

STATE OF ILLINOIS
DEPARTMENT OF REGISTRATION AND EDUCATION
NATURAL HISTORY SURVEY DIVISION
STEPHEN A. FORBES, *Chief*

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THE NATURAL HISTORY SURVEY DIVISION
STEPHEN A. FORBES, *Chief*

H. C. OESTERLING, *Editor*



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ERRATA

- Page 117, third line in table, for *Sofo* read *Soft*.
- Page 118, transpose *Heavy soils* and *Light soils* in columns 3 and 4 of Table VIII.
- Page 170, third line above figure, for *83* read *169*.
- Page 200, fourteenth line, for *sand* read *stand*.
- Pages 208, 211, 214, 219, in headings, for *Bacellariaceae* read *Baeillariaceae*.
- Page 209, middle of table, for *oligactus* read *oligactis*. Same correction on page 213, first line of table, and on page 225, second line from bottom.
- Page 211, fifth line in table, for *Aphanothera* read *Aphanothece*. Same correction on page 218, sixth paragraph.
- Page 215, fourth line in table, for *acuminata Ehr.* read *acuminatum (Kutz.) Cl.* Same correction for *acuminata* on page 220, fifth paragraph.
- Page 224, fourth line from bottom, for *Pandorin* read *Pandorina*. Omit last line and read *Traverse Bay region*.
- Page 228, fifth line from bottom, for *Antario* read *Ontario*.
- Page 267, for *top row* read *bottom row*, and *vice versa*.
- Page 327, second line, for *Eutettic* read *Eutettix*.
- Page 348, third line in second paragraph, for *roscsus* read *roseus*.

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STEPHEN A. FORBES, *Chief*

Vol. XVII.

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Article I.

Epidemic Diseases of Grain Crops in Illinois, 1922-1926

**The Measurement of Their Prevalence and Destructiveness
and**

**An Interpretation of Weather Relations
Based on Wheat Leaf Rust Data**

BY

L. R. TEHON



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EPIDEMIC DISEASES OF GRAIN CROPS IN ILLINOIS, 1922-1926

The Measurement of Their Prevalence and Destructiveness
and
An Interpretation of Weather Relations
Based on Wheat Leaf Rust Data

L. R. TEHON

As the first of the necessary steps in a study of the epidemiology of crop diseases, the Natural History Survey published a report in 1924 on the occurrence and distribution of the common diseases of crop plants in Illinois*, which was based chiefly on specimens and notes secured during the three years 1921, 1922, and 1923, but which also contained brief histories of each disease.

The second step consists of the accumulation of data which will show the differences in abundance and severity of disease from year to year, from season to season, in diverse regions, and even in diverse localities. In order to fulfill these requirements, the data must be both precise and as accurate as circumstances governing the work will permit. Comparative words, such as "mild", "light", "moderate", "heavy", and "severe", which have been used commonly, are not sufficiently precise when applied to diseases, for their meanings are as varied as the experiences of the persons who hear or speak them. The most satisfactory statement, and the one most likely to be understood by everyone, is therefore the one which presents the facts of disease attack in numerical terms. This implies not only that it is possible to measure the attack but also that the measuring can be done by means of quantitative units quite as definite in their particular application as are the feet, pounds, and gallons of commerce.

Since the beginning of the survey in 1921, methods have been adapted and devised by which disease abundance can be measured with a considerable degree of accuracy, and large quantities of data have been secured each year for many diseases.

In both the accumulation and the analysis of data, problems have arisen which have made it necessary to adopt standard arithmetical methods, the use of which is quite as important in plant disease surveying as

* A preliminary report on the occurrence and distribution of the common bacterial and fungous diseases of crop plants in Illinois. By L. R. Tehon. Bull. Ill. State Nat. Hist. Surv. Vol. XV, pp. 173-325. 1924.

are the calculations made by the civil engineer with the data he secures by transit and chain.

The detailed account given in these pages of the means used to measure diseases, of the methods by which the data are analysed, and of the results obtained, is confined to the diseases of cereals. It is presented, not merely because it follows so directly the task accomplished by the first report, nor yet because it represents the first intimate and extensive study of crop diseases growing naturally in Illinois fields, but especially because it will enable the grower of crops to understand, better than he ever has, the destructive effect of diseases which he all too often ignores.

GENERAL METHODS USED IN THE SURVEY

The survey of crop diseases was begun in midsummer of 1921. The first task, that of determining the kinds and the distribution of diseases attacking crop plants in Illinois, was undertaken at once. At the same time, a start was made toward securing quantitative records of the amounts of each disease, for it was clearly seen that a means of arriving at definite comparisons could be found only in measurements of disease abundance.

One of the first difficulties encountered was that of handling diseases difficult to identify in the field because of the lack of distinctive symptoms. This problem, after six years of work, has not been solved entirely, for the certain identification of some diseases requires equipment and a personnel for routine work that is beyond our resources. However, for diseases more or less readily identifiable by the eye, the hand lens, or the compound microscope, a system was developed by the beginning of the growing season of 1923, which, though requiring variation in its application to different types of disease, has the following general plan.

Whenever the identification of a disease can not be made with absolute certainty in the field, a typical, representative, and copious sample of it is taken at the time the field is examined. The specimen is given a temporary "collector's" number, which is placed on a small paper label along with other identifying and suggestive information, such as the name

SPECIMEN LABEL

Collector's No. T 76

Host *Wheat—Kanred mixed.*

Disease *Node cankers.*

Cause *Examine for pycnidia of Septoria nodorum.*

Town *Fisher*

County *Champaign*

Date Collected *July 29, 1926.*

of the crop, a brief note of the type of injury, and the place and date of collection. The specimen, with its label, is then packed in a small pressing and drying device carried by the observer. As often as convenient, the collected samples are sent to the laboratory where, when the process of drying is completed, they are arranged in sequence in the order of their numbers and stored away to await further examination.

As a matter of convenience, and to assure the inclusion of sufficient information with each specimen, the labels have been printed and arranged in pads. The label with typical notes, shown at the bottom of the preceding page, furnishes an example of its use.

For recording the amount of disease in a field, standard blanks measuring 8 by 11 inches are used. They also are printed and arranged in pads convenient to carry. The reproduction on the following page shows the type of blank that has been developed and the use that was made of it in recording the leaf rust infection in one wheat field.

A complete statistical summary of the information carried on these blanks would show the number of fields in which a disease was found, the number of acres comprised by them, the particular varieties of the crop on which a disease was mild or serious, whether or not preventive treatments were used consistently, the average percentage of diseased plants, and the average amount of disease per plant. There would also be data bearing on the ability of disease to reduce yield, on differences in the dates of first appearance from season to season and in various localities, on common sources of infection, local histories, and kinds and numbers of diseases encountered in a field, as well as special notes on local weather relations.

Finally, the number given by the observer to the sample he collected is noted in the lower right hand corner of the blank. It connects the record blank to the disease sample preserved in the laboratory.

The filled-in record blanks are sent, at suitable intervals, to the laboratory, where they are sorted according to crops and diseases. They are kept in a permanent file, the records for the various diseases being allotted individual folders which are arranged in the alphabetic order, first of the crop and then of the disease names. Separate folders are maintained, as a rule, for each year's records of a disease.

In securing the information required for the field record, it has been found that the greatest care must be exercised, both in the identifying and estimating of amounts of disease. The observer must not be over-confident of his ability to distinguish diseases in the field but must be constantly watchful to provide adequate evidence, by means of representative samples, of the accuracy of his judgments and the reliability of his estimates.

In estimating disease abundance, different procedures are necessary for different types of disease. An estimate of the amount of loose smut in a wheat field may be secured by determining the number of smutty heads among a representative number in the field, but an estimation of rust

1926

PLANT DISEASE RECORD BLANK

Crop *Wheat* Disease *Leaf rust (Puccinia triticina)*County *Adams* Locality *Camp Point*Variety of crop *Kanred (somewhat impure)* Size of field *20 acres*State of development *Heads just now emerging from the boot.*Control measures (Applied
(not applied X) Kind used

When used

How applied

Infection: % of culms diseased *25.8* Amount per plant *20.8 per cent*Data: *362 in 800**580 in 3000**348 in 1200**1290 in 5000*

Scale classes:

	0	5	10	25	40	65	100
F.	3	19	37	26	14	7	1

C. X F.	0	95	370	650	560	455	100
---------	---	----	-----	-----	-----	-----	-----

S. C. F. *2230* $\frac{2230}{107} = 20.8 \text{ per cent}$ S. F. *107*

Type of injury

Estimated damage $20.8\% \times 25.8\% = 5.36\%$

Date first observed

Source of infection

Past history

Association with other diseases *Stem rust, loose smut, bunt, scab, speckled leaf spot, Septoria nodorum on culm nodes.*

Additional notes (weather, phenology, etc.)

Date of observation *June 19*Specimen No. *T 421*Observer *L. R. Tchon.*

infection requires not only an examination of numerous plants to prove the presence of the disease but also a close examination of the diseased parts of the plants to determine the average amount of rust on those parts.

To obtain reliable data from any field, the number of plants examined must be large enough to give an average which will be representative of the entire field. There must be standards, also, for measuring the diseased area of leaf and stem, which can be carried and used with ease in the field. One of these standards is already widely used; it, and the others which we have devised, will be described in connection with the diseases with which they are used.

ANALYSIS OF DATA

In order that the observations made in fields by the methods outlined briefly above may be of use, they must be subjected to an analysis which will reduce them to brief and concise statements.

The first step is to make certain that the diagnosis made of the disease in the field is correct. In most instances, a microscopic examination of the sample indicated by the collector's number is sufficient. The sample is labeled with its proper scientific name; this name is noted at the top of the field record; and the serial "accession" number given to the specimen replaces the collector's number on the record blank. The sample is filed according to a system (the details of which are immaterial here) and serves as permanent and substantial evidence particularly of the accuracy of the diagnosis but also to some extent of the severity of the attack. Reference can be made between record sheet and specimen at any future time, and the two together constitute the entire record.

In many cases, two items enter into a calculation of the amount of disease present in a field. One is the proportion of diseased plants, and the other is the amount of disease present on each diseased plant. The latter is expressed as the area of leaf or stem destroyed by disease, or as the proportion of the head injured or destroyed.

