation between these types of attack and prevalence.

FRUIT INTENSITY

Data are at hand to show the intensity of fruit attack in the case of only, three diseases, scab, blotch, and black-rot. These are shown, in Table XI. In the first year, 1922, blotch attack was the most intense, occurring on 41.36 per cent. of the fruit in the plantation found to be diseased and scab was only slightly less intense, with an index of 37.45 per cent.

Throughout the entire period black-rot occupied a very minor place only once, in 1924, attacking in excess of 1 per cent. of the fruit. The place of first importance as a fruit disease was held 4 times by blotch (1922, 1925, 1926, and 1927), while scab was most important in the three seasons 1923, 1924, and 1928.

The totals given for the annual indexes show the total incidence of disease on the fruit each year. As these figures indicate, 1922 with its total index of 79.61 is outstanding for the amount of fruit attacked. Next in order stands 1923 with an index of 69.83. The remaining years 1924 to 1928 inclusive, have total indexes of a much lower grade; but 1925 with its very low index of 9.09 is very certainly the year of least fruit injury.

Disease	1922,	1923	1924	1925	1926	1927	1928
Blotch Scab Black-rot Total	$ \begin{array}{r} 41.36\\37.45\\.80\\\hline 79.61\end{array} $	$ \begin{array}{r} 32.15 \\ 37.23 \\ .45 \\ \hline 69.83 \end{array} $	3.8924.521.0529.46	9.09 trace trace 9.09	$ \begin{array}{r} 12.48 \\ .01 \\ .17 \\ 12.66 \end{array} $	$ 18.34 \\ 6.36 \\ .01 \\ 24.71 $	9:37 10.36 .01 19.74

TABLE XI

SUMMARY OF INTENSITY OF APPLE DISEASES ON FRUIT

The trends of the individual fruit disease indexes and of the total index are compared in Figure 13. In this case, the fact that the trend of the total intensity index follows directly the large changes from year to year in the blotch and scab indexes indicates the importance of these diseases. The practical maintenance of the scab index of 1922 in 1923 was not, however, sufficient to maintain the height of the total index in the fact of the slight fall in the blotch index; but it does not appear that the sharp fall, in 1923, in the already small black-rot index contributed very largely to the downward movement of the total index line. A continued downward movement of the total index line in 1924 was due to decided drops in both the blotch and scab indexes of fruit intensity and in 1925 to the very sudden fall in the scab index since the value of the total index that year was exactly that of the blotch index. A slight rise in the indexes of both blotch and black-rot in 1926 started the total fruit-disease index line on an upward trend, which was extended through 1927 by the continued rise of the blotch index and the resurgence of the scab index. This height was not maintained in 1928

however, even though the scab index continued to rise, for the blotch index fell off so sharply as to cause a distinct lowering in the total amount of diseased fruit.

The outstanding fact illustrated in Figure 13 is that in spite of the annual fluctuations of individual disease indexes the total fruit-disease index moved steadily from the high point of 1922 downward to the low point of 1925, after which it began again to rise; and though its upward progress has not been uniform, the upward trend is evident through 1928.



FIG. 13. COMPARISON OF THE TRENDS OF THE TOTAL ANNUAL FRUIT INTENSITY INDEXES WITH THOSE OF THE ANNUAL FRUIT INTENSITY INDEXES OF EACH APPLE DISEASE. SEE TEXT FOR DISCUSSION.

INTENSITY OF ATTACK ON TWIGS

Data have been taken, as shown in the special discussion of diseases for twig disease produced by blotch, black-rot, and fire-blight. The indexes of intensity derived from these data are brought together in Table XII, where they are shown comparatively by years; and the total effect of these diseases is estimated for each year by summing the intensity indexes. With the single exception of 1924, blotch was more intense in its twig attack than either fire-blight or black-rot; and black-rot was the least intense in all years. Fire-blight occupied the middle place in all years except 1924, when it exceeded blotch by the small amount of 2.28 per cent. The year 1923 is outstanding for its exceptionally heavy manifestation of twig disease; and it is also worthy of special notice that 1925, a year when fruit attack was at a minimum and leaf disease at a very low ebb, has the second place for intensity of twig disease.

The trends of the individual diseases, as manifested in terms of diseased twigs, is shown in Figure 14 in comparison with the total percentage of diseased twigs. Starting at the moderate total of 13.45 in 1922, the total intensity of twig disease rose very sharply in 1923 to the high total of 91.35, following very closely in this the upward trends of blotch and fire-blight, which were opposed by a sharp fall in the slight intensity of black-rot. From this high point, the total intensity fell in 1924 to 21.36, chiefly as a result of the sharp decline in the blotch intensity index; but the rate of fall of the total intensity line was lessened by an appreciable rise in the fire-blight index and a

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SUMMARY OF	TWIG	INTENSITY	OF .	APPLE	DISEASES
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Diseases	1922	1923	1924	1925	1926	1927	1928
Blotch Fire-blight Black-rot	$10.49 \\ 1.86 \\ 1.10$	$81.29 \\ 9.61 \\ .45$	$8.41 \\ 10.69 \\ 2.26$	54.54 4.76 trace	4.49	$7.59 \\ 0.09 \\ 0.0$	3.59 3.05 trace
Total	13.45	91.35	21.36	59.30	4.494	7.68	6.64

sharp upward movement in the black-rot trend. In 1925, the total intensity line rose again, reaching 59.30, the rise being due entirely, as may be seen in Figure 14, to the sharp climb made by the blotch index, and its failure to reach a point nearly equal to that attained in 1923 was due to a distinct falling off in the indexes of both fire-blight and blackrot.

The downward trend shown for the total index line between 1925 and 1926 may be much too steep. In the latter year, circumstances beyond our control prevented the accumulation of adequate data for blotch on twigs; but it is probable, in view of the general decline of other types of infective blotch material in 1925, that the twig intensity of 1926 was at least as low as in 1924. The upward trend of the total index line from 1926 to 1927 is, for the same reason, probably slightly exaggerated. Its real trend may actually have been downward.

Between 1927 and 1928 the trend of the total index is shown to have sloped downward. This results, as may readily be seen, from a fall in the blotch index, which was only partly balanced by the rapid rise of the insignificant fire-blight index. It is of interest to note that, of the three diseases causing twig injury, fire-blight appears to fluctuate less from year to year than the other two. The changes exhibited by both blotch and black-rot, as exemplified in the years 1922-1925, are rather extensive and cause their lines on the graph to move sharply up and down. It is striking also that in the four comparisons which the data for year-to-year trends make possible, the indexes for these two diseases travel consistently in opposite directions. In the four possible comparisons between blotch and fireblight, there are three instances of opposed trends, and one of similar



FIG. 14. COMPARISON OF THE TRENDS OF THE TOTAL ANNUAL TWIG INTENSITY INDEXES WITH THOSE OF THE ANNUAL TWIG INDEXES OF EACH APPLE DISEASE. SEE TEXT FOR DISCUSSION.

trend, while the six comparisons of trend which can be made between fire-blight and black-rot furnish three instances in which the trends are opposite and three in which they are similar.

LEAF INTENSITY

The injury done to apple trees by destruction of the leaves may result from any one or all five of the epidemic diseases. Fire-blight, however, causes injury to the leaves mainly by killing the young twigs upon which the leaves are borne; and in this sense it is not, at least in Illinois, an epidemic leaf disease. Seab, blotch, black-rot, and rust, however, have a distinctive type of leaf attack, which results in the killing or injurying of a particular portion of a leaf while the remainder of the leaf maintains a healthy, functioning condition. The extent of the leaf injury which these diseases cause by direct attack has been shown for each disease in the individual discussions, where an index was given representing the average leaf area occupied by lesions each year. These indexes are gathered together in Table XIII for comparison, and their annual totals, given at the bottom of the table, furnish within the limits under which they were gathered, a statement of their total effect in terms of the percentage of leaf area occupied or destroyed.

TABLE XIII

Diseases	1922	1923	1924	1925	1926	1927	1928
Scab Blotch Rust Black-rot Total	8.132.561.57.3612.62	$ \begin{array}{r} 14.45 \\ 3.89 \\ 3.70 \\ .18 \\ \hline 22.22 \\ \end{array} $	6.65 trace .25 .52 7.42	$ \begin{array}{r} 0.22 \\ 1.93 \\ \hline 1.09 \\ \hline 3.24 \end{array} $	$\begin{array}{r} 0.22 \\ .01 \\ 14.63 \\ .16 \\ \hline 15.02 \end{array}$	· 1.95 trace .06 .15 2.16	2.84 trace .10 .05 2.99

SUMMARY OF LEAF INTENSITY OF APPLE DISEASES

Excepting in 1925 and 1926, seab was the most destructive of the diseases attacking leaves, the area occupied by its lesions amounting to two-thirds of the total occupied leaf area in 1922 and 1923, more than six-sevenths in 1924, and nearly the entire amount in 1927 and 1928. Blotch was the chief cause of leaf damage only in 1925, though in 1922 and 1923 its importance was greater than either rust or black-rot. In general, rust was of slight significance, its ordinary maximum of 3.70, attained in 1923, being of no great importance; but the extraordinarily large rust index of 1926, 14.63, which compares directly with the scab index of 1923, shows that under certain conditions the rust of apples can become a serious menace to apple foliage. Black-rot was in all years a disease of very minor significance, only in 1925 becoming serious enough to account for a reduction in leaf area exceeding one per cent.

When taken together, the leaf intensity indexes indicate that of the 7 years shown by our data, 1923 was outstanding as the year of severest leaf disease, with 1927 ranking as the year of least severity. There is, as might be expected, a very considerable difference between the individual years, as regards both the individual diseases and their total effects.

The year-to-year trend of each disease, and of the annual totals of their indexes, is shown graphically in Figure 15. Here it appears that the total index line, as well as those for scab, blotch, and rust, follows the same trends—a rise from 1922 to 1923 and a fall from 1923 to 1924 —during the first three years, while black rot moves in an opposite manner. With the arrival of 1925, however, this agreement in trend is

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broken, the downward trend of the total index line resulting almost entirely from the steep fall of the scab index, since blotch and rust unite in the opposite trend. In 1926, again, rust alone is responsible for the upward turn in the total index line, the trend of all other diseases being downward, except scab which moved neither up nor down.