With cereals, data are secured for the entire area of a field by making counts of a representative number of stems. In taking data on the leaf rust of wheat, for example, a hundred stems may be counted in one place, two hundred in another, and other quantities in other places, until a large number—10,000 if necessary—have been examined. The same proportion of diseased stalks is not found, as a rule, in each group, and an average must be secured for all the counts. This is done in either of the following ways:

1. If 5000 stalks are examined, the counting may show that

362	stalks among	800	bore disease
580	" "	3000	" "
348	" "	1200	" "
<hr/>		<hr/>	
1290	" "	5000	" "

The totals show that 1,290 of the 5000 stalks were diseased. The proportion of diseased stalks, expressed finally as a percentage derived from the totals, is in this case 25.8.

2. If, in the same instance, the group counts had been recorded directly as percentages, the following data would appear on the record blank.

45.2	per cent among	800 stalks bore disease
19.3	" " " "	3000 " " "
29.0	" " " "	1200 " " "

It is not permissible to add and average these percentages. Such a procedure gives for the above figures 31.2 per cent, which, as can be seen from the percentage obtained by the first method, is entirely erroneous. The error arises from the fact that in this average the high percentages found among the smaller numbers of stalks are each given equal weight with the low percentages found in a much larger number of stalks. To avoid this error, these differences must be equalized by giving the percentage of each group a proper weight with respect to the other groups. This may be done by proportion. In the example just cited, in which the total count is 5000, the first count of 800 stems is four twenty-fifths of the total, the second fifteen twenty-fifths, and the third six twenty-fifths; hence the first count, representing $\frac{4}{25}$ of a total of 25 parts, has a relative value, or weight, of 4, while the second and third counts have similar values or weights of 15 and 6, respectively. It is necessary now to multiply the percentage secured in each group count by the weight of its group, add the multiple percentages thus obtained, and compute the average percentage by dividing the total multiple percentage by the total of the weights. The process is as follows:

Group percentage		Group weight		Multiple percentage
45.2	×	4	=	180.8
19.3	×	15	=	289.5
29.0	×	6	=	174.0
		—		—
		25		644.3
$644.3\% \div 25 = 25.77\%$				

The average percentage of 25.77 secured in this way is found to be very nearly correct when compared with the 25.8 per cent obtained by the first method.

When the numbers involved are small or so constituted as to be handled easily, this "weighting" may be done more conveniently by carrying the calculations through without first reducing the items to their least common denominator. In the example just given it is immaterial whether the first group is regarded as $\frac{4}{25}$ or $\frac{800}{5000}$ of the entire count. Hence the calculation can be performed as follows:

Group percentage		Group weight		Multiple percentage
45.2	×	800	=	36,160
19.3	×	3000	=	57,900
29.0	×	1200	=	34,800
		<hr/>		<hr/>
		5000		128,860
<hr/>				
$128,860\% \div 5000 = 25.77\%$				

Dividing the sum of the multiple percentages by the total weight of the counts, an average of 25.77 is obtained, which is identical with that secured when the group weights were reduced to their least common denominator. This short-cut is used in the tabulated calculations of the disease data appearing in the tables which exemplify other parts of the analysis.

The method of calculating "weighted" averages, though mathematically a very elementary process, is emphasized and explained in detail at this point because it is of vital importance not only in the treatment of data from a single field but also in the proper evaluation of the data from many fields of varying sizes and locations. It is employed as a basic principle in all the statistical summaries of data reported in this paper.

The foregoing example illustrated only the means of arriving at the proportion of plants bearing disease, but in most cases this alone is not a sufficiently complete statement of the amount of disease. With diseases such as the rusts, a large part of the plant is capable of becoming infected and destroyed; but usually the infection does not reach its maximum; and the result is that it is necessary to measure the extent of the infection on the diseased plants. By comparing a number of representative diseased parts with prearranged standards which indicate accurately the surface area, or some similar characteristic, occupied or destroyed by the disease, an exact statement of the extent of infection can be obtained for a sample; and the average of an adequate sample may be considered as representing the average amount of disease on each diseased plant.

Because they apply only to the diseased plants in the field, the data thus far secured are not yet satisfactory. An average is needed which is applicable to every plant in the entire field, and which may be compared with averages from other fields. The method used to obtain such an average can be explained best by continuing the example that has been in use.

In it, leaf rust was shown to occur on 25.8 per cent of the wheat stems in a field. A number of leaves selected at random from these stems show, when compared with the rust-measuring standard, an average of **20.8** per cent of their surface area occupied by rust. Since these leaves were taken only from rust-infected plants, this figure represents only

the average amount of disease on each diseased plant. In order to transform it so that it will be applicable to the entire field, the following theoretical calculation is used as a basis.

Let the various items of the calculation be indicated by symbols, as follows:

D = the average amount of disease per diseased plant.

P = the number of diseased plants.

T = the total amount of disease on all the diseased plants.

N = the total number of plants in the field, whether diseased or not.

Then, the average amount of disease per plant in the field may be found by evaluating $\frac{T}{N}$.

However, as it is apparent from the above that $T = D \times P$, by substituting, the average amount of disease per plant is equivalent to $\frac{D \times P}{N}$.

Since percentages can be used as well as integral numbers, the percentages of the example can be substituted for the symbols of the formula, giving $\frac{20.8 \times 25.8}{100}$, the value of which, 5.3664 per cent, represents the average amount of disease for every plant in the field in question.

As it is customary to record data secured in routine field examinations as percentages, a convenient short-cut may be taken, in which the percentages are treated as decimals—.208 x .258 in our example. Percentages being expressions of parts per hundred, the use of the decimal point automatically eliminates the denominator of the fraction given in the preceding paragraph, and the result—.053664—appears at once as the product of the two decimals. This product may be expressed as a percentage by moving the decimal two places to the right.

By the methods now outlined, the following data have been secured from the field represented by the record blank shown on page 4.

1. 20 acres of wheat.
2. 25.8 per cent of the stems bearing disease.
3. 20.8 per cent of the leaf area on these culms destroyed by disease.
4. 5.36 per cent of the leaf area infected, on an average, for every stem in the field.

These items are recorded for every field examined, as many fields of each crop being visited each season as circumstances will permit. In bringing together the data for each disease, the field record sheets, assorted by diseases, are arranged in their folders first by counties (the counties, for convenience, following one another in the alphabetic sequence of their names), and then in the order of dates of examination. Finally, they are given numbers which are placed at the upper right-hand corner and serve the same purpose as the numbering of the pages of a book.

The data presented by the sheets in each folder are then arranged in a table, in the manner illustrated by the following short tabulation.

TABLE I

AN EXAMPLE OF THE FIRST TABULATION AND CALCULATION MADE WITH THE DATA PRESENTED BY THE FIELD RECORD SHEETS

The data used relate to wheat leaf rust

Record sheet No.	County	Acres examined	Prevalence: Stems with diseased leaves			Destructiveness: Leaf-area diseased		
			Percentage observed	Acreage-percentage product	Weighted percentage	Percentage observed	Acreage-percentage product	Weighted percentage
1	Adams	20	25.8	516		20.8	10,732	(5.3)
2	Adams	12	100.0	1,200		40.0	48,000	(40.0)
3	Adams	20	90.0	1,800		65.0	117,000	(58.5)
	Total	52		3,516	67.6		175,732	33.7
37	Tazewell	40	100.0	4,000		55.0	220,000	(55.0)
38	Tazewell	20	90.0	1,800		60.0	108,000	(54.0)
39	Tazewell	20	90.0	1,800		30.0	54,000	(27.0)
40	Tazewell	20	60.0	1,200		20.0	24,000	(12.0)
	Total	100		8,800	88.0		406,000	40.6
42	Will	1	100.0	100		7.0	700	(7.0)
43	Will	40	90.0	3,600		15.0	54,000	(13.5)
	Total	41		3,700	90.2		54,700	13.3
	Total	193		16,016	82.9		636,432	32.9

The first column contains the page numbers of the record sheets, which serve as a means of referring the figures in the table to the sheets from which they are taken. In the second column appear the names of the counties in which the observations were made, and in the third column are the acreages of the fields examined.

The fourth, fifth, and sixth columns are concerned with data bearing on the proportion of disease-bearing plants. In column 4 appear the observed percentages shown by the record blanks; and, in order that the necessary calculations may be made, column 5 contains the products secured by multiplying the acreage of each field by the percentage of diseased plants found in it. For want of a better term, this quantity is called the "acreage-percentage product." Since the individual percentages entered in column 4 usually apply to fields of different sizes, computing this product gives a proper acreage weight to each observation. The process of weighting in terms of acreage is exactly similar to that explained already (see pp. 6 and 7), the construction of the table permitting, however, the use of the short-cut described therewith.

The sixth column contains the percentages indicated by the weighting process as the proper averages for the county groups of data on prevalence and, finally, the weighted average for all these data.

The last three columns show the amount of disease per plant. The percentages of disease observed in the individual fields are entered in column 7 directly from the record blanks. The process of "weighting" to secure the true average percentage for all the observations requires that the product of the items of columns 3, 4, and 7 shall be obtained in each instance. When secured, it is listed in column 8. From it, a percentage, listed in column 9, is obtained for each observation by dividing by the acreage. In the table above, this final figure for each field is shown in parentheses because it is not used in computing the final results. In practice, it is neither computed nor written into the table. The weighting accomplished in column 8 permits direct computation of average percentages of diseased leaf-area for each county and for all the data. These important items appear in bold-face type, in the last column, and in practice they are the only figures entered there.

This table, which is made up entirely from the data secured in the field, is designed to show:

1. Prevalence of disease, by counties, in terms of diseased stems.
2. Severity of disease attack, by counties, in terms of plant parts occupied, or killed, by the disease-producing organism.
3. Prevalence and severity for the total acreage examined.

To distinguish between prevalence and severity is not only logical but necessary. It is comparable to the distinction made between the prevalence and the mortality-rate of human diseases. The prevalence of diphtheria, for example, is expressed as the proportion of the population contracting the disease, but the mortality—the deaths—due to it, being much less than the former, is a separate consideration. The proportion of plants becoming infected is, quite comparably, a measure of the prevalence of plant disease, and the amount of plant tissue occupied or killed is likewise a proper measure of what may be termed "plant mortality." Hence, the figures which conclude the above table may be interpreted as meaning that the disease to which they refer was 82.9 per cent prevalent and resulted in a "mortality"—destruction—of 32.9 per cent of leaf, in the acreage examined.

The term prevalence is quite appropriate; but the fact that few diseases bring about either immediate death or complete destruction of the plants they attack makes it desirable to replace "mortality" with a more suitable word. The attacks of cereal diseases are limited, in the main, to specific plant parts, either actually, as are leaf spots and rusts, or in their outstanding effects, as are smuts. The damage they do is correspondingly limited, consisting of a measurable destruction of particular parts. For this reason, "destructiveness", applied to the parts of an individual plant, is a better expression of the severity of attack.