The rapid fall in 1927 of the rust index, coupled with only very slight changes in all other indexes except that of scab, brought the total index trend down practically to the level of the increasing scab index;



FIG. 15. COMPARISON OF THE TRENDS OF THE TOTAL ANNUAL LEAF INTENSITY INDEXES WITH THOSE OF THE ANNUAL LEAF INTENSITY INDEXES OF EACH APPLE DISEASE. SEE TEXT FOR DISCUSSION,

and in 1928 the continued rise of the scab index, though unaccompanied by marked changes in the insignificantly low indexes of the other leaf diseases, started the total index of leaf disease again in an upward direction.

The general trend of leaf disease was upward from 1922 to 1923, but downward from 1923 through 1925, while in 1926 the constant level of scab and the high rust index predict the beginning of a later general rise which becomes somewhat more apparent in 1927 and 1928.

Total Effect of Apple Diseases

The diseases of apple trees combine, in the intensity of their various types of attack, to injure the trees permanently and to interfere with the annual production of crops both by the permanent injury they do and by the season's infection on the fruit and the damage done to leaves, upon which the tree depends for a supply of material with which to form its fruit.

The effects of these diseases, as we have observed them in Illinois, are shown graphically in Figure 16. The tabulation presented as part of the graph shows the totals of the annual indexes for each type of attack, and the cross-hatched blocks of the diagram present a visual comparison of the yearly sums. Thus, it is evident that 1923 held first place as a year of destructive disease, while 1926 was the year of least



FIG. 16. COMPARISON OF THE TOTAL INTENSITY OF THE ANNUAL EPIDEMICS OF APPLE DISEASES

The total indexes of fruit, twig and leaf intensity shown in the table are combined graphically in the block diagrams to show the relative intensity of all epidemics in each of the years covered by the survey. The tendency of fruit, twig, and leaf disease to fluctuate independently from one year to another is also shown.

destructive disease. It appears also that the two first years, 1922 and 1923, were characterized by a very great severity in disease, but that in 1924, and in the succeeding years, the intensity of disease attack decreased to moderate or small amounts.

The graph also illustrates the proportional effects of each type of attack in each year and shows how an increase in the intensity of one type of attack, even when accompanied by decreases in the intensity of the other types, may serve to heighten the total effect of disease. Thus in 1922, the intensity of attack on fruit constitutes a little over 75 per cent. of the entire manifestation of intensity, while the remaining 25 per cent. is divided quite evenly between twig and leaf intensities. In the following year, however, the intensity of fruit attack was actually less by one-eighth and the leaf intensity nearly double that of 1922, yet the length of the column is greater by nearly three-fourths, because of the excessive increase in twig disease, which amounts to nearly half the total manifestation for the year. The very great decrease in the total manifest disease in 1924 is due to marked shrinkage in all types of attack, the proportional reduction being greatest in twig disease, which was less than one-fourth as intense as in 1923, while the reduction in both leaf and fruit intensity was approximately two-thirds.

In 1925, a year known among commercial growers for the very small amount of apple tree disease, there appears actually to have been a total manifestation of disease large enough to rank third among the years covered by our observations; but it will be seen that this is due entirely to an increase in twig disease to nearly three times its amount in the preceding year, and that the intensities of leaf and fruit attack, the latter especially noticed by the orchardist, decreased to approximately one-half and one-third, respectively, of their preceding amounts. The still further decrease in total manifestation of disease evident in 1926 did not materially impress the grower, for the reason that the decrease resulted very largely from the heavy falling off of twig disease from an index of 59.30 in the previous year to 4.49 in that year, while the fruit and leaf attacks, both of which he was more apt to observe, showed definite increases over the previous year and thereby gave, falsely, the impression of an increased amount of disease.

In 1927, there was only a very slight increase in the total manifestation of disease, but the change from 1926 consisted in doubling of the fruit intensity index, thus characterizing the season's disease attack as being commercially destructive to almost the same extent as that of 1924, with an increase in twig disease to but twice its former small amount and a decrease in leaf intensity to one-seventh. In 1928 there was not much change in the amounts of leaf and twig disease, but the total manifestation of disease appeared somewhat less through a decrease in the fruit infection to about four-fifths of the amount present in 1927.

In general, Figure 16 serves to illustrate and emphasize, from the point of view of total disease manifestation, the tendency of each type of attack to fluctuate from year to year entirely independently of other types of attack. It is also evident that commercial phases of disease, or those readily observable by growers, are apt by themselves to lead to erroneous estimates of the total effects of disease attack. It is only by compiling data on all phases that the real characteristics of any year with respect to disease severity can be determined.

It is of interest, also, to see what our data indicate in the way of a general condition which the orchardist must face in the intensity of disease attack through a period of years. As was illustrated in Figure 16, the total intensity of disease and also the intensity of each type of attack may vary widely from one year to another. The average condition derived from these variations may, however, be indicative of the relative importance of each disease and, in general, also of the relative importance of each type of disease manifestation over a period of years.

Figure 17 compares the average annual intensity in fruit, twig, and leaf attack of the diseases listed in tables on previous pages, as shown by our data. The tabulation which appears as part of the diagram gives the average annual intensities of each type of attack as exemplified by our data for each disease and also the total average intensity of each type of attack brought about by all diseases. The figures in the table are shown graphically by the series of blocks.





The tabulation gives the average annual fruit, twig, and leaf intensity indexes for each disease, and these indexes are shown graphically by the block diagrams.

From these, it is readily seen that black-rot, previously determined to be the most prevalent of apple diseases, is over a period of years actually the least serious disease. Rust, with its single measured manifestation of leaf disease, appears to be of minor importance also, though a certain small additional fruit attack which we have never measured lends it a commercial importance approaching that of black-rot. Fireblight, which we have measured only in terms of twig disease, appears third in the ascending order of importance, but as a commercial factor it probably ranks higher than the graph seems to indicate, since necessarily a considerable reduction in yield occurs as a result of the acute annual attack on blossoms and fruit spurs.

Scab, with its average annual fruit infection index of 16.56, is second only to blotch as a limiting factor in the commercial production of apples, but its wider geographical range in Illinois would seem to justify giving it the first rank in importance for the State as a whole. In its destructive effect upon the trees, however, it is plainly less important than blotch, as its leaf infection index of 4.92, though more than four times as great as that of blotch, is more than compensated for by the high intensity of blotch twig attack. Hence, it appears that of all the epidemic diseases, blotch holds first place in importance, at least in the commercial regions of the state.

The average total intensity of the epidemic diseases, taken over a period of years, is shown also in Figure 17. Of the three manifestations of intensity, the fruit attack is the largest, though it exceeds the twig attack by only a small amount. Leaf disease, often the most conspicuous phase, appears on the whole to be the least significant, though the more particular pains taken to measure it may have reduced its expression in a somewhat misleading way. It seems, however, from the data at hand, that over a period of years, a fruit grower may expect fruit disease and twig disease to dominate leaf attack, the first averaging annually about 35 per cent. of the crop, the second, year after year involving an average of about 33 per cent. of the new tree growth, and the leaf disease amounting on an average to slightly less than 10 per cent. of the total leaf area.

In these totals, black rot will play but a small part; rust will contribute chiefly to leaf-injury; fire-blight will be important in twig injury; scab will seriously effect both the fruit and leaves; and blotch will be the most serious of the diseases on fruit and twigs, but of minor importance on leaves.

PEAR DISEASES

In Illinois, pears suffer as a rule from the attack of only one serious disease, namely blight. There are, of course, other diseases, particularly two that appear as leaf spots; but the damage they do is very slight indeed, and it has been our experience that they occur but rarely in destructive amounts and then only in very restricted areas. The 'leaf blight' due to the fungus *Fabraea maculata* (Lev.) Atk. is perhaps the more serious of these, as it also appears at times upon the fruit; and the more common Septoria leaf-spot (caused by *Mycosphaerella sentina* (Fr.) Schr.) does very little injury. Consequently, our data on pear diseases is concerned only with pear blight.

PEAR BLIGHT

Caused by Bacillus amylovorus (Burr.) Trev.

The commercial production of pears in Illinois is very largely conditioned by the annual epidemics of pear blight. The disease, caused by the same bacterium as fire-blight on apples, manifests itself as blossom and twig blight, as spur blight, and as a very severe canker of the limbs and trunk. Its destructiveness, which may be seen to be very great, has been observed by pear growers to vary to such an extent from year to vear that they commonly designate years as of mild or of heavy blight. In measuring the annual epidemics of pear blight in Illinois, we have taken into account only the phase of its attack known as twigblight, including in this general type, however, the spur-blight phase and leaving out for the present any separate consideration of blossomblight or cankers. Our data consist of percentage statements, obtained by representative counts, of the prevalence of blight infection among trees and of the intensity of the attack, expressed as the percentage of blighted twigs and fruit spurs.

Data on Pear Blight

Because of the scattered distribution of pear plantations, as well as because of the relatively small number of pear trees grown in the State, we have not been able, in the course of our survey, to secure as abundant records for pear diseases as for the diseases of the more important fruits.

TABLE XIV

	Prevalence	Intensity	Basis of data				
Year	Percentage of pear trees infected by blight	Percentage of twigs infected by blight	Number of records	Number of trees represented by the records	Number of counties represented in the records		
1922 1923	$20.45 \\ 96.28 \\ 71.64 \\ 45.33 \\ 81.19 \\ 30.72 \\ 5.53$	$\begin{array}{c} \cdot & 1.59 \\ 18.44 \\ 20.53 \\ 5.61 \\ 14.21 \\ 2.31 \\ 0.16 \end{array}$	88 38 70 13 21 5 5	17,064 8,085 8,996 4,059 4,806 2,109 2,231	38 23 41 11 14 4 2		
Averages		8.98	34	6,764	133		

PREVALENCE AND INTENSITY OF PEAR BLIGHT

As shown in Table XIV, however, there have been 240 observations made of pear-blight in the course of the survey, or an average of 34 per year, and the average number of trees represented in the yearly records is 6,764. There has also been an average of 19 counties represented annually in the records.