The weighted prevalence and destructiveness percentages determined in the foregoing table and in two others described on subsequent pages, besides being precise analytical summaries of data, may be regarded also as arbitrary indexes. Complete prevalence or destructiveness would have an index of 100, while lesser degrees of prevalence or destructiveness would have indexes proportionately less—82.9 and 32.9 in the example.

Because the quantity of data pertaining to any disease that is secured in a season is limited by the amount of help available, the duration of the period of prevalence, and the opportunities for examining the crop it infects, that which is obtained is regarded as exemplifying the disease condition existing not only in the fields that were seen but also in the territory adjacent to them, and in the State as a whole. It is, therefore, necessary to transform the field data, by more extensive calculations, into terms representative of these larger areas.

Statistics relating to acreages and yields of crops in Illinois are furnished in the reports of the Agricultural Statistician*, in which the counties, used as statistical units, are grouped into the nine geographic districts shown in Figure 1. Acreages and yields are given not only for

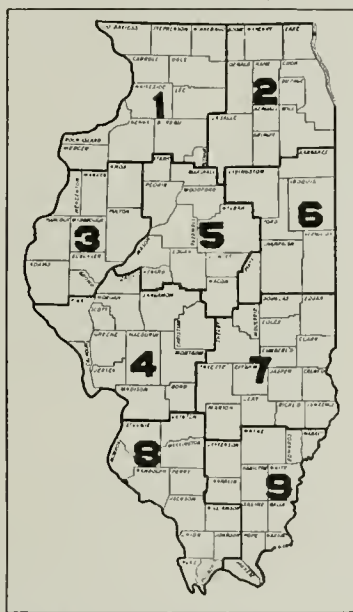


FIG. 1. THE DISTRICTS INTO WHICH ILLINOIS IS DIVIDED IN COMPILING AGRICULTURAL STATISTICS

The counties of Illinois are divided by the Agricultural Statistician into these 9 nearly-equal groups. The same grouping is utilized conveniently in the analyzing of plant disease data in connection with agricultural statistics.

the entire State but for the counties and districts as well. Because the observations on diseases of cereals are made on an acreage basis, the statistical units adopted for crops are conveniently utilized in the further analysis suggested above.

Adjacent territory is defined, for statistical convenience, as the acreage devoted to a particular crop in the county in which disease prev-

* Illinois crop and livestock statistics. Issued by the U. S. Dept. Agr., Bureau of Agricultural Economics cooperating with Illinois Dept. Agr.

alence and destructiveness have been measured in sample fields. The weighted percentages, expressive of prevalence and destructiveness, that were obtained for county groups of data in the foregoing table are held to represent the prevalence and destructiveness of disease in the entire acreage devoted to the diseased crop by those counties. Proceeding on these assumptions, the county acreages reported in the agricultural statistics and the disease indexes for the counties shown in the first table are combined in a second tabular computation, in the following manner.

TABLE II
AN EXAMPLE OF THE SECOND TABULATION AND CALCULATION
MADE WITH DISEASE DATA

The county acreages for a given crop, as estimated by the Agricultural Statistician, are combined with the county indexes of prevalence and destructiveness computed in the first tabulation, and indexes obtained from them for the total acreage directly represented by the sample fields. These data apply to the leaf rust of wheat.

County	Wheat acreage per county	Prevalence: Stems with diseased leaves		Destructiveness: Leaf- area diseased	
		Weighted percent- ages per county	Acreage- percentage product per county	Weighted percent- ages per county	Acreage- percentage product per county
<i>1</i>	<i>2</i>	<i>3</i>	<i>4</i>	<i>5</i>	<i>6</i>
Adams	61,400	90.0	5,526,000	40.4	2,480,560
Gallatin	29,600	100.0	2,960,000	15.0	444,000
Hamilton	24,500	22.8	558,600	7.7	188,650
McLean	42,300	93.7	3,963,510	39.8	1,683,540
White	59,300	97.4	5,775,820	38.6	2,288,980
Totals for the coun- ties listed	217,100	86.6	18,783,930	32.6	7,085,730

In column 1, all the counties are listed which appeared in the first tabulation. Their acreages of the crop concerned, taken from the Agricultural Statistician's reports, are listed in the second column. In columns 3 and 5 appear the weighted percentages of prevalence and destructiveness, respectively, which were computed for each county in the first table. As the acreage devoted to a given crop in one county is seldom the same as in another, it is necessary to give the percentages of each county weights which are proportionate to their acreages. Weighting is done here in the same manner as in the first tabulation, except that, since a true percentage of destructiveness is used in column 5, the acreage-percentage product in column 6 is obtained directly as the product of the items in columns 2 and 5.

When all the items needed for the tabulation have been set down or computed, the figures in columns 2, 4, and 6 are added, and the totals of columns 4 and 6 are each divided by the total of column 2. More

specifically, the sums of the acreage-percentage products for prevalence and destructiveness each are divided by the total acreage of the crop in the counties listed. The resulting quotients—86.6 and 32.6 in the example—are weighted percentages indicative of the prevalence and destructiveness, respectively, of the disease in question in the entire territory adjacent to the fields from which data were obtained by examination.

In order to compare prevalence and destructiveness of diseases year by year for the entire State or for smaller districts, it is necessary to go a step further and compute indexes which will apply to the State's total acreage of a given crop in each year, and to the acreages of the statistical districts (see page 11). Satisfactory indexes can be obtained for this purpose by extending the observed data, first to the county acreages, as was done in the foregoing table, and then to the total acreages of the agricultural districts and of the State. An example of the method is given in the following table.

TABLE III

AN EXAMPLE OF THE TABULATION AND CALCULATION USED TO OBTAIN INDEXES OF PREVALENCE AND DESTRUCTIVENESS FOR EACH OF THE NINE DISTRICTS AND FOR THE ENTIRE STATE

These data apply to the leaf rust of wheat. For the sake of brevity, it is assumed in this example that the State is composed of the three districts listed.

Counties grouped by districts	Wheat acreage per county	Acreage-percentage products by counties		Weighted percentages by districts		Wheat acreage per district	Acreage-percentage products by districts	
		Prevalence	Destructiveness	Prevalence	Destructiveness		Prevalence	Destructiveness
<i>1</i> Dist. 2	<i>2</i>	<i>3</i>	<i>4</i>	<i>5</i>	<i>6</i>	<i>7</i>	<i>8</i>	<i>9</i>
Cook	3,200	10,560	512					
La Salle	41,300	4,130,000	826,000					
Total	44,500	4,140,560	826,512	93.0	18.5	146,000	13,578,000	2,701,000
<i>1</i> Dist. 3								
Adams	61,400	5,526,000	2,480,560					
Hancock	57,300	5,512,260	1,358,010					
McDonough	44,000	4,400,000	880,000					
Total	162,700	15,438,260	4,718,570	94.8	29.0	343,000	32,516,400	9,947,000
<i>1</i> Dist. 7								
Coles	22,100	360,230	50,830					
Douglas	21,600	1,944,000	388,800					
Payette	44,100	4,410,000	954,920					
Marion	14,600	1,460,000	511,000					
Shelby	40,800	3,170,160	428,400					
Total	143,200	11,344,390	2,313,950	79.2	16.1	303,000	23,997,600	4,878,300
State total	.....	.....	.....	88.5	22.1	792,000	70,092,000	17,526,300

With the exception of the district acreages shown in column 7, which must be secured from the reports on agricultural statistics, this table is made up entirely from Table II.

First, the counties appearing in the two previous tables are arranged in proper district groups in accordance with the districting in the statistical reports (see page 11). They then are listed in column 1. In columns 2, 3, and 4, the acreage of the crop per county and the acreage-percentage products relating both to prevalence and destructiveness are entered, the figures being transferred directly from Table II. Totals are taken of the items in these columns for each district, and the weighted district percentages shown in columns 5 and 6 are obtained by dividing the two sums of the acreage-percentage products by the total county acreage. The resulting quotients represent prevalence and destructiveness by districts.

In column 7 are the acreages reported by the Agricultural Statistician to be devoted to the crop in question in each of the districts. The acreage-percentage products in columns 8 and 9 are based on these district acreages. They are obtained by multiplying the district acreages by the corresponding weighted percentages entered in columns 5 and 6.

When all of these items are entered, totals are taken for columns 7, 8, and 9. The totals of columns 8 and 9 are divided by the total of column 7, which is the State acreage of the diseased crop. The quotients thus obtained are placed, for convenience, at the foot of columns 5 and 6. These final weighted percentages—88.5 and 22.1 in the example—are concise expressions of the average prevalence and average destructiveness of a disease throughout the State.

It probably has been noticed that in the sample tables no calculations have been carried farther than one decimal place. Because most of the computations involve percentages, which are arithmetically really decimals extended to the second place, the usual mathematical procedure would be to stop the calculations with the first decimal and then either increase the unit place by one or discard the decimal, as it was either greater than 0.5 or less than 0.6. However, as round numbers occur very often in the acreage statistics, it is possible to retain the decimal without adding greatly to the labor. The result is that the final percentages, though not greatly influenced, are a trifle more accurate than they otherwise would be.

In practice, computations similar in all respects to those just described are made whenever possible for every disease for which field data are secured, and each year's folder of field records for each disease contains these statistical analyses, comprised of the three complete tables, as a part of the permanent record.

DATA ON THE YEAR-TO-YEAR PREVALENCE AND DESTRUCTIVENESS OF CEREAL DISEASES

In order to obtain useful data on disease prevalence, fields must be examined in as many parts of the State as possible. Traveling by automobile, observers go from county to county, visiting fields along the way. This amounts in practice to a random sampling of disease conditions in crops throughout the State, the quantity of samples taken of each disease on each crop depending on the intensity of cultivation accorded it, the number of observers at work, and the length of time elapsing between the appearance of a disease and the arrival of harvest.

The procuring of the data presented in this paper has been influenced also by the fact that the observers at the same time were gathering similar information on diseases of the tree and bush fruits and forage and truck crops. Through the summer of 1922, four men acted as observers; in the summers of 1923, 1924, and 1926, two men; and for the greater part of the summer of 1925, only one man. This, together with the large size of the State, the number of crops to be examined, and the number of diseases—more than 200 of which are serious—to be seen, contributed to what may appear an unnecessarily haphazard grouping of the grain fields subjected to examination. But the wide prevalence of diseases and the comparative uniformity of their destructiveness in regions having the same latitude compensate in a large measure for these apparent but unavoidable faults.

Cereal crops are grown throughout the State, some intensively in all parts, others only in restricted regions. The acreages devoted to particular kinds vary considerably in different regions, as shown by Figure 2 which presents graphically the acreage statistics reported for 1925 by the Agricultural Statistician. The lines in this figure which divide the State into four roughly equal parts follow county boundaries, separating the counties into groups characterized in the main by the intensity with which certain cereals are cultivated.

Corn predominates in each of the four sections, with a total of 9,240,000 acres in the State, or almost 56 per cent of the total acreage for all grain crops. Oats rank next to corn except in the south where the oat acreage is exceeded by the wheat acreage. Wheat has large acreages everywhere, although it is exceeded by barley in the north. Barley is important only in the north, and rye is unimportant when compared with the others.

In the two central sections, which together have 62 per cent of the State's grain acreage, the order of importance of the various crops is: (1) corn, (2) oats, (3) wheat, (4) rye, and (5) barley.

In the northern section, the order of importance of crop acreages is: (1) corn, (2) oats, (3) barley, (4) wheat, and (5) rye.

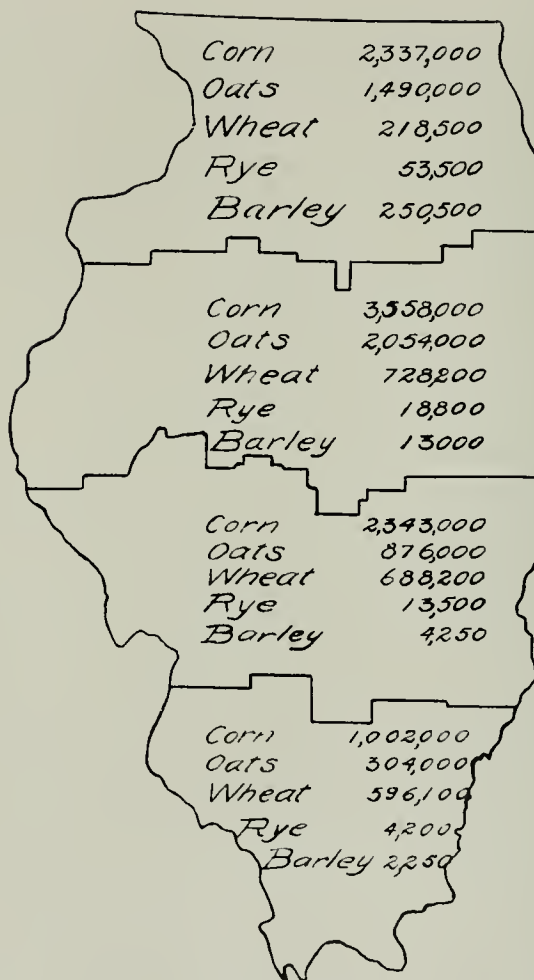


FIG. 2. ACREAGES DEVOTED TO THE GROWING OF CEREALS IN DIFFERENT SECTIONS OF ILLINOIS (1925)

Next to corn, which is the most important crop throughout the State, oats have the largest acreages in all sections except the south where wheat is grown more extensively than oats. Wheat is a major crop in all sections except the north where its acreage is slightly smaller than the barley acreage. Rye, though important in the north, is almost negligible when compared with the other cereals.

A slightly different order prevails in the south, where wheat is second only to corn, with an acreage almost twice as great as the oats acreage. Rye and barley, both unimportant, are fourth and fifth, as in the two central sections.

The data secured in sample fields representing these acreages and analyzed in accordance with the simple methods described in the preceding pages will serve as bases for comparing both the prevalence and the destructiveness of diseases during the period covered by the survey—1922-1926. For brevity of treatment, it is advisable to group cereal diseases into general classes according to the kinds of injury they cause, thus bringing together those requiring similar handling both in securing and in analyzing data, in order to eliminate constant repetition of method and description. If descriptions of individual diseases more complete than those given here are desired, they may be found in the report referred to at the beginning of this paper.

Cereals are grown in fields comprising, as a rule, rather large acreages. The plants are small and grow closely crowded together. These two facts have an important bearing on the obtaining of disease data, for even in a very small field an examination of every plant is an impossibility and, furthermore, the crowding of plants makes it extremely difficult to distinguish one from another without digging out and carefully separating them—a procedure which would not, and should not, be tolerated by the owner of a field.

Hence, it is necessary, in securing data representing prevalence, to use the stem instead of the plant as a unit. The degree of prevalence is indicated by the proportion of disease-bearing stems. Counts are made of a number of stems sufficiently large to give a dependable representation of the infection in the field. Because of variations in soil and topography, disease prevalence is apt to vary noticeably from one part of the field to another. In order to equalize such variations, parts of the field count are apportioned to different places. The selection of the places for the counts and the decision as to the comparative number of stems to be counted in each place rests upon the judgment of the observer, but his aim must be to secure as true a representation as possible.

Inasmuch as each disease destroys a particular part of its host, the measure of destructiveness must be suited to that part. The device used is described in the discussion of each disease.

It should be explained at this point, however, that although neither the devices for measuring destructiveness nor the methods of computing values from the data obtained by using them were employed extensively or consistently in the first years of the survey, the collection and preservation of adequate and representative samples enabled us to measure, at a later time, the destructiveness of diseases during those years.

CEREAL RUSTS

The most constantly prevalent type of disease in our grain fields is that known as rust. No cereal crop grown in Illinois escapes attack, and with the exception of corn, each is subject to two distinct rust diseases. The rusts are almost unique, in that they are not amenable, under present agricultural practices, to treatments designed either to prevent their attack or reduce their destructiveness. They present, therefore, the outstanding opportunity for a study of the relation of disease to the natural environment.

Rusts do not kill their hosts. Individual infections are limited to very small portions of the plant, seldom extending over an area twice that of the rusty pustule which is the outward sign of the disease; but a multiplicity of individual infections results in the conversion of a large part of the host tissue to the uses of the parasite, giving the appearance of a heavily rusted plant. Measuring the destructiveness of a rust attack thus becomes a matter of ascertaining the relative abundance per plant of the individual infections, or—for convenience—the relative amount of plant surface occupied by pustules. An actual measurement of this area would be impracticable, of course, under field conditions, and a substitute must be used.

A standard was devised by N. A. Cobb in 1892, which he used extensively and successfully while studying rust diseases of grains in Australia. An adaptation of it which has been used extensively in experimental work has been found equally useful for field work. As indicated in Figure 3, it consists of a number of diagrammatic pictures

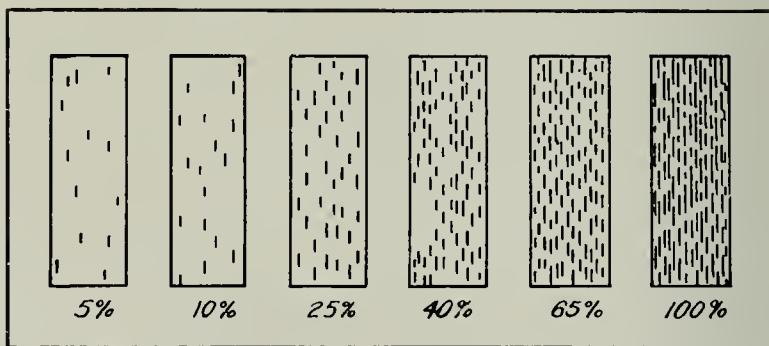


FIG. 3. SCALE USED IN MEASURING THE INTENSITY OF RUST ATTACKS

Because the diagram at the right represents the highest possible degree of infection, it is assigned an arbitrary value of 100 per cent., and the gradations represented by the other diagrams are in the indicated proportions with respect to it. Specimens of rust, selected at random in a field, are compared with the standards in this scale, and an average of the readings so secured represents the infection in the field. (See page 19.)

which illustrate a series of typical rust attacks ranging from slight to heavy by easily distinguishable intervals. The classification of the units in the series is based on the relative abundance of rust pustules. The heaviest attack illustrated is the heaviest infection possible and is given an arbitrary value of 100 per cent, the lesser infections being graded as percentages in their proper relation to the heaviest.

A copy of this scale is carried by the observer in a small notebook. As he makes his counts in a field to determine the number of stems carrying rust, he selects from time to time and quite at random a copious sample of the disease, which, either then or later, is compared with the scale by fitting its individual parts, one after another, between the two diagrams which they most closely resemble. In order to eliminate errors of judgment as completely as possible, each part of the sample is classed as the lesser of the two units of the standard between which it falls, rather than being assigned an estimated intermediate value. From one sample so measured (see the typical record sheet on page 4), the following data were secured.

Scale classes of rust abundance	Number of parts of the sample in each class	Class value times frequency
0 per cent	3	0
5 " "	19	95
10 " "	37	370
25 " "	26	650
40 " "	14	560
65 " "	7	455
100 " "	1	100
	107	2,230

Destructiveness (mean for the sample) of rust on disease-bearing stems, $\frac{2230}{107} = 20.8$ per cent.

These items are recorded on the field record sheet, and serve as a complete and permanent record of the examination made in that field.

Since the individual values given above have no adaptability as a usable figure, they must be reduced to a single value representative of the whole sample. The simplest way to obtain it is to compute the arithmetical mean. This process will require some explanation. Since it is obvious that the larger numbers of moderately rusted sample parts will have a greater significance than the lesser number of heavily and lightly rusted parts in determining the average of the sample, it is necessary to give each class of infection its proper weight with respect to the other classes, as determined by the number of parts of the sample falling in it, by multiplying the value of the rust-class by the frequency with which it occurred in the sample. The product in each instance, indicated in the above tabulation as "class value times frequency," shows approximately the total rust infection in that class, and the sum of these products is approximately the total rust infection in the sample.

To find the average rustiness of the sample, it is now necessary only to divide the sum of the products of the class values and frequencies by the number of parts in the sample. The value resulting, **20.8** per

cent in the above example, is considered to represent the destructiveness of the rust on the disease-bearing stems. For the field as a whole, destructiveness is calculated by the methods outlined previously (p. 8).

In the main, the rusts of cereal crops are classified as "stem" rusts and "leaf" rusts, according to the plant part which they customarily inhabit. This characteristic demands that the destructiveness of stem rusts be measured as diseased stem surface and that of leaf rusts as diseased leaf surface. It is customary to speak of stem area and leaf area, rather than "surface."

WHEAT LEAF RUST

Caused by *Puccinia triticina* Erikss.

The period during which wheat leaf rust has been under observation extends from the spring of 1922 through the harvest of 1926. In each of these five seasons, fields of many varieties of wheat were examined in many parts of the state, and careful records were kept and summarized in accordance with the statistical methods previously explained. Each year's records represent as accurate a statement of the prevalence and severity of leaf rust as could be obtained by sampling, with the means at hand.