In 1922 observations on pear blight were made in 88 plantations containing a total of 17,064 trees and distributed among 38 counties. The prevalence of the disease, as determined from these observations, is shown in Table XIV as 20.45 per cent., and the same observations give the disease a twig-blight intensity of 1.59 per cent. In 1923, however, the records obtained from 38 plantations show a very great increase in prevalence, the index being 96.28, and an even greater relative increase in twig-blight intensity, which has an index of 18.44.

For 1924, the prevalence of pear blight was determined to be 71.64 per cent. and the twig-blight intensity 20.53 per cent. This shows a decided fall in prevalence from the previous year but a slight increase in intensity.

The epidemic of 1925, as shown by our 13 observations, was milder than those of either 1923 or 1924, but more severe than that of 1922. Its prevalence was 45.33 per cent. and its intensity 5.61 per cent. This



FIG. 18. TRENDS OF PREVALENCE AND INTENSITY OF PEAR-BLIGHT. SEE TEXT FOR DISCUSSION

tendency to decrease was not maintained in 1926, however, for in that year 21 records representing 4,806 trees gave the high prevalence index of 81.19 and a twig intensity index of 14.21.

In 1927 the epidemic was again mild, the prevalence of the disease being only 30.72 per cent. and its twig intensity 2.31 per cent. This very sharp reduction in the severity of blight was continued into 1928, when the prevalence index reached the very low point of 5.53 and the twig intensity index fell to 0.16.

The year-to-year trends of the prevalence and twig intensity phases of the pear blight epidemics are shown graphically in Figure 18. In general, the movement of both phases follows the same trend, though between 1923 and 1924, when prevalence moved downward and twig intensity upward, the opposite appears to have been true. The upward or downward trend is usually more pronounced in the intensity phase than in the prevalence phase.

The graph illustrates, also, the great prevalence and destructiveness of the blight epidemics in the years 1923, 1924, 1925, and 1926, which are in marked contrast with the rather mild destructiveness of 1922, 1927, and 1928.

Through the period covered by our data, as may be seen in Table XIV, pear-blight has been present on an average of 50.16 per cent. of the trees we have examined, and 8.98 per cent. of all twigs on all these trees have been attacked by the disease.

PEACH DISEASES

Though they have always been important limiting factors in production, peach diseases have recently taken on a still greater economic significance in Illinois because of a great increase within the last 10 years in the number of commercial peach plantations set out within the State. The Bureau of Agricultural Economics of the U.S. Department of Agriculture made a survey of the peach trees in Illinois during the fall and winter of 1925–1926, the results of which, made available in May, 1926, indicate that there were in the State at that time 2,293 peach orchards of 100 or more trees. And it was estimated that there were in these orchards 1,923,012 peach trees, of which a little over 320,000—approximately one-sixth of the entire number—were less than two years old and 772,000, or 40 per cent., were two and three years old. Since the completion of this survey, these trees have come into bearing and more orchards have been planted, and both together are yielding crops estimated at 1,122,000 bushels in 1927 and 1,638,000 bushels in 1928. The farm value of the 1927 crop was estimated to be \$2,300,000 and that of the 1928 crop \$2,293,000.

All the important or destructive diseases that occur on peaches in Illinois are epidemic in their behavior, that is, they attack one or more parts of the tree anew each year; and the success of each year's attack is determined in large measure by the prevailing weather. In the measurement of these annual epidemics, the methods that have been used are the same as those described for apple diseases.

PEACH BROWN-ROT

Caused by Sclerotinia cinerea (Bon.) Schroeter

The attack of the brown-rot disease on peach trees is by no means limited to the fruit, from which it takes its name, but is destructive also to blossoms and twigs. In measuring its annual epidemics, however, we have had to limit the collection of data to the fruit-rot phase of the disease, except for the years 1926 and after, when data were taken on twig-blight also. At present, however, we intend to present the accumulated data on prevalence and fruit-rot only.

Data on Brown-rot

During the period of our survey, we have observed brown-rot in 135 peach plantations, an average of 19 per year. The average number of trees furnishing the annual records is 15,973 and the average number of counties represented yearly is 8. As may be seen in Table XV, the average annual prevalence of brown-rot indicated by these records is 42.67 per cent., while the average intensity of its attack on fruit is 5.73 per cent.

TABLE XV

	Prevalence	Intensity	Basis of data			
Year	Percentage of peach trees infected by brown-rot	Percentage of fruit infected by brown-rot	Number of records	Number of trees represented by the records	Number of counties represented in the records	
1922 1923 1924	88.24 25.22 97.41	2.29 0.53 27.36	$35 \\ 10 \\ 7$	$\left \begin{array}{c} 1,796\\ 4,310\\ 7,705\end{array}\right $	17 9 7	
1925. 1926. 1927. 1928	trace 9.26 55.88 22.68	trace trace 8.47 1.52	$ \begin{array}{c} 19\\ 16\\ 48 \end{array} $	5,041 12,400 80,565	13 5 10	
Total			135	111,817	61	
Averages	42.67	5.73	19	15,973	8	

PREVALENCE AND INTENSITY OF PEACH BROWN-ROT

The annual variation in the prevalence and intensity of brown-rot is also shown in Table XV. In 1922, when 35 orchards were examined and data secured from a total of 1,796 trees distributed among 17 counties, the brown-rot prevalence index stood at 88.24 per cent., while the intensity of the fruit attack had an index of 2.29 per cent. In the next year, 1923, 10 records taken in 9 counties and representing the diseased condition of 4,310 peach trees showed a drop in prevalence to 25.22 per cent. and a corresponding drop in the intensity of the fruit attack to 0.53 per cent. But with 1924 there was a very sharp increase in both prevalence and intensity, the former rising to 97.41 per cent. and the latter to 27.36 per cent., both of these being the highest indexes recorded for brown-rot. No satisfactory data were obtained in 1925; but our general observations, coupled with those of peach growers and horticultural experts, establish the practical absence of the disease that year. The indexes for 1926, 9.26 per cent. for prevalence and a trace only for fruit intensity, indicate both the severe effect of the previous very unfavorable year upon the disease and the fact that the disease was again beginning to attain importance. In 1927 the prevalence index rose to 55.88 per cent. and that for fruit intensity to 8.47 per cent., marking the epidemic of that year as second in intensity and third in prevalence among the years covered by the survey. With the arrival of 1928, however, brown-rot once more encountered unfavorable conditions and dropped in prevalence to 22.68 per cent. and in intensity to 1.52 per cent.

The trend of these annual brown-rot epidemics is shown graphically in Figure 19. It may be seen that with the exception of the change from 1925 to 1926, where the intensity of the fruit attack appears to have lagged behind the rising prevalence, the trends of both the prevalence and the intensity indexes follow the same courses throughout.



FIG. 19. TRENDS OF THE PREVALENCE AND INTENSITY OF THE BROWN-ROT AND BACTERIAL SHOT-HOLE DISEASES OF PEACH

The trend lines for both diseases show sharp changes from year to year, indicating their sensitivity to weather change. The year 1925 was marked by a sudden drop in the prevalence and intensity of both diseases, from which the bacterial shot-hole recovered in 1926. Brown-rot, however, though recovering its prevalence within a year, exhibits a lag of a year in recovering its former intensity.

The sharp movements both upward and downward of the prevalence and intensity lines indicate also that the disease is very greatly influenced by annual fluctuations in weather.

BACTERIAL SHOT-HOLE

Caused by Pseudomionas Pruni E. F. Smith

This disease, named from the shot-hole effect which its spots produce on peach leaves, also attacks the fruit and twigs. Of these three modes of manifestation, leaf attacks and fruit attacks are the most serious. Our data, however, will be presented to show only the prevalence of the disease and the intensity of its leaf attack.

In order to determine the annual intensity of shot-hole on peach leaves, the scale shown in Figure 20 has been devised. It is used in the same manner as the other leaf-spot scales which we have already described in connection with apple scab and other diseases. It should be emphasized especially that in this case as in all others the purpose of the scale is to measure the intensity of the disease attack in terms of



FIG. 20. Scale for measuring the intensity of attack of bacterial shothole on peach leaves

diseased leaf area and that it does not take into account the effect of the disease, which is to produce a distressingly high percentage of defoliation whenever the trees it attacks are growing in poor soil or when warm, moist atmospheric conditions prevail.

Data on Shot-hole

A total of 259 records have been secured for the bacterial shot-hole of peach during the course of our survey. As summarized in Table XVI, from an annual average of 37 records of the disease on 39,221 trees distributed among 17 counties, they indicate that shot-hole prevalence has -5 had, the high average annual index of 77.11 per cent. and that the intensity of its attack on leaves has resulted, as an average, in occupation by lesions of 10.33 per cent. of the leaf area of all trees observed.

Table XVI also shows the variation, as indexes of prevalence and intensity, of the annual epidemics. Data taken in 1922 from 90 plantations containing 12,921 trees indicate a prevalence for that year of 79.62 per cent. and a corresponding leaf intensity of 2.21 per cent. In 1923, according to records taken in 21 plantations containing a total of over 76,000 trees, the prevalence of shot-hole dropped to 59.59 per cent. and its leaf intensity fell to 1.27 per cent. The following year, 1924, the data contained in 40 records representing 44,640 trees show a considerable increase in prevalence, the index rising to 95.52 per cent. and an even sharper rise in leaf intensity, the index for which stood at the very high level of 53.53 per cent.

TABLE XVI

PREVALENCE AND	INTENSITY OF	PEACH SHOT-HOLE
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	Prevalence	Intensity	Basis of data			
Year	Percentage of peach trees infected by shot-hole	Percentage of leaf area occupied by shot-hole	Number of records	Number of trees represented by the records	Number of counties represented in the records	
					1	
1922	79.62	2.21	90	12,921	42	
1923	59.59	1.27	21	76,303	11	
1924	95.52	53.53	-40	44,640	27	
1925	14.54	0.01	8	15,880	8	
1926	93.98	8.41	28	23,530	13	
1927	99.09	4.07	27	28,773	9	
1928	97.47	2.87	45	72,505	10	
Total			259	274,552	120	
Averages	77.11	10.33	37	39,221	17	

In sharp contrast with the high prevalence and intensity of 1924 is the condition shown by the 8 records of 1925, which represented 15,880 trees. The prevalence index fell to 14.54 per cent. and the leaf index to 0.01 per cent. these values being the lowest recorded by us in the seven years covered by our data. The apparently very adverse conditions of 1925 seemingly did not have a very prolonged effect on shot-hole, for in 1926, as our 28 records show, its prevalence rose to 93.98 per cent. among a total of 23,530 trees and the leaf intensity index rose to the relatively high point of 8.41 per cent. This rise was carried into 1927, when the data furnished by our 27 records indicated a rise in prevalence to 99.09 per cent. though at the same time the intensity of the leaf attack fell to 4.07 per cent. somewhat less than half its former value. In 1928, with 45 records furnishing data on the state of the disease as it prevailed among 72.505 trees, prevalence was shown to have fallen slightly to 97.47 per cent. and leaf intensity somewhat more sharply to 2.87 per cent.