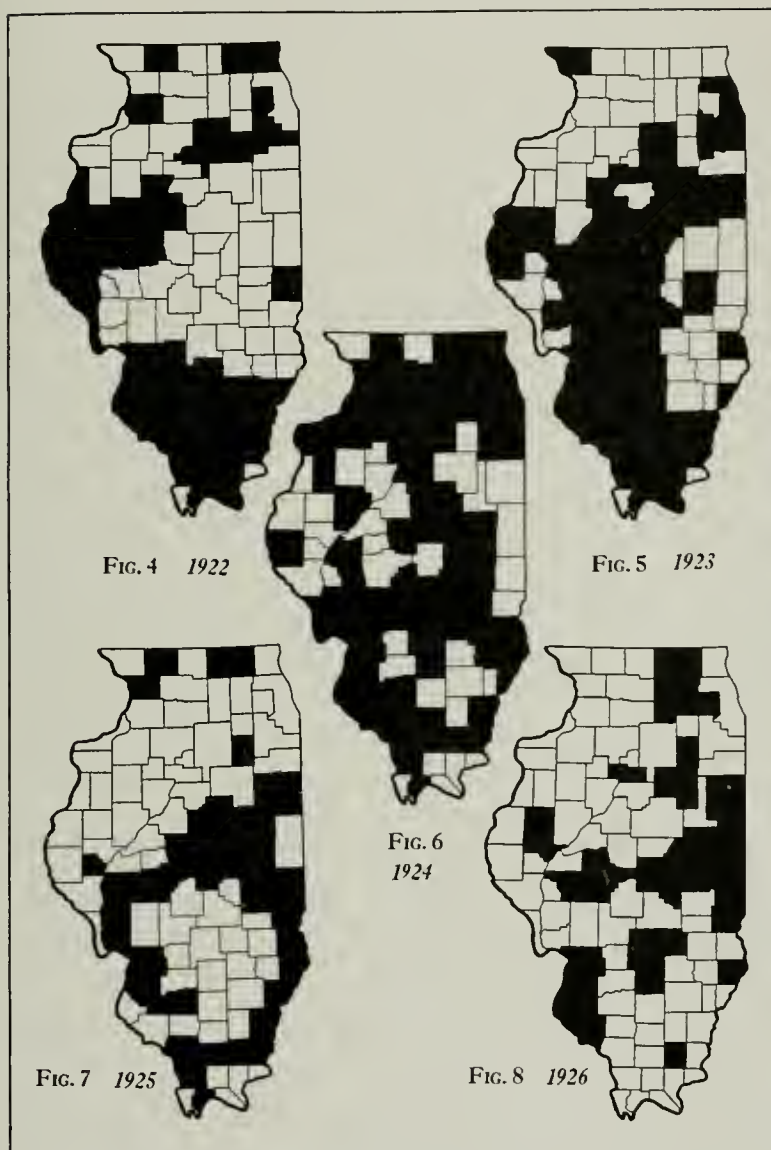
During the early summer of 1922, before wheat harvest, leaf rust was observed in 139 fields, so distributed as to furnish data applying to the territory shown in black in Figure 4. This being the first season of attempted quantitative recording, it was found later that only 43 of these fields had been sufficiently well examined to allow statistical consideration of the observations. These fields, which were distributed among 17 counties, contained 862 acres. In them, an average of 95.4 per cent of the wheat stems bore rust-infected leaves, and an average of 50.6 per cent of the entire leaf area was occupied by pustules.

An exceedingly large number of fields were examined in 1923, records relating to leaf rust being secured from a total of 10,963 acres distributed among the 52 counties shown in Figure 5.

In this acreage, the average proportion of stalks bearing rust-infected leaves was 92.0 per cent; in the entire acreage of the counties represented, 91.0 per cent; and for the state as a whole, 89.7 per cent. It was determined that the rust pustules occupied an average of 46.6 per cent of the leaf area of every stem in the acreage examined, 33.8 per cent in the county acreage, and 31.3 per cent in the state's acreage.

Records were taken on the prevalence of leaf rust in 1924 from fields containing 8,686 acres. They were distributed among the 68 counties shown in Figure 6.

For the acreage involved, an average of 74.6 per cent of the wheat stems bore rust-infected leaves, and 49.5 per cent of the leaf area per stem was occupied by pustules. When the data were extended to the county acreages, the index of prevalence became 67.4 and that of destructiveness 19.1; while for the entire state the index of prevalence was 68.3 and of destructiveness 19.1.



FIGS. 4-8. SOURCES OF WHEAT LEAF RUST DATA, 1922-1926

The black regions on these maps show the territory from which data were taken each year. Nearly 16,500 acres of wheat were examined in the five years. These maps do not represent the distribution of the disease, which is supposedly state-wide every year, but simply show the counties in which our observations were made. (See page 20.)

In 1925 records of leaf rust were taken in fields aggregating 3,225 acres. The fields in which the observations were made were distributed among the 36 counties shown in Figure 7. When the data that were secured were subjected to analysis, the ratio of stalks bearing rusted leaves in the acreage examined was found to be 63.5 per cent and the average amount of rust-occupied leaf area per plant 6.5 per cent. The index of prevalence for the total county acreage represented by the sample fields was 46.3 and the index of destructiveness was 6.0, while for the entire state the indexes were 52.6 and 17.1, respectively.

Fields aggregating 1,445 acres and distributed among the 31 counties shown in Figure 8 furnished leaf rust data in 1926. Since agricultural statistics have not yet been provided for this year, it has been impossible to carry out all of the usual computations; but the data secured show in their preliminary analysis, that in the acreage examined 57.2 per cent of the stems carried rusted leaves and 11.2 per cent of the leaf area was occupied by pustules.

As a very close agreement has been evident between the indexes secured directly from field data and those secured for district and State acreages by indirect computation, the direct indexes for 1926 will be compared in subsequent pages with the computed indexes of previous years.

The summarized data for the five seasons are brought into closer comparison in the following table:

Year	Acreage examined	Prevalence: Calculated percentages of wheat stems bearing diseased leaves			Destructiveness: Calculated percentage of leaf area occupied by rust		
		For the acreage examined	For the county acreage represented	For the State's wheat acreage	For the acreage examined	For the county acreage represented	For the State's wheat acreage
1922	862	95.4	94.9	94.1	50.6	53.9	50.3
1923	10,963	92.0	91.0	89.7	46.6	33.8	31.3
1924	8,686	74.6	67.4	68.3	49.5	19.1	19.1
1925	3,225	63.5	46.3	52.6	6.5	6.0	17.1
1926	1,445	57.2	....	....	11.2	....	....

There is a considerable difference in both the prevalence and the destructiveness of leaf rust between any two years, and there has been a marked and continued decrease in both through the five-year period. The first two of the five years were characterized by very heavy attacks, while in each of the last three years the attack was moderate or light. When considered from the point of view of destructiveness alone, these contrasts are especially evident, but they are borne out in very certain terms also by the corresponding decrease in prevalence.

OATS CROWN RUST

Caused by *Puccinia coronata* Corda.

The crown rust of oats is essentially a leaf rust, at least under average Illinois conditions, for though it often attacks the stems, infection as a rule does not occur there until a day or two before harvest and usually results in but little damage. Quite early in the season, however, its red pustules appear on the leaves, multiplying rapidly until harvest.

Measurements of the destructiveness of crown rust are obtained in exactly the same way, and by employing the same standard, as are those of the leaf rust of wheat (see page 19 and Figure 3).

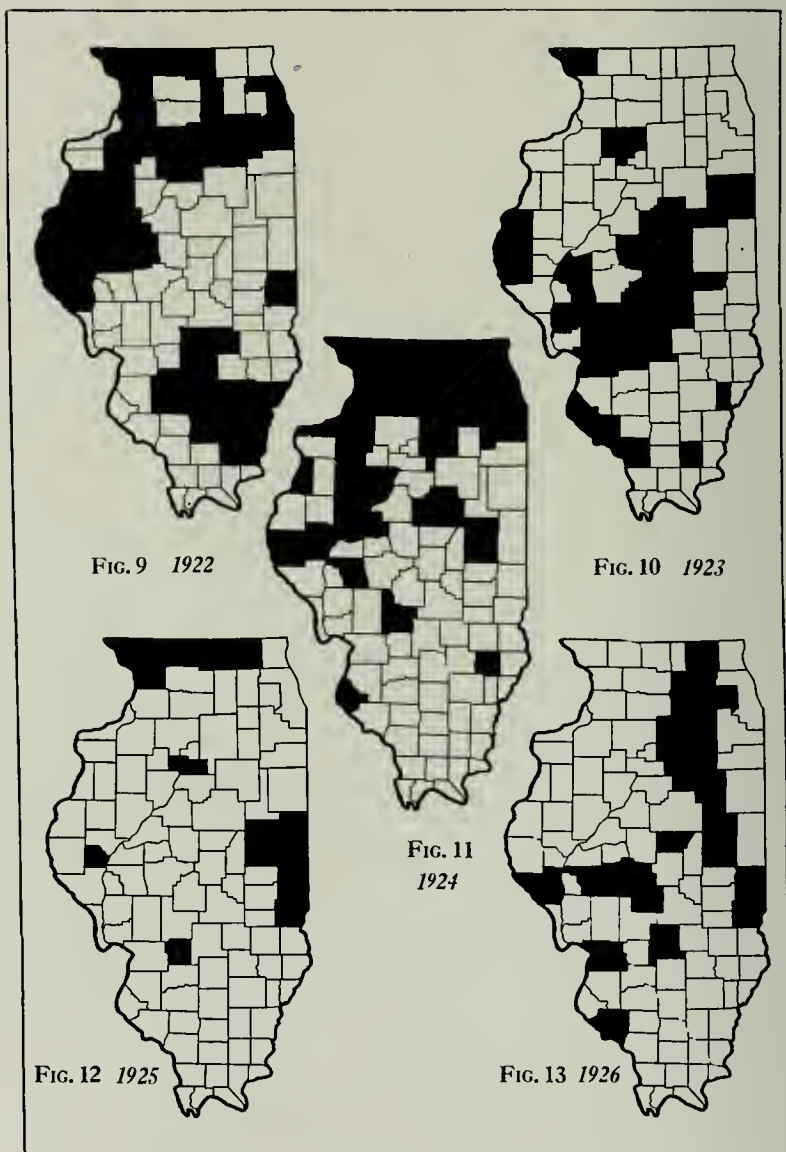
In 1922 crown rust was seen in oat-fields distributed among the 44 counties shown in Figure 9. Data were secured from 705 acres, the remaining fields not having been sufficiently well examined to give usable information. In this acreage, 78.7 per cent of the stems bore rust infected leaves, 37.6 per cent of the leaf area being occupied by pustules. The field data when applied to the total acreages of the counties which they represented, gave a prevalence index of 69.2 and a destructiveness index of 28.0. The indexes for the State's acreage are respectively 67.0 and 27.3.

The epidemic of 1922 was preceded by an abundant and heavy fall infection on volunteer oats throughout at least the southern half of the state. This infection is known to have extended on the eastern side of the state as far north as Champaign County where specimens of actively sporulating rust were collected as late as the latter part of October.

In 1923 crown rust infection was observed in fields located in the 28 counties shown in Figure 10. Fields totaling 1,306 acres were examined, and the records secured in them indicate a prevalence of 93.5 per cent and a destructiveness of 41.2 per cent. For the total county acreage to which the data applied, the indexes were 83.3 and 28.8 for prevalence and destructiveness, respectively, while for the State's acreage they were 83.1 and 30.6.

The epidemic of 1923 was early in starting. By June 4 an infection was observed in Jackson County involving an average of 25 per cent of the leaf area on 50 per cent of the stems, and two days later infection was seen in Saline County involving 1.5 per cent of the leaf area on about 10 per cent of the stems. The infection, thus started, spread and increased until, by harvest, the heavy epidemic indicated by the figures given above had developed.

In 1924, crown rust was observed in fields located in the 33 counties indicated in Figure 11. It is remarkable that the epidemic of this year, as suggested by the map, was confined largely to the northern section of the state, the crop in the south almost completely escaping attack. Field data were secured from 1,080 acres parcelled among 29 counties. The analysis of them indicates that in those fields 79.9 per cent of the oats stems bore infected leaves and that 14.8 per cent of the leaf area was occupied by pustules. The data, when applied to the total county acreage of which they are typical, show a prevalence index of 65.7 and a destructiveness index of 10.7. For the State's acreage, these indexes are 64.3 and 11.9, respectively.



FIGS. 9-13. SOURCES OF DATA ON OATS CROWN RUST, 1922-1926

The black regions on each of these maps show the territory from which data were taken in each year of the period. The fields examined contained more than 4,000 acres. (See page 23.)

The rust was late in getting started. All the observations were made during July and August, the earliest July fifth in Adams and Brown Counties, at which time the crop was already ripening. One isolated and very early report from the north (June 27 at Rockford) showed an exceedingly light infection apparently originating from a crown rust infected buckthorn hedge nearby, but elsewhere the usual seasonal development prevailed.

Crown rust was not a very important disease in 1925. Records of its presence were secured only from the 13 counties shown in Figure 12, which lie chiefly in the northern half of the state. The earliest infection was seen near Greenville, in Bond County, where, by June 26, an average of .03 per cent of the stems bore rusted leaves, one leaf on each of these stems having one or two pustules.

The fields from which data were secured contained only 297 acres. In them, an average of 14.8 per cent of the stems bore rust, only .17 per cent of the leaf area being occupied by pustules. These data may seem to be insufficient for further use, but in view of the very mild attack it is worth while to evaluate them for the greater acreages. For the total county acreages of which they are typical they indicate a prevalence of 28.2 per cent and a destructiveness of .4 per cent, while for the State's acreage the corresponding figures are 27 per cent and .6 per cent, respectively.

In 1926, crown rust appeared early. It was found first June 2 near Marshall, Clark County. Throughout the southern half of the state this original infection was so slow in spreading that it never reached heavy proportions; but farther north, after becoming established, it spread rapidly and became exceedingly abundant. As a result, records were obtained chiefly in the north. The fields from which records were taken were distributed among the 20 counties indicated in Figure 13, aggregating 697 acres.

In them, 50.4 per cent of the culms bore crown rust and 9.9 per cent of the leaf area was occupied by pustules. Owing to the lack of acreage statistics, the data can not be carried farther to show the prevalence and destructiveness of the disease throughout the state.

For closer comparison of the differences in crown rust infections in the years concerned, the data are brought together in the following table:

Year	Acreage examined	Prevalence: Calculated percentages of oat culms bearing diseased leaves			Destructiveness: Calculated percentages of oat leaf area occupied by rust pustules		
		For the acreage examined	For the county acreage represented	For the State's oats acreage	For the acreage examined	For the county acreage represented	For the State's oats acreage
1922	705	78.7	69.2	67.0	37.6	28.0	27.3
1923	1,306	93.5	83.3	83.1	41.2	28.8	30.6
1924	1,080	79.9	65.7	64.3	14.8	10.7	11.9
1925	297	14.8	28.2	27.0	.17	.4	.6
1926	697	70.4	....	....	9.9	....	....

No two years show exactly the same indexes, and even when the indexes of prevalence are similar, as in 1922 and 1924, those of destructiveness are quite different. With respect to prevalence, the five years listed fall into two groups, 1922, 1923, 1924, and 1926 showing great prevalence and 1925 slight; but with respect to destructiveness, there is an even more distinct grouping, 1922 and 1923 ranking high and the subsequent years very low.

BARLEY LEAF RUST

Caused by *Puccinia simplex* (Koern.) E. & H.

The method of measuring the leaf rust of barley is the same as that used in the two leaf rusts just discussed, but since the host crop is confined in a very large measure to the northernmost third of the state (see page 16), the data must be held to apply particularly to that region.

Owing to the limited distribution of the barley fields, which are concentrated in the north but occasional elsewhere, data for this disease have not been obtained in the same abundance as for the ones previously discussed. Although in some cases they are too few to be treated statistically, they are summarized here very briefly in order to afford such comparison as they will permit in the latter part of this paper.

In 1922, in a single field examined in Boone County 25 per cent of the stems carried rusted leaves, about 5 per cent of the leaf area being rust-covered. This indicates an average destructiveness of about 1.2 per cent. In 1923, a single examination, similar to the one above, made in Ogle County showed a prevalence of 100 per cent and a destructiveness of 5 per cent.

Single fields were examined in 1924 in Kendall, McHenry, Lee, and Ogle Counties. They contained a total of 40 acres, in which 100 per cent of the stems were so lightly rusted that only 4.4 per cent of the leaf area was occupied. Only 1 field furnished data in 1925. In 15 acres near Rockford 5 per cent of the leaf area was occupied by pustules, but the disease was confined to 34.6 per cent of the stems.

The data for 1926 were more complete. In the north, records taken from fields in Boone, DeKalb, DuPage, Kane, and McHenry Counties showed 100 per cent of the stems to be rust-infested and 10 per cent of the leaf area rust-covered. Other records were secured in Jackson and Mason counties. Only a trace of rust was found in the first county, but in the second 1 or 2 infected leaves, each bearing from one to five pustules, occurred on 13 per cent of the stems. Averages of these data indicate a prevalence of 76.1 per cent and a destructiveness of 7 per cent.

The several years compare as follows:

Year	Prevalence: Observed percentage of stems carrying rust	Destructiveness: Observed percentage of leaf area occupied by pustules
1922	25.0	5.0
1923	100.0	5.0
1924	100.0	4.4
1925	34.6	5.0
1926	76.1	7.0

These data, insofar as they are indicative, show fluctuation from

year to year in prevalence, but not equally in destructiveness, for the indexes of the latter were closely similar every year.

RYE LEAF RUST

Caused by *Puccinia dispersa* Erikss.

Leaf rust data can be secured more readily for rye than for barley, not only because the rye acreage is greater but also because the fields are more widely distributed. Nevertheless, in comparison with wheat and oats, the acreage is small, and its wide distribution results in fields of small size, except in the small regions especially adapted to its culture, which are characterized especially by sandy soils.

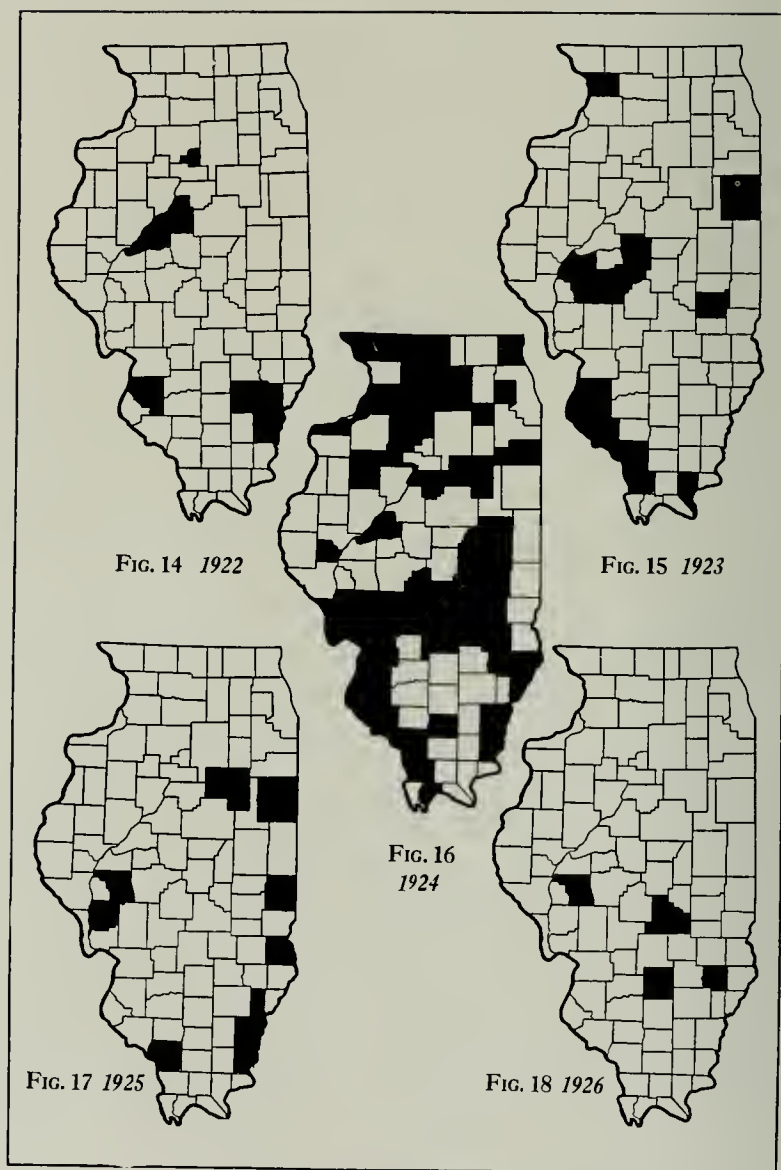
In 1922 data were secured from fields located in the seven counties shown in Figure 14. Although taken from a small number of fields, they have considerable weight, both because of their relative uniformity and because of the representative distribution of the fields. A considerably greater acreage of rye was examined for leaf rust in 1923, the fields being distributed among the 13 counties shown in Figure 15. The examinations yielded data of considerable significance, especially because a fairly large number of the fields were located in regions of intensive rye culture.