The trends from year to year of the shot-hole epidemics, as exhibited by their prevalence and leaf intensity indexes, are shown in Figure 19. With the exception of the change from 1926 to 1927, the trends of prevalence and intensity follow the same course; but it is evident that the changes in intensity are much sharper than those in prevalence. Following the very unfavorable year of 1925; both trends rise sharply and there is no apparent tendency for one to lag behind the other, as appeared to be the case with brown-rot. However, the changes from one year to another are rather sharp, as is observable also for brown-rot, and indicate that the disease is remarkably sensitive to annual changes in weather.

PEACH LEAF-CURL

Caused by Exoascus deformans (Berk.) Fuckel.

Leaf-curl is a common and often destructive disease in every peach region in the world and it is, naturally, prevalent throughout Illinois. It attacks the tree in a number of ways, causing a severe type of twig blight, attacking the blossoms and fruit and causing them to fall from the tree, and producing especially a leaf disease, which is termed curl from its characteristic appearance.

We have thus far found it impractical to measure accurately the intensity of leaf-curl attack. As the disease manifests itself in Illinois, it seldom produces any noticeable damage on either the flowers or the fruit, but it occasionally appears in limited regions as a severe twig blight and is everywhere prevalent as a leaf disease. Upon the leaves, it may appear in very small or in large amounts; but it always results in such a curling and malforming of the leaves that we have not been able to devise a workable series of measuring standards with which to gauge its leaf intensity. Consequently, we furnish here only our data on its prevalence.

Data on Leaf-curl

We have obtained an average of 25 records per year on the prevalence of leaf-curl during the years covered by our survey. As shown in Table XVII, these records represent annually an average of 8,879 trees, and the disease is indicated to have an average annual prevalence of 52.02 per cent.

In 1922, when the prevalence of leaf-curl among 5.873 peach trees was shown by the data in 64 records obtained in 27 counties, the index stood at 36.23 per cent. In the following year prevalence increased to the highest point in our record, 95.64 per cent.; but in 1924 it decreased, reaching 19.6 per cent., the lowest point in our records. For 1925 we have no adequate data; but an increase in prevalence to 51.17 was shown by the 15 records taken in 1926; and this tendency to increase was continued into 1927, when on the basis of data contained in 26 records drawn from 21,548 trees the prevalence index was placed at

TABLE XVII

	Prevalence: Percentage of trees having leaf-curl infection	Basis of data			
Year		Number of records	Number of trees represented by the records	Number of counties represented in the records	
1922 1923 1924 1924 1926 1927 1928	$\begin{array}{r} 36.23\\ 95.64\\ 19.60\\ 51.17\\ 84.97\\ 24.51\end{array}$		$ \begin{bmatrix} 5,873\\ 5,950\\ 1,229\\ 5,274\\ 21,548\\ 13,400 \end{bmatrix} $	27 18 15 8 9 4	
Total		151	53,274	81	
Averages	52.02	25	8,879	13	

PREVALENCE OF PEACH LEAF-CURL



FIG. 21. TRENDS OF THE PREVALENCE OF LEAF-CURL AND OF THE PREVALENCE AND INTENSITY OF SCAB

Data for 1925 are lacking, but the tendency for these diseases to fluctuate sharply from year to year is evident. The high indexes of intensity shown by the fruit attack of scab would be unusual for other diseases but are characteristic of scab. 84.97 per cent. This high level was not maintained, however, for in 1928, when 7 records showed the state of the disease among 13,400 trees located mainly in the worst leaf-curl region of the State, the prevalence index stood only at 24.51 per cent.

The trends of these annual epidemics are shown graphically by the solid line in Figure 21. The tendency to fluctuate sharply from one year to another, which has been apparent with other peach diseases, is also marked in the case of leaf-curl. Though data are lacking for 1925, it is reasonable to suppose that the disease behaved as did most other diseases that year, falling to a very low point of prevalence; and this would give the leaf-curl graph an even more irregular aspect.

PEACH SCAB

Caused by Cladosporium carpophilum Thuemen

With its general range including Europe and the entire eastern half of the United States, peach scab is, of course, found commonly throughout Illinois. Like the other peach diseases, it manifests its presence by attacking the twigs, the leaves, and the fruit: but the two phases confined to twigs and leaves are relatively rare and do but little injury to the trees. It is the fruit attack that gives this disease its importance; and as this is its most common manifestation in Illinois, we have chosen to measure the intensity of the annual scab epidemics in terms of infected fruit.

Data on Peach Scab

In all, 122 records of peach scab have been gathered during our survey, an average of 20 per year, representing as an average 14,098 trees per year. As is indicated by the summary of our data given in Table XVIII, the average annual prevalence of the disease in Illinois stands at 66.53 per cent., while its average annual intensity, expressed as the relative proportion of infected peaches, stands at 41.34 per cent. This latter figure does not, of course, indicate the economic loss which results from the disease, since in taking our counts we include all instances of infection, no matter how light they may be.

The annual variations exhibited by the peach scab epidemics are also stated in Table XVIII. In 1922, when a total of 4.097 trees distributed among 16 counties furnished 36 usable records, the prevalence of the disease amounted to 62.68 per cent. and the intensity of the fruit attack to 24.31 per cent. The following year these indexes were found, on the basis of 25 records including 9.673 trees distributed among 18 counties, to have increased quite decidedly, that for prevalence having reached 88.83 per cent. and that for fruit intensity 71.99 per cent. And though in 1924 there were only 9 records representing only 1.526 trees, prevalence continued to rise, reaching the very high index of 100 per cent., which was attained also by the fruit intensity index.

No records are available for 1925; but since the disease entirely escaped the notice of horticultural experts that year, it was probably neither very prevalent nor very destructive. In this, it would have followed the same course that was taken by other peach diseases that year. In 1926, however, there appears to have been abundant scab infection. Though only 11 records were secured and only 112 trees were represented by them, they were distributed among 6 important peachgrowing counties; and the high prevalence index of 100 per cent. and the moderately high fruit intensity index of 42.76 per cent. probably represent the relative state of the disease rather accurately.

In contrast with these years of great prevalence and intensity, 1927 and 1928 stand out as years of mild scab. The six records taken in 1927 apply to orchards containing a total of 4,100 trees and furnish a prevalence index of 24.48 per cent., while in 1928 the 35 records accumulated represent a total of 65,080 trees and give a prevalence index for scab of 23.22 per cent. The indexes indicating the intensity of the scab attack on fruit for these two years were 4.27 per cent. and 4.75 per cent. respectively.

TABLE XVIII

	Prevalence Intensity		Basis of data			
Year	Percentage of trees having scab infection	Percentage of peaches infected by scab	Number of records	Number of trees represented by the records	Number of counties represented in the records	
1022	62 68	94-31	36	4 097	16	
1923	88.83	71.99	25	9.673	18	
1924	100.00	100.00	9	1,526	9	
1926	100.00	42.76	11	112	6	
1927	24.48	4.27	6	4,100	2	
1928	23.22	4.75	35	65,080	10	
Total			122	84,588	61	
Averages	66.53	41.34	20	14,098	10	

PREVALENCE AND INTENSITY OF PEACH SCAB

The trends of the prevalence and fruit intensity indexes of peach scab are shown graphically by the broken lines in Figure 21. Discounting the false trend indicated, through lack of data in 1925, as occurring between 1924 and 1926, the curves for both the prevalence and the fruit intensity indexes follow essentially the same trend from year to year. It is notable that this disease does not fluctuate so sharply from one year to another as do other peach diseases. Rather, from the beginning of our record through 1926, it appears to have followed a rather even, high course (though, of course, we cannot state the actual trends for 1925), while during the last two years, 1927 and 1928, it has maintained a similar even course, though at a lower level.

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DISEASES OF FRUIT TREES, 1922-1928

SUMMARY OF PEACH DISEASE DATA

In the preceding discussion of peach diseases the data gathered each year for each disease have been given in tabular summaries, and comparisons have been made of the prevalence and intensity of each disease.

Prevalence of Peach Diseases

In Table XIX, the annual indexes of prevalence for the several peach diseases have been brought together so that the diseases may be compared with one another.

In the first year of our survey, brown-rot stands out as the most prevalent of the peach diseases, but the bacterial shot-hole disease and scab also had high indexes, while leaf-curl occupied the lowest position. For 1922, the average incidence of diseases per tree was 2.67. In 1923, the diseases formerly occupying first and last placees changed positions

TABLE XIX

SUMMARY OF PREVALENCE OF PEACH DISEASES

Diseases	1922	1923	1924	1925	1926	1927	1928
Brown-rot Bacterial shot-hole Leaf-curl Scab	$\begin{array}{r} 88.24 \\ 79.62 \\ 36.23 \\ 62.68 \end{array}$	$\begin{array}{r} 25.22 \\ 59.59 \\ 95.64 \\ 88.83 \end{array}$	$97.41 \\ 95.52 \\ 19.60 \\ 100.00$	trace 14.54	$9.26 \\ 93.98 \\ 51.17 \\ 100.00$	$55.88 \\99.09 \\84.97 \\24.48$	$22.68 \\97.47 \\24.51 \\23.22$
Average incidence of disease per tree	2.67	2.69	3.12	. 14	2.54	2.64	1.68

so that leaf-curl held first place and brown-rot last place. Scab was second in the order of prevalence and bacterial shot-hole was third, while the average incidence of diseases per tree rose very slightly to 2.69. Scab attained first rank in prevalence in 1924, with brown-rot and shothole also having indexes of 95 per cent. or more, but leaf-curl attained only the slight prevalence of 19.6 per cent. For this year the average incidence of disease was 3.12 per tree, the highest point reached in the period of our records.

The year 1925 probably ought to stand out more strikingly than it does, with the indexes for two diseases missing, as a year of very little disease. Brown-rot, usually a distinct menace to the peach crop, was so rare that its prevalence could be described only as a trace while the bacterial shot-hole disease exhibited the exceptionally small index of 14.54 per cent.

All diseases showed an increase in prevalence in 1926, but scab and bacterial shot-hole were most successful, while brown-rot was still of minor importance; and the average incidence of diseases per tree amounted only to 2.54. In 1927 brown-rot, shot-hole, and leaf-curl practically attained to their former states, but scab fell off in prevalence to a very low point. The average incidence of diseases per tree attained the high point, 2.64.

In 1928 bacterial shot-hole was the only disease exhibiting a high degree of prevalence. Brown-rot fell off markedly, and so also did leafcurl, while scab remained at essentially the level of the year before. Consequently, the average incidence of disease per tree fell to 1.68, the lowest point in our record with the exception of the incomplete 1925.

The trends of prevalence for each of the peach diseases are shown in the lower part of Figure 22, and the trend from year to year of the average incidence of diseases is shown in the upper part. From 1922 to





The lower part of the figure gives the trends for each disease and the upper part the trend of average annual incidence of disease per tree. The break in the lower part is necessary to show the great drop in brown-rot prevalence in 1925. Data for 1925 are lacking for leaf-curl and scab.

1923 the trends of leaf-curl and scab moved upward, but this was counterbalanced by a downward movement by brown-rot and shot-hole, with the result that the level of average incidence was scarcely changed.

The upward movement of seab was continued into 1924, and brown-rot and shot-hole both reversed their downward trends, as did

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leaf-curl its upward trend, with the result that, in spite of the steep fall of leaf-curl, the trend of average incidence was turned distinctly upward.

Partly through lack of data for two diseases, but more evidently because the year was very unfavorable to peach diseases, as is indicated by the steep falls of the brown-rot and shot-hole trend lines from 1924 to 1926, the average incidence curve was bent down very sharply in 1925. With all four diseases tending to increase their prevalence in 1926, the average incidence line returned again to nearly a normal level; and with the continued rise in the trends of brown-rot, leaf-curl, and shot-hole, the incidence curve rose a trifle higher in 1927 and was held to a level slightly below that of the 1922 only by the sharp decline of scab. Between 1927 and 1928 all trends were downward, those of brown-rot and leaf-curl very distinctly so, those of scab and shot-hole perceptibly so, with the result that the trend of average incidence moved downward also.



FIG. 23. COMPARISON OF THE AVERAGE ANNUAL PREVALENCE OF PEACH DISEASES

Brown-rot is prevalent to the least extent and bacterial shot-hole to the greatest, while leaf-curl and scab are intermediate. These four diseases, by their combined attack, give an average annual incidence of disease of 2.21 per tree.

There appears to be but little agreement among peach diseases as to their prevalence reaction in ordinary years. While certain ones may move together in one year they are apt to move in opposite directions in another year. Each disease appears to be influenced to a marked degree, either favorably or unfavorably, by changes in some one or more factors in the environment provided from year to year. It is notable, however, that in spite of the great fluctuations exhibited by the individual diseases, their various reactions result, on the whole, in maintaining the curve for the average incidence of disease at a surprisingly uniform level.

ILLINOIS NATURAL HISTORY SURVEY BULLETIN

By summing the annual indexes of prevalence for each disease and apportioning this sum equally among all the years for which we have records, a statement may be obtained of the average prevalence of each disease over a period of years. This is illustrated in Figure 23. Brownrot is shown to be, on an average, the least prevalent of the peach diseases, having an average annual prevalence index of 42.67 per cent. Leafcurl, with its average annual prevalence index of 52.02 per cent., is approximately one and one-fifth times as prevalent as brown-rot; scab, with its average index of 66.53 per cent. is one and a half times as prevalent as brown-rot; and bacterial shot-hole, with an average index of 77.11 per cent., is one and four-fifths times as prevalent as brown-rot.

The average incidence of peach diseases per tree, as indicated in Figure 23, is 2.21.

Intensity of Peach Diseases

Owing to the fact that in our survey of peach diseases we have not, as a rule, measured the intensity of any one disease by more than one of its various manifestations, we shall not attempt to make the same variety of comparisons that were made with the apple diseases. But in order to make as complete a statement as possible, we shall introduce some data on types of intensity not given in the previous discussion. These data, as will be seen by examining Table XX, show the results of our observations on the intensity of the fruit attack of the bacterial shot-hole disease in 1927 and 1928, the intensity of the twig attack of brown-rot in 1926, 1927, and 1928, and the intensity of the twig attack of leaf-curl for all years except 1925 when no data were taken. We do not believe, however, that the twig intensity indexes for leaf-curl for the years prior to 1926 are sufficiently accurate to indicate in more than a relative way the intensity of the disease.

TABLE]	XX
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Diseases	1922	1923	1924	1925	1926	1927	1928	Averages
On fruit: Brown-rot Scab. Shot-hole	2.29 24.31	.53 71.99	27.36 100.00	t rac e	trace 42.76	$8.47 \\ 4.27 \\ 13.78$	$1.52 \\ 4.75 \\ 31.20$	$5.73 \\ 41.34 \\ 22.49$
On twigs: Brown-rot Leaf-curl	3.43	22.78	4.70		. 05 3. 98	$5.18\\10.20$.61 3.36	$1.94 \\ 8.07$
On leaves: Shot-hole	2.21	1.27	53.53	.01	8.41	4.07	2.87	10.33

SUMMARY OF INTENSITY OF PEACH DISEASES

Always bearing in mind the limitations of accuracy that affect these data, the material given in Table XX can be rearranged graphically, as is done in Figure 24, to show the variations in total annual intensity of the peach diseases. The table included in this figure gives by years the totals of the annual intensity indexes of all diseases, as listed in Table XX, for each type of disease manifestation, and these totals are represented graphically by the blocks in the diagram. Hence, each year's block shows in black the percentage of fruit infected by all diseases, by cross-hatching the percentage of twigs infected by all diseases, and by vertical shading the total percentage of leaf-area occupied by disease lesions.

The year 1924 stands out as the year of most intense disease epidemics; but 1925, though following immediately, had the least intense



FIG. 24. COMPARISON OF THE TOTAL INTENSITY OF PEACH DISEASES BY YEARS

The table in the chart gives the sums of the indexes of fruit, twig, and leaf intensity of all diseases, and these sums are shown graphically by bars for each year. See text for further explanation.

epidemics. All phases of intensity vary from year to year; but that on fruit, though varying to a greater extent than any other, has always been the most important. Excepting in 1924 and 1926, twig intensity was of more importance than leaf intensity, but it is readily seen that in the 1924 block fruit intensity and leaf intensity make up by far the greater part, as is true also of the 1926 block.

Through 1924, peach diseases appear to have been increasing very rapidly in the intensity of their epidemics; but with the advent of the universally unfavorable 1925 all epidemics appeared in mild form. Subsequently, however, peach diseases increased the intensity of their attacks and attained a level in 1926, 1927, and 1928 somewhat higher than they had occupied in 1922.

It is worthy of note that the tendency of peach disease to attack fruit to a greater extent than any other part of the tree gives them an especial importance, inasmuch as they are therefore an annual threat against the harvesting of an abundant and profitable crop.

The average comparative intensities of each of the peach diseases, as they have manifest themselves during the period covered by our survey and as they probably may be expected to manifest themselves over a similar period of years, are shown by the table and diagrams in Figure 25. In the table, the figures show the averages of the annual intensity indexes of each disease for each of its measured manifestations, and these values are shown diagrammatically for easy comparison by the horizontal shaded blocks.





The table gives the average annual intensity index for each measured manifestation of each peach disease and the length of the bars expresses these indexes graphically. For further explanation see text.

Brown-rot, though it has been measured in terms of fruit intensity and twig intensity, does not equal any other diseases in either of these respects; and its epidemics may therefore be considered the mildest from the disease standpoint, though not from the commercial, of any of the peach diseases. Leaf-curl, the intensity of which we have measured only in terms of diseased young growth, exceeds in this respect brownrot, and the two diseases combine to furnish almost the total amount of twig destruction. Bacterial shot-hole, for which indexes have been computed to show the intensity of attack on fruit and leaves, exceeds brownrot by nearly four times in its fruit intensity and contributes almost the entire amount of leaf area reduction not attributable to the attack of leaf-curl. Scab, which we have measured only as a fruit disease, exhibits the greatest average intensity of attack of any of the peach diseases. The comparisons made in Figure 24 ought not, however, to be understood as in any way representing the relative commercial importance of the peach diseases. Brown-rot, ranked on the basis of our data as least important in the intensity of its epidemics, is the most important commercially of the four; and bacterial shot-hole, shown by our diagram to be milder in its epidemics than seab, usually out-ranks scab very greatly in its injurious effects upon the peach crop. This, however, only serves to emphasize the necessity of considering the disease separately from its effects on yield, if data are to be useful in explaining the annual fluctuations in prevalence of disease and in intensity of disease attack.

CHERRY AND PLUM DISEASES

As was pointed out in our discussion of the distribution of fruit trees in Illinois, neither cherries nor plums are grown as extensively as apples and peaches. For the most part, they are to be found in small groups in farm orehards, though there are of course larger plantations of a hundred trees or more scattered here and there through the State. As a consequence, these fruit trees do not in general receive the same eare, either in cultivation or in spraying, as the more important kinds of fruit trees; and this naturally results in a greater prevalence of disease and usually in a greater intensity of disease attack.

The epidemic diseases of cherries and of plums are similar. Brownrot, previously discussed as an important peach disease, also attacks both cherries and plums. The bacterial shot-hole disease of peaches is very common on plums and is occasionally encountered on cherries. Both cherries and plums suffer also from leaf-spot injury resulting from the attack of fungi classed as species of *Coccomyces*.