The season of 1924 provided data much more complete than any other year included in this report. The 48 counties shown in Figure 16 each furnished data from one or more fields, the fields examined reaching 73 in number and containing a total of 393 acres. Fields located in the 11 counties shown in Figure 17 furnished data on rye leaf rust in 1925. With the exception of Morgan County, where three fields were examined, observations were made in one field in each county. The wide distribution of the counties, however, gives weight to the data, particularly since important rye sections are included. While very little data could be secured in 1926, several small fields were examined in the 4 rather centrally located counties shown in Figure 18.

The results of the field examinations, as shown by an analysis of the data, are briefly as follows:

Year	Acreage examined	Prevalence: Calculated percentages of rye stems bearing rust infected leaves			Destructiveness: Calculated percentages of rye leaf area occupied by rust		
		For the acreage examined	For the county acreage represented	For the State	For the acreage examined	For the county acreage represented	For the State
1922	97	77.2	97.7	99.1	46.4	34.0	55.1
1923	217	59.8	54.8	50.3	12.0	9.2	8.2
1924	393	39.7	45.0	22.2	6.3	2.7	2.0
1925	230	75.0	30.9	44.5	1.9	0.6	0.9
1926	23	19.1	....	....	1.7	....	....

Here, as in the cases of the rusts previously discussed, there is variation in both prevalence and destructiveness from year to year.



FIGS. 14-18. SOURCES OF RYE LEAF RUST DATA, 1922-1926

The black regions on these maps show the territory from which data were taken in the years making up this period. There were, in all, 960 acres in the rye fields examined. (See page 27.)

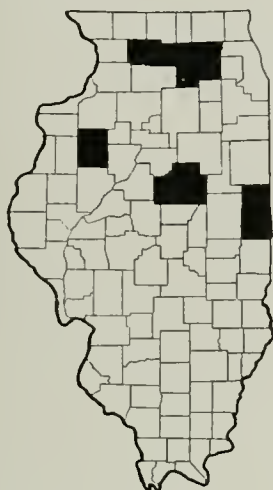


FIG. 19 1922



FIG. 20 1924



FIG. 21 1925



FIG. 22 1926

FIGS. 19-22. SOURCES OF CORN RUST DATA

The black regions on these maps show, respectively, the territory from which data were taken in 1922 and in the period 1924-1926. In 1923, data were obtained in Douglas, Effingham, and McLean counties only. (See page 30.)

This rust has been, on the whole, much milder than the other leaf rusts, the season of 1922 being the only one in which a really destructive attack occurred. The yearly variation appears to have been concerned with prevalence more than with destructiveness.

CORN RUST

Caused by *Puccinia sorghi* Schw.

Corn, the most important both in yield and acreage of all the cereals grown in Illinois, is subject to the attack of but one rust. It is a leaf rust.

In securing data on corn rust, the only phase of the attack that has been studied is prevalence. The intensity of the attack is exceedingly hard to estimate, first because of the large size of the corn leaf, and second because the pustules occur very sparsely on the leaf and only in limited spots. No means for estimating the severity of the attack has yet been devised.

In 1922, corn rust was not very prevalent. As a result, data were secured only from the 6 counties shown in Figure 19, the small acreage represented being located entirely in the northern half of the State. The data, though meagre in comparison with other years, were nevertheless representative. Even less abundant in 1923 than in the previous year, rust was recorded in only three fields, one in Douglas, one in Effingham, and one in McLean Counties. If the infection in these fields was typical of that throughout the State, the prevalence would be expressed as 3 per cent.

An abundance of data was obtained in 1924. In the 60 counties shown in Figure 20, data were taken from 84 fields aggregating 3762 acres. For 1925 the data are less copious than for the preceding year, but the 17 counties shown in Figure 21 contributed records from fields aggregating 450 acres.

Exactly 70 fields, distributed among the 63 counties shown in Figure 22, furnished data in 1926. Rust prevalence was exceedingly variable, being very high in some districts and very low in others. The data for the 5 years are brought together in the following table for more intimate comparison.

Year	Acres examined	Prevalence: Calculated percentage of corn stems bearing rust-infected leaves		
		For the acreage examined	For the county acreage concerned	For the State
1922	115.7	41.8	42.2	34.6
1923	40.5	3.0		
1924	3,762.0	63.0	61.0	62.6
1925	450.0	26.6	30.0	33.3
1926	1,333.0	11.4		

Although prevalence only has been recorded, a difference from year to year is evident. It is remarkable that the greatest prevalence occurred in 1924, succeeding the year of least prevalence.

Comparison of all leaf rust data

In the preceding pages the yearly indexes of prevalence and destructiveness shown by data taken directly from cultivated fields have been given for the several leaf rusts. As they were considered, it became apparent that, though year-to-year variation was a common characteristic, the particular years of greatest and least intensity of attack were not the same for all. This fact is brought out more clearly in Figures 23 and 24.

The indexes of prevalence for the entire state, as listed in the foregoing tables (see pp. 22-30), are shown graphically for all the leaf rusts in Figure 23. The year 1922 appears to have been very favorable to the leaf rusts of wheat, oats, and rye, but unfavorable to those of

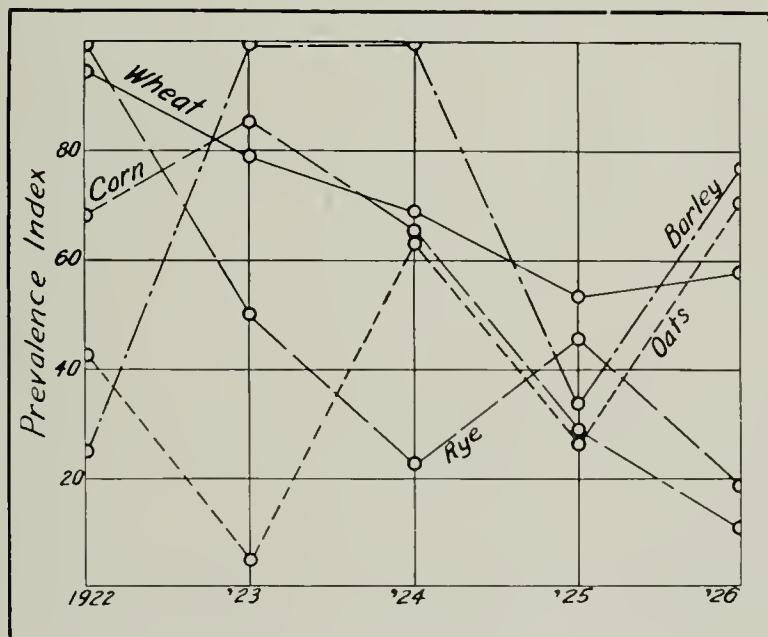


FIG. 23. PREVALENCE OF CEREAL LEAF RUSTS, 1922-1926

The prevalence indexes computed for the leaf rusts from field data and given in tables in the text are shown graphically here. The wide differences in the prevalence of these rusts in each year and in the trend of prevalence from year to year suggest that there is a particular combination of weather conditions most suitable for the maximum prevalence of each rust. (See page 32.)

corn and barley. The following year, 1923, was somewhat less favorable for wheat leaf rust and very much less favorable for the corn and rye rusts, while the oats rust found better conditions and the barley rust attained its maximum prevalence. The general trend in 1924 was downward, as compared with 1923, although the barley leaf rust maintained the high prevalence of the previous year, and corn rust found the best conditions of any of the five years. Rye leaf rust, alone of the five, was able in 1925 to increase its prevalence over that of the preceding year, the four others showing very marked decreases. Definite increases in prevalence were shown by the barley, oats, and wheat leaf rusts in 1926, while those of corn and rye decreased beyond their low points of the year before.

Through the five years to which these records apply, the same trend of prevalence has been followed by the leaf rusts of barley and oats in one instance, and of wheat and rye in another; but corn rust has had an individual trend, quite distinct from either of the two other groups. It is especially noteworthy that in no one year did the prevalence indexes of all move in the same direction.

In contrast with the foregoing is the fact, illustrated in Figure 24, that through all of the four years previous to 1926 the general trend of destructiveness was downward, ranging from severe attacks in 1922 and 1923 to mild and insignificant attacks in 1924 and 1925. With the exception of wheat leaf rust, a general upward trend is apparent for 1926.

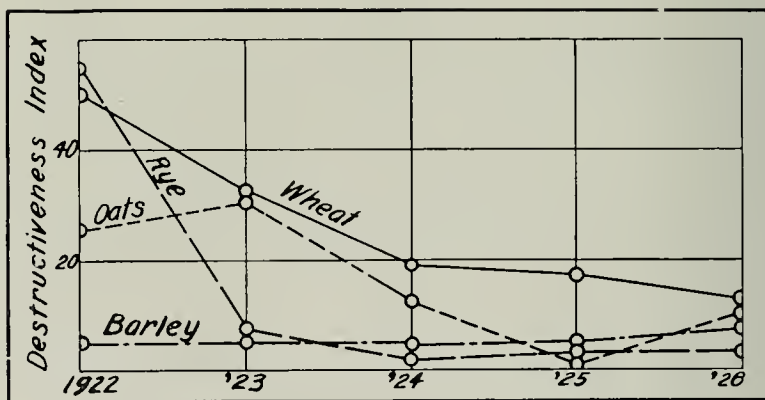


FIG. 24. DESTRUCTIVENESS OF THE CEREAL LEAF RUSTS, 1922-1926

The indexes of destructiveness computed from field data and given in tables in the text are shown graphically here. Since 1922, the general trend has been downward; but crown rust increased in 1923 and 1926, and barley leaf rust increased in 1926.

The Stem Rust of Cereals

Caused by *Puccinia graminis* Pers.

Although each of the cereal crops grown in Illinois has an individual leaf rust, the stem rust is the same for all, attacking all but corn. Special races of the stem rust exist, however, which are so limited in their ability to attack that each occurs on one crop only. The varied requirements of each crop in length of season and planting and growing periods present diverse conditions for the development of stem rust epidemics on each crop. Hence, it is not likely that the same phenomena of prevalence and destructiveness will be exhibited by this rust upon any two crops in a given year. It is necessary, therefore, to treat the stem rust on each crop as though it were a separate rust.