In measuring the annual epidemics of cherry and plum diseases, we have taken into account both prevalence and intensity; but owing to the abundance of disease upon the leaves, we have distinguished in our records only brown-rot and leaf spotting, including in the latter category all types of leaf spotting, without regard to cause. Figure 26 shows the scale we have used in estimating the leaf-area occupied or destroyed by leaf-spot diseases of cherries, and Figure 27 shows the scale we have used for plum leaf spotting.

Data on Cherry and Plum Diseases

During the period eovered by our survey, we have secured data on the diseases of plums and cherries more or less incidentally as we carried on our work with the diseases of more important commercial erops. Nevertheless in 1922, 1923, and 1924 data were obtained on brown-rot attack from a total of 2,127 cherry trees; in the years 1922-1924 and 1926 and 1927, data on brown-rot were secured from 1,069 plum trees; and through the period of the survey data on cherry leaf spotting was taken from a total of 10,796 trees and on plum leaf spotting from a total of 408 trees. The results of these examinations are summarized in Table XXI.

In 1922 the brown-rot epidemic on cherries was very light. The prevalence of the disease had the very low index of 12.17 per cent.,

while the intensity of its attack on fruit was only 1.12 per cent. But in 1923 the epidemic was severe, prevalence then rising to 100 per cent. and intensity to 17.21 per cent. In the following year, 1924, there was no appreciable reduction in brown-rot prevalence. The index for that year stood at 99.94 per cent., a reduction of only .06 per cent. from 1923; but the intensity of brown-rot attack on the fruit increased to 29.05 per cent.



FIG. 26. SCALE FOR ESTIMATING THE INTENSITY OF SPOTTING ON CHERRY LEAVES

In each example the area of the spots is expressed as a percentage of the area of the leaf. No effort is made in using this scale to distinguish between leaf-spots resulting from different causes.

Though these three are the only years of the period covered by our survey for which we have representative data, they serve to indicate the importance of brown-rot as a cherry disease. With an average annual prevalence of 70.7 per cent. and an average annual index of fruit intensity amounting to 15.79 per cent., this disease is annually a menace to cherry production.

Leaf spotting of cherry trees. as may be seen in Table XXI, always has a high prevalence. In 1922 its prevalence index was 92.66 per cent., in 1924 it was 99.35 per cent., and in all other years except



FIG. 27. SCALE FOR MEASURING THE INTENSITY OF SPOTTING ON PLUM LEAVES

In each example the area of the spots is expressed as a percentage of the area of the leaf. This scale measures roughly the combined intensity of the bacterial shot-hole and coccomyces leaf-spot lesions.

1925, for which we have no adequate data, it was computed to be 100 per cent. Its prevalence in Illinois, as exemplified by our data for six vears, averages annually 98.66 per cent.

There is, however, a very considerable annual variation in the intensity of cherry leaf spotting. In 1922 the index of intensity stood at .55 per cent.; in 1923 it rose to 1.97 per cent., nearly four times the previous amount: and in 1924 it rose still further, reaching 4.65 per cent. No data are available for 1925, but the index for 1926, 2.28 per cent., suggests that leaf spotting in common with several diseases of other fruit trees, may have decreased very considerably. The year 1927 is remarkable for the exceptionally intense attack of leaf spotting diseases on cherries. The index for that year, 15.69 per cent., the highest we have recorded, is merely three and a half times as great as the previous high index of 4.65 per cent. recorded in 1924. It is rather surprising, after so intense an attack, to find the index of intensity falling in the next year, 1928, to so small an amount as .69 per cent., but this serves to emphasize once more the tendency of diseases to fluctuate greatly from one year to another, under the influence of varying weather conditions.

Diseases	1922	1923	1924	1925	1926	1927	1928	Average
Prevalence on cherries: Brown-rot Leaf-spotting	$12.17 \\ 92.66$	100.00 100.00	$99.94 \\ 99.35$		100.00	100.00	100.00	70.70 98.66
Intensity on cherries: Brown-rot Leaf spotting	1.12 .35	$17.21 \\ 1.97$	$29.05 \\ 4.65$		2.28	15.69	. 69	$15.79\\4.30$
Prevalence on plums: Brown-rot Leaf-spotting	$ 84.61 \\ 95.58 $	$97.64 \\ 100.00$	100.00 96.49		100.00	100.00	100.00	97.04 97.36
Intensity on plums: Brown-rot Leaf-spotting	$9.21 \\ 1.53$	49.00 6.71	29.42 4.80		80.00	25.00		$38.52 \\ 4.35$

TABLE XXI PREVALENCE AND INTENSITY OF CHERRY AND PLUM DISEASES

The six epidemics represented by our data indicate an average annual intensity for the leaf spotting discases of cherries of 4.3 per cent. This index may, however, be a little high, because of the lack of data for 1925, a year generally characterized by low intensity of disease attack.

On plums, brown-rot appears to be even more prevalent and destructive than on cherries. Its index of prevalence in 1922, as stated in Table XXI, was 84.61 per cent.; in 1923 it was 97.64 per cent.; and in each of the years 1924, 1926, and 1927 it was 100 per cent. The average annual prevalence of brown-rot on plums, as computed by averaging these indexes, is 97.04 per cent., one and one half times as prevalent as our data show the disease to be on cherries.

In the intensity of its attack on fruit, brown-rot is also a destructive disease of plums. Beginning with an intensity index of 9.21 in 1922, the

disease increased in severity in 1923 to the point of attaining an index of 49 per cent. Though this high percentage of fruit disease fell off to the not very moderate amount of 29.42 per cent. in 1924, the attack again attained such serious proportions in 1926 that the intensity index stood at 80 per cent. This was reduced in 1927 to 25 per cent.; but the seriousness of plum brown-rot as an annual menace to the plum crop is well expressed by its average annual fruit intensity index of 38.52 per cent.

Leaf spotting of plums appears in our records only for the years 1922, 1923, and 1924. In the first of these years its prevalence among the plum trees examined was 95.58 per cent.; in 1923 it was 100 per cent.; and in 1924 it fell slightly to 96.49 per cent. Its average annual prevalence, as indicated by these three indexes, is 97.36 per cent.



FIG. 28. COMPARISON OF THE AVERAGE ANNUAL PREVALENCE AND INTENSITY OF CHERRY AND PLUM DISEASES

Brown-rot is less prevalent on cherries than on plums but leaf spotting is nearly equally prevalent on both. In intensity brown-rot is more severe on both cherries and plums than is leaf spotting. The intensity of leaf spotting is nearly equal on both fruits. (Brown-rot prevalence should read 97.04 instead of 96.45. See Table XXI.)

The intensity of the leaf-spot diseases for these years is shown in Table XXI as 1.53 per cent. in 1922, 6.71 per cent. in 1923, and 4.8 per cent. in 1924. These three indexes indicate an average annual intensity of 4.35 per cent.

The average annual prevalence and intensity of the cherry and plum diseases are compared graphically in Figure 28. Brown-rot may be seen to be less prevalent on cherries than on plums and much less prevalent on cherries than is the leaf spot either on cherries or plums. On plums, brown-rot and leaf spotting are nearly equally prevalent.

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In the average intensity of its attack on cherries, as illustrated in Figure 28. brown-rot exceeds leaf spotting, but is less than one-half as severe as it is on plums. There is little difference between the average intensities of leaf spotting on cherries and on plums.

SUMMARY OF DATA

In our detailed discussion, the methods employed in taking data on fruit-tree diseases have been described; the simple statistical methods used in evaluating these data have been explained; and the results of our annual surveys of fruit-tree diseases, determined by this statistical treatment, have been presented in a manner designed to show with exactness the year-by-year variations in the prevalence and severity phases, as well as the average condition, for each important epidemic disease of each kind of fruit tree. These results, being based, without exception, upon separate percentage calculations for every phase of disease attack, are entirely comparable, whether comparisons be made between the indexes of one disease for different years or between the indexes of different diseases of the same or of different kinds of trees. The only limitation that can be placed upon these comparisons arises from natural and unavoidable variations in the quantity and dependability of field data; but these matters can readily be tested and evaluated by several well-known statistical indicators, such as the standard deviation or the probable error.

It now remains to present, from these same data, a general picture of fruit-tree disease, in which the total effect of disease can be clearly seen, in its year-to-year variations and in its average condition, upon each kind of fruit tree. In so doing, the mass of detail given earlier must be combined as much as possible; but it is still desirable to maintain, both for clearness and because of the impossibility of uniting the several modes of disease attack in one inclusive measurement, the distinctions we have made not only between prevalence and intensity but also between fruit disease, twig disease, and leaf disease.

We have enumerated for apples five separate epidemic diseases; for pears, one disease; for peaches, four; and for cherries and plums, two each. Fruit trees, like other living things, are not rendered immune to further maladies by becoming infected with one disease. As every orchardist knows, an apple tree may suffer from scab alone, from blotch alone, or from both, and even from blight, black rot, and rust also. So it may readily be understood that if the several sets of indexes of all the diseases of one kind of fruit-tree for any one year are added together their totals will show the amount of disease on the average tree.

ANNUAL PREVALENCE OF FRUIT-TREE DISEASES

For apple diseases in 1922, the scab index for prevalence of 93, the black rot index of 65.64, the blotch index of 53.03, the fire blight index of 42.64, and the rust index of 26.29, when added, give a total of 280.60. This at first suggests what is apparently unreasonable, that in every 100 trees the percentage of diseased trees was 280.6; but actually the meaning is that, on an average, in every 100 trees there were about 281 cases

DISEASES OF FRUIT TREES, 1922-1928

of disease, when the separate kinds of disease are recognized. An equally concrete, perhaps a more easily understood statement of the same fact is that the individual tree was attacked on an average by 2.8 diseases. The sums of prevalence indexes, when regarded in this way, are an expression of the number of cases of disease per 100 trees, and by dividing this by 100 we obtain a number which we may very properly term the average incidence of disease per tree.

The average incidence of disease per tree, because of the manner in which it is derived, expresses briefly and accurately the prevalence of disease in any year or, by an average of years, for any desired longer period of time.

In Table XXII the average incidence of disease per tree, derived by totaling the prevalence indexes given previously for the several dis-



FIG. 29. Comparison of the annual incidence of disease per tree for each of the five tree fruits

Apples are most subject to disease attack every year and peaches are next. Plums and cherries are nearly equally subjected to attack, and pears less than any. This ranking on the basis of disease prevalence would not, however, correspond to a ranking on the basis of commercial injury.

TABLE XXII

Kind of tree	1922	1923	1924	1925	1926	1927	1928
Apple	2.81	3.50	$3.38 \\ 71$	3.50	2.86	3.68	4.27
Peach	2.67	2.69	3.12	.14	2.54	2.64	1.68
Plum	$1.03 \\ 1.80$	$\frac{2.00}{1.97}$	$1.99 \\ 1.96$		1.00	1.00	1.00

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AVERAGE INCIDENCE OF DISEASES PER TREE

eases and dividing the sum by 100, is given by years for each of the five kinds of fruit trees dealt with.

Upon comparing the items in this table it will be found that the apple and the peach, our two most important horticultural crops, succumb quite consistently to the attack of more diseases than do the less important pear, cherry, and plum. It may be seen also that the total of disease prevalence fluctuates from year to year just as noticeably as the prevalences of single diseases.

The data tabulated in Table XXII are shown graphically in Figure 29. The height of the columns represents the average incidence of disease per tree. It is evident that of the five kinds of fruit trees important in Illinois horticulture, the apple has in every year been most subject to the attack of epidemic diseases. In comparison with other kinds of fruit trees, the prevalence of disease on the apple has varied the least from year to year. The peach, next to the apple, has been most subject to disease attack; but the prevalence of disease among peach trees has varied to a far greater extent from year to year than it has among apple trees. The plum and the cherry, being as a rule susceptible to the same diseases, have been subjected almost equally to disease attack, though the actual prevalence of disease may be greater on one in one year and on the other in an other year. With pears, for which in our state there is but one generally severe epidemic disease, the columns in Fig. 29 serve only to represent its annual fluctuations in prevalence.

ANNUAL INTENSITY OF DISEASE ATTACK

Intensity of attack, as our discussion of the individual diseases has suggested, is in many respects distinct from disease prevalence and, as it has been measured separately throughout our surveys, it should be maintained separately in our summary.

In order to determine, for each kind of fruit, to what extent the intensity of attack of all the epidemic diseases affects the average tree, it is necessary to add together in separate categories the annual indexes for fruit disease, for leaf disease, and for twig disease determined from the field data. The results may then be regarded as showing the annual intensity of disease attack on the average tree. This summation is given in Table XXIII. The total intensity of disease attack on the apple is shown for the fruit, twig, and leaf, on the pear for twig-disease only, on the peach for fruit, twig, and leaf, and on the cherry and plum only for the fruit and leaf disease.

For clearer presentation and more ready comparison, these data are given graphically in Figure 30. The intensity of the various phases of disease for the several kinds of fruit trees is shown year by year. The first column of bars relates to intensity of attack on fruit, the second to intensity on twigs, and the third to the intensity of leaf disease.

Intensity of Disease on the Fruit

Fruit intensity data in Table XXIII apply only to apples, peaches, cherries, and plums. The bars representing these data in Figure 30 are

arranged for each year in the order in which the fruit were named. In the years 1922, 1923, and 1924, the intensity of fruit disease on apples, shown by black bars, tended to decrease, while fruit diseases on peaches, shown by doubly cross-hatched bars, tended to increase. This opposition of trends is of interest, not only because it suggests a possible general and opposite difference in the effect of weather conditions upon apple and peach fruit-diseases but also because the general increase in fruit disease intensity on cherries and plums in the same years indicates that conditions increasingly unfavorable to diseases on pomaceous fruits may be increasingly favorable to diseases attacking fruits of drupaceous trees.

The year 1925 is outstanding because of the very slight intensity of disease attack on fruit, but in the succeeding years, 1926, 1927, and 1928, the attack on fruit is shown to have increased again in the case of every kind of fruit tree for which data were obtained. And in these

TABLE XXIII

Kind of fruit	1922	1923	. 1924	1925	1926	1927	1928
Apple:							
Fruit	79.61	69.83	29 46	9.09	12.66	24 71	19.73
Twig	13 45	91 35	21 36	59 30	4 49	7 68	6 64
Leaf	19.62	22.22	7 42	3 91	15 02	2.16	2.00
Pear	1	22.22		9.21	10.02	2.10	2.00
Twin	1 59	18 .1.1	20 53	5.61	1.1.91	2 31	16
Peach:	1.00	10.11	20.00	0.01		- 01	.10
Fruit	26 60	72.52	127 36	trace	42 76	26.52	37 47
Twio	3 43	22.78	4 70		4 03	15.38	3 97
Leaf	9.29	1 27	53 53		8 41	4 07	2.87
Cherry	~ . ~ 1	1	00.00		0.11	1.01	2.01
Fruit	1 19	17 21	20.05				
Logf	1.14	1 07	1 65		9.98	15 69	69
Plum.	.00	1.57	1.00		~ 0	10.00	.00
Fruit	0.21	10.00	20.12		80.00	25.00	
Loof	1 53	6.71	1 80		00.00	a.9.00	
Licai	1.00	0.71	4.00]			

INTENSITY OF DISEASE ATTACK ON FRUIT TREES

years it is again observable that seasons not particularly favorable to the development of apple fruit-disease appear to favor the development of disease on drupes.

In 1926 there was an increase in apple fruit-disease intensity over 1925, but the smallness of this increase indicates a season generally unfavorable. It is notable that in this same year peach fruit-disease increased very remarkably in intensity, while plum fruit-disease attack reached the highest intensity recorded in our data. Accompanying the increase in apple fruit-disease intensity shown for 1927, there was a decided diminution in the intensity of disease attack on the fruits of both peach and plum; and in 1928, with the lessened intensity of apple fruit-disease, there again occurred an increase in the intensity of the fruit-attacking peach diseases.



FIG. 30. COMPARISON OF THE ANNUAL INTENSITY OF DISEASE ON EACH OF THE FIVE TREE FRUITS

The bars in the column at the left compare fruit intensity by years, those in the middle column twig intensity, and those in the column at the right leaf intensity. For further explanation, see the text.

DISEASES OF FRUIT TREES, 1922-1928

The causes of this oppositeness of reaction exhibited by the diseases of pomaceous and drupaceous fruits may be sought for in the weather which prevailed during those periods when the distinctly different diseases of the two types of fruits were developing.

Intensity of Twig Disease

Data on intensity of twig-disease are given in Table XXIII for each kind of tree for which they are available. These data are shown graphically by the middle column of bars in Figure 30. Data have been obtained for twig-disease of apples, pears, and peaches. The bars in Figure 30 are arranged in this order. The blank spaces marked "no data" indicate the absence of twig-disease data for the plum and cherry, except for 1925 when data were also lacking for peaches.

The fluctuations from year to year in intensity of disease attack on twigs are more generally in agreement for all kinds of truit trees than was the case with fruit-disease. In 1922, indexes for twig-disease intensity were relatively low for apples, pears, and peaches, but in 1923 they increased, that for apples very greatly and those for pears and peaches to a lesser extent. In 1924 the twig-disease intensity indexes for the apple and the peach fell, that for the peach nearly to the level of 1922, while the index for pears rose somewhat above its 1923 level. The vear 1925, conspicuous for its detrimental influence upon fruit and leaf infection, allowed the twig-disease intensity index for apples to reach a very high point, but at the same time the pear index dropped to about one-fourth its former value. Lacking data, the trend of the peach index cannot be determined. In the following years, 1926, 1927, and 1928, all indexes for the intensity of twig disease are low, and it may be assumed from this that 1925 eventually proved as detrimental to this form of disease as it was to other forms, though the effect was manifested later. The small increases and decreases of the twig-disease indexes manifested from year to year in this last period of our survey are followed consistently by the diseases of apple and peach, and no distinction can be made between the twig-disease trends of drupaceous and pomaceous trees. They appear to react uniformly to weather conditions.

Intensity of Leaf Disease

The totaled indexes of leaf-disease intensity are given in Table XXIII and are shown graphically by the third column of bars in Figure 30. Data are available for leaf-disease on apples. peaches, cherries, and plums, and the bars in Figure 30 which represent these data for each year are arranged in the order in which the fruits have just been named. Intensity of leaf-disease attack was low for all fruits in 1922. There is, however, no observable subsequent general tendency toward increase. In 1923, apple leaf-disease increased in intensity, peach leaf-disease decreased, and leaf-disease on both cherry and plum increased. In 1924, a marked falling off in the intensity of apple leaf-disease by two-thirds of its former amount was accompanied by an even more remarkable increase in peach leaf-disease intensity, while the corresponding index for cherries increased and that for plums decreased.

The year 1925 was very severe in its effect on leaf-disease, reducing the index for apple to a low point but being apparently more favorable to apply diseases than to peach diseases, as the latter was too slight to measure. With 1926, the leaf-disease intensity indexes rose again, those for the peach and the cherry increasing to moderate points and that for the apple rising above its 1922 level. In 1927, the rearrangement of these indexes placed that for cherry highest, with the peach index intermediate and that for apple lowest. There were no data upon which to base an index for plum leaf-disease. In 1928, the apple index rose slightly above its previous level, the peach index was diminished to about three-fourths of its former value, and the cherry index fell to the lowest recorded point.

In the fluctuations of the yearly indexes of intensity for disease attack there is no complete agreement, but it is worthy of note that the tendency to move in opposite directions previously demonstrated by the indexes of fruit-disease intensity for the apple and peach is again well defined in the movements of the leaf-disease indexes of these trees. From 1922 to 1923 the change in the leaf-disease intensity index for apple was upward, the change in the peach index downward; from 1923 to 1924 the apple index moved downward, the peach index upward; the indexes of both trees suffered great reductions in the disastrous season of 1925 (though the apple index was affected less than the peach index); the very considerable increase in the apple index in 1926 was accompanied by similar increase in the peach index; in 1927 a great decrease in the apple index was accompanied by a decrease only half as great in the peach index; and in 1928 the slight increase in the apple index was again contrary to the decrease in the peach index.

There is not. in this case, the completeness of opposing trends that was exhibited by the intensity indexes for fruit-disease, and the movements of the leaf-disease indexes for the cherry and plum do not uphold a consistent difference in trends between leaf-disease on drupaceous and on pomaceous trees; but it does appear that seasons favoring intense leaf-disease attack on apple trees are adverse to the development of leafdisease on peaches.

AVERAGE PREVALENCE AND AVERAGE INTENSITY OF FRUIT-TREE DISEASES

In summarizing our data on the prevalence and intensity of attack exhibited by the individual diseases of each kind of fruit-tree, we have computed for each disease a set of indexes to show its average annual prevalence and intensity through the period of our survey, and from these averaged indexes we have also computed indexes which express numerically the average annual incidence of disease per tree and the average annual intensity of disease attack on fruit, twig, and leaf for each kind of fruit tree. These final indexes are all brought together in Table XXIV, and the values there shown are given graphical expression in Figure 31.

As would naturally be expected from the fact that it is subject to attack by the largest number of epidemic diseases, the apple has the highest average disease incidence per tree. The peach ranks second in

this respect. the plum third, the cherry fourth, and the pear, with its one important disease, fifth. But it is interesting to find that in susceptibility to disease attack the apple also ranks first, and this is true in spite of the larger number of apple diseases. On an average, an apple disease succeeds in attacking 68 or 69 out of every 100 trees, while a peach disease succeeds in attacking only 55 trees in a hundred. The average susceptibility of the plum and cherry to disease attack appears rather high when the figures given in Table XXIV are interpreted strictly, being respectively 67 and 77 trees per 100; but since the leaf spot disease. as recognized in the accumulation of data. is in each case really a composite of two diseases, their apparent susceptibility is reduced thereby to about 44 and 48 trees per 100, respectively, or less than the susceptibility of the peach. From the graphical presentation of data in Figure 31, it may be seen that the differences between kinds of fruit-trees that have been shown to exist with relation to disease prevalence are neither constant nor parallel with relation to the intensity of



FIG. 31. COMPARISON OF THE AVERAGE ANNUAL PREVALENCE AND INTENSITY OF DISEASE ON FRUIT TREES IN ILLINOIS

The data given in Table XXIV are presented graphically for ready comparison. Incidence of disease shows the average number of diseases attacking each kind of fruit tree, and the total intensity of the attack of these diseases is shown for fruit, leaf, and twig. See text for discussion.

TABLE XXIV

AVERAGE	ANNUAL	PREVALENCE	E AND	INTE INTE	INSITY	\mathbf{OF}	FRUIT-TREE	DISEASES	IN
ILLI	INOIS, AS I	DETERMINED	From	Data	COVERI	NG	THE PERIOD	1922 - 1928	

Find of tree	Number of diseases included	Incidence	Intensity of disease attack				
Kind of tree		per tree	On fruit	On twigs	On leaves		
Apple Pear. Peach. Cherry. Plum.		$3.43 \\ .50 \\ 2.21 \\ 1.34 \\ 1.55$	35.01 47.03 15.79 38.53	29.18 8.98 9.05	$9.38 \\ 10.34 \\ 4.30 \\ 4.35$		

disease attack on fruit, twig, and leaf. The second column of bars in Figure 31 compares the average intensity of fruit-disease on our fruit trees. Though attacked by fewer diseases, as a rule, than the apple, the average peach tree suffers more from fruit-disease, while the plum, with nearly the same incidence of disease as the cherry, suffers over twice as much fruit infection.

The average annual intensity of twig attack, which is compared in the third column of bars in Figure 31 for the apple, pear, and peach, is greatest on the apple, least on the pear, and intermediate on the peach. This order corresponds exactly to the order of disease prevalence.

The average intensity of leaf-disease, shown for all our fruit trees except the pear by the fourth set of bars in Figure 31, is again greatest on the peach, though on the apple it is not much less. On cherry and plum it is about equal, but is, on each, less than half as severe as on peach or apple. The average intensity of leaf-disease runs parallel, in respect to the kind of fruit trees, with the average intensity of fruitdisease on peach and apple, but parallel with the average incidence of disease on plum and cherry trees.

RECAPITULATION

In Illinois, as elsewhere, the productiveness of orchards is curtailed by the injury to trees and their fruit that results from the attack of destructive diseases. Each kind of fruit tree is subject to a particular group of diseases, of which some are serious and some mild. Certain diseases, after obtaining a foot-hold, work continuously to accomplish the death of the trees they attack. Others leave their host-trees during some part of every year and, returning annually at some particular time to renew their attack on special parts of their hosts, exhibit striking variations both in prevalence and in destructiveness, from one year to another. In this respect they are similar to the recurring diseases of mankind and equally deserve to be called epidemic.

Research and investigation have revealed the causes of these diseases, the life histories of the parasites, and the poisons most effective against them. Sprays are, however, seldom completely effective. Often they fail.

To increase the efficiency of disease control, an understanding of the effects of weather variations upon epidemics is necessary. This may be gained by studying simultaneously, and in detail, both the weather and the epidemics. The former has for many years been accurately measured and recorded, but epidemics have not been subjected to a similar scrutiny.

From 1921 through 1928, a survey was made in Illinois of the epidemic diseases of fruit-trees. During these years, methods of measuring the epidemics had to be devised, tested, and perfected; in every year the epidemics were measured with the means at hand, and the measurements were recorded according to definite plans. The full results of this survey are now reported in the text of this paper.

An epidemic is considered to have two primary aspects. These are, first, the prevalence of the disease and, second, the intensity of its attack.

The former we have measured and recorded simply as the percentage of trees succumbing to infection; but the latter, being more complex, has had to be considered from three points of view.

Diseases of an epidemic nature usually produce lesions on fruit, on new and immaturely lignified twigs, and on leaves. The attack may be on any one, on any two, or on all three of these tree parts, according to the disease. To measure fully the intensity of an epidemic, each phase of its attack must be taken into account and the measurements must be maintained as a separate indicator of the success of the epidemic.

Prevalence and intensity of attack have been measured for 5 apple diseases, 1 pear disease, 4 peach diseases, 2 plum diseases, and 2 cherry diseases. The data so accumulated have been evaluated and reduced to averages, which we have called indexes.

Each epidemic disease has an index of prevalence for each year of the period of our survey, unless data were not obtainable, and, according to the mode of attack characteristic of the particular disease, its annual intensity is represented by one or more indexes. The blotch disease of apple, for example, is given the following indexes for 1922: prevalence, 53.03; intensity of fruit attack, 41.36; intensity of twig attack, 10.49; intensity of leaf attack, 2.56. These indexes, the exact significance of which is fully explained in the section entitled Analysis of Data, present a complete evaluation of apple blotch, in all its epidemic aspects, for the summer of 1922. Corresponding sets of indexes for 1923 and each succeeding year state with exactness the increases and decreases of the disease in prevalence and intensity through the period covered by the survey. Sets of indexes for the other epidemic diseases of the apple and for the diseases of other fruit trees make it possible to compare the fluctuations of all the apple diseases with one another from year to year and to compare at will the variations of any disease of any kind of fruit tree with any disease of any other kind of tree. Many such comparisons have been made in the text, both directly from the tabulated indexes or by means of diagrams based on the indexes.

It seldom happens that all the diseases of one kind of fruit tree follow, in one year, the same course of increase or decrease from the previous year. Two diseases may increase in nearly the same proportion from one year to the next, but in the third year their trends are apt to become opposed, one disease continuing to increase, the other manifesting a great diminution in prevalence and in one or more of its phases of intensity.

The changes exhibited from year to year by fruit-tree diseases appear to be governed by no general law. Fluctuations of individual diseases are often so great, and occur in such diverse directions and amounts, as to suggest only capriciousness. The interdependence that might be expected between prevalence and intensity of attack does not occur consistently. High prevalence and mild intensity are often combined, as are also moderate prevalence and high intensity. Of the three phases of disease intensity, one may be high in a given year and the others low, and the changes that occur in succeeding years follow no apparent rule. Evidently, each phase of each disease fluctuates from year to year with considerable independence from the other phases.

ILLINOIS NATURAL HISTORY SURVEY BULLETIN

To these general statements, there is one exception. The year 1925 proved disastrous to all diseases. Whatever the conditions of that year may have been, whatever their differences from previous and succeeding years, they were beyond doubt so unfavorable that, excepting only apple blotch in its twig phase, no fruit-tree disease was able to achieve significant proportions, either in prevalence or intensity. So fatal was this year to the organisms that cause fruit-tree diseases, that in the three subsequent years included in the survey few diseases have been able to attain their former levels of prevalence and intensity.

The fruit trees of Illinois are of two classes. Apples and pears, with their several-seeded cores, are called pomaceous; while peaches, plums, and cherries, with their hard-pitted fruits, are drupaceous. This botanical separation of the two groups is accompanied by an equally distinct difference in diseases. And more remarkable still, our comparisons show that the fluctuations of disease on pomaceous and on drupaceous trees are nearly always in opposite directions. A year that favors apple and pear disease is detrimental to disease on the drupaceous trees; and, conversely, a year favorable to disease on peaches, plums, and cherries inhibits the development of disease on apples and pears.

In the production of such a diversity of disease phenomena, many elements are combined. As direct causes of disease, there are fungi and bacteria. These have various means for reproducing themselves and various abilities for infecting their hosts through chance openings, by exerting mechanical force, or by accomplishing the chemical dissolution of protective membranes. Success in reproduction, in accomplishment of infection, and in the subsequent growth and extension of these parasites is conditioned and governed by many external factors, among them being light, heat, and moisture. In different amounts or combinations, these factors impede or expedite the production of disease, determine times of infection, and influence reproductive processes. Since the ability of the parasites to maintain themselves vicariously in adverse conditions and to flourish under favorable conditions results in the variations in epidemics, the prevalence and intensity a disease attains is a definite indication of the favorableness of the conditions under which it developed.

Epidemics have now been analyzed and measured, and their characteristics have been stated in terms sufficiently concrete to enable the making of exact comparisons for similar and dissimilar environmental conditions. Of the environment, temperature and precipitation are measured regularly in Illinois and a large mass of data is available. The next step is to determine what combinations of these elements, as indicated by the characteristics of accompanying epidemics, favor or inhibit the development of fruit-tree diseases.

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Errata

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ERRATA

Page 6, footnote, for 31 read 18, and omit 31.

Page 112, first line, for *The* read *This*; tenth line from bottom, for *The Red Oak* read *Q. borealis*.