The method of measuring the prevalence of stem rust is similar to that used for the leaf rusts. Instead of individual plants, individual stems are taken as units, and prevalence is computed according to the method described on pp. 6-8. Destructiveness is expressed in terms of stem area occupied by the rust pustules, and the standard shown in Figure 3 is used as described on pages 18 and 19 as a measure of stem area.

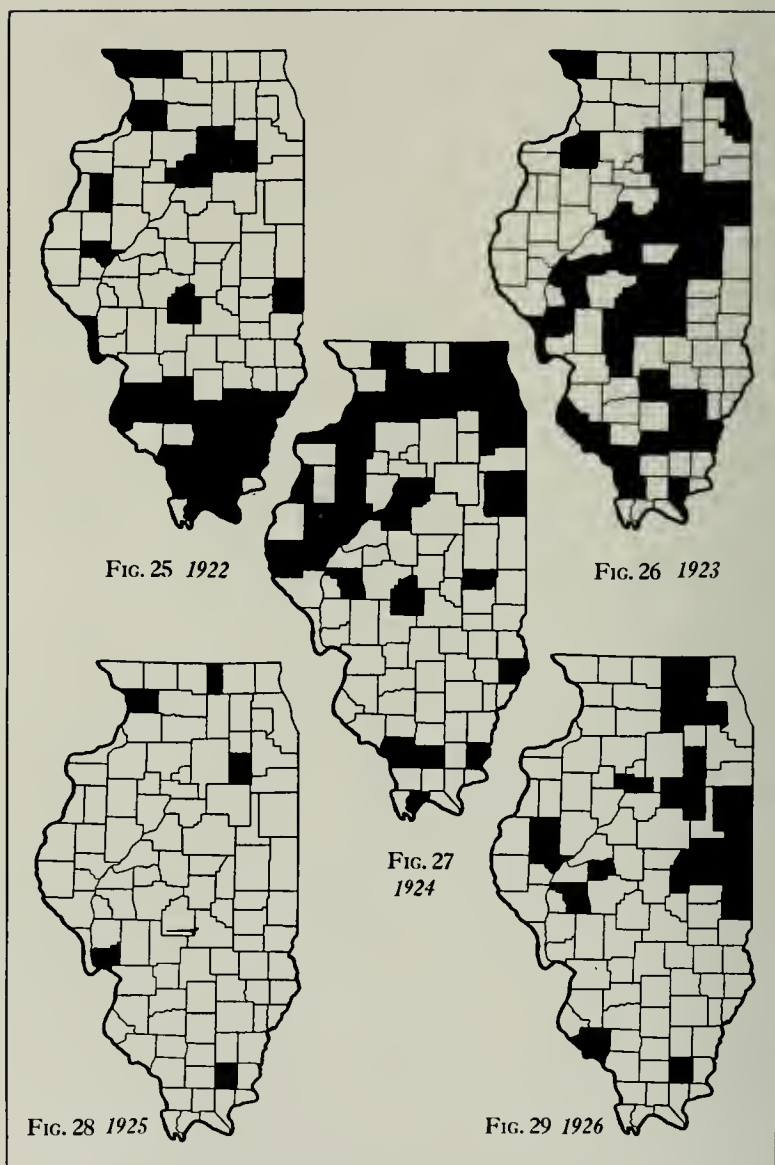
THE STEM RUST ON WHEAT

At the time field work was begun in 1922, stem rust infection was already widely prevalent on wheat. Its occurrence was demonstrated in the 30 counties shown in Figure 25. Although no definite records of prevalence or severity were secured from the southern territory marked on the map, data were taken from 17 fields in the northern part of the state, and the destructiveness indicated by them agrees well with that shown by the specimens collected in the south.

The earliest record of infection in 1923 was made June 4 in Jackson County. Isolated infections such as those subsequently found June 7 in Bond County, June 12 in Franklin County, and June 11 in Hamilton and White Counties served as *foci* from which, about June 16, disease dissemination began; and by June 22 the epidemic had become general. Data were secured from 72 fields distributed among the 39 counties shown in Figure 26. The extent of the territory from which the data were secured is particularly fortunate, in view of the intensity of the rust attack.

During 1924 stem rust was more prevalent in the north than in the south. Data were secured from 61 fields parcelled among the 31 counties shown in Figure 27. The original infections took place at least 8 days later than was the case the year before, and the period of moderate temperatures was so curtailed in the south that only a mild epidemic resulted there.

So rare was stem rust during 1925 that only six records of it were obtained. The fields from which these records were taken were located



FIGS. 25-29. SOURCES OF STEM RUST DATA FOR WHEAT, 1922-1926

The black areas on these maps show the regions from which the data discussed in the text were taken in each year. The fields from which records were taken during the five years contained 3,851 acres. (See page 33.)

in the counties shown in Figure 28. A recrudescence of stem rust occurred in 1926, which, by comparison with the light attack of the previous year, gave rise among wheat growers to grave fears of damage, fortunately not realized. During the season data were taken from 27 fields located in the 19 counties shown in Figure 29. As in previous years, abundant infection was found less readily in the south than in the north.

The variations in prevalence and destructiveness alluded to in the foregoing paragraphs are illustrated in the following table, in which the final figures arrived at in the statistical analyses of the data are brought together.

Year	Acreage examined	Prevalence: Calculated percentage of diseased stems			Destructiveness: Calculated percentage of diseased stem area		
		For the fields recorded	For the county acreage represented	For the State's acreage	For the fields recorded	For the county acreage represented	For the State's acreage
1922	256.5	9.9	41.2	22.06	1.8	32.8	17.8
1923	2,305.8	42.0	33.4	35.7	8.1	7.3	8.0
1924	659.0	22.0	15.7	11.1	6.7	0.5	0.6
1925	90.0	23.8	8.4	14.9	2.1	0.6	1.2
1926	540.0	57.8	....	....	11.2	....	....

The figures relating to the epidemic of 1922 are very inconsistent, showing much too wide a divergence in the separate columns of the table relating to both prevalence and destructiveness. This is due to exceedingly uneven weights given, of necessity, to the observations, in terms of the acreages to which they apply. It was to be expected, however, that in the first season of quantitative measuring of disease abundance some such discrepancies would appear. Since the indexes of prevalence and destructiveness secured for the acreage examined are more in harmony with those secured in subsequent years and with the general trend of the notes taken, they will be used in later discussions.

The figures for the remaining years are generally consistent, not only for the acreage examined, but also for the county acreage represented and for the State's acreage. They illustrate variation in both prevalence and destructiveness, and they show in a very emphatic way the fact that, of the two wheat rusts, stem rust has been the less significant.

THE STEM RUST ON OATS

In 1922 stem rust was prevalent on oats only in the northern part of the state. Its presence was observed in the 17 counties shown in Figure 30, but usable data were secured from only 14 fields in counties located in the extreme west and north. So rare was infection of oats during 1923 that not one specimen of stem rust was collected. No

notes or data of any kind could be secured to show either its relative prevalence or destructiveness. As more than 1,300 acres of oats were examined without a single stem rust infection being found, the indexes of prevalence and destructiveness may be considered as zero for the year.

In contrast with the preceding year, in 1924 oats throughout the State were abundantly infected. The infection was particularly heavy in the northern half of the State. Fifty-eight fields distributed among the 34 counties shown in Figure 31 furnished data on prevalence and destructiveness. Again in 1925, the oats crop was infected throughout the northern half of the State. Data were taken from 8 fields in the seven counties shown in Figure 32. Although apparently inadequate in total acreage, the fields were widely distributed and were representative, to that extent, of the entire oats acreage.

Data were taken from 42 fields in 1926, these fields being scattered among the 29 counties shown in Figure 33. They were representative to a remarkable degree of the oat acreage of the State. Stem rust was very abundant, and quite destructive in the northern counties, as compared with previous years.

The indexes of prevalence and destructiveness for the five years are brought together in the following table.

Year	Acreage examined	Prevalence: Calculated percentage of infected stems			Destructiveness: Calculated percentage of stem area occupied by rust		
		For the acreage examined	For the county acreage represented	For the State's acreage	For the acreage examined	For the county acreage represented	For the State's acreage
1922	232	27.7	54.7	56.9	14.6	25.8	29.0
1923	1,306	0	0	0	0	0	0
1924	1,079	41.6	38.1	45.5	8.8	13.8	13.8
1925	162	27.8	26.3	21.6	6.7	5.1	4.5
1926	728	85.5	....	....	42.7	....	....

The variation exhibited by the indexes recorded above for 1922 is to be expected, partly because of lack of experience in measuring the quantity of rust and partly because of the very limited distribution of the fields from which data were taken. In their computation the southern part of the state was not represented. For the other years, the indexes, though modified in accordance with the extent of the territory to which the data are applied, are consistent and representative, giving by comparison with each other a fairly accurate depiction of the infections in each year.

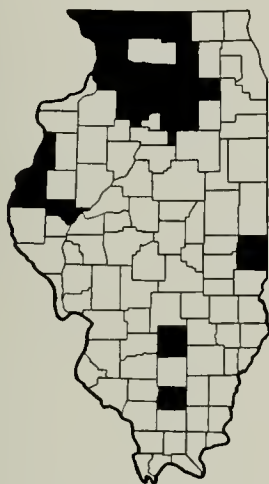


FIG. 30 1922



FIG. 31 1924

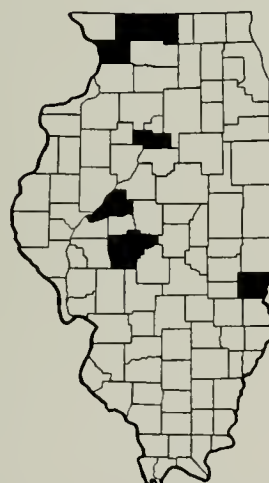


FIG. 32 1925

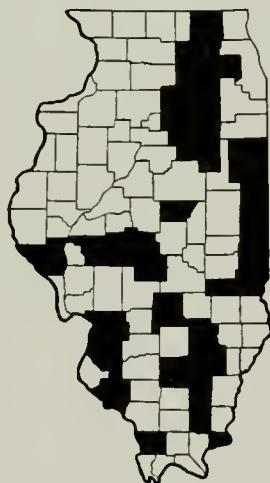


FIG. 33 1926

FIGS. 30-33. SOURCES OF STEM RUST DATA FOR OATS

The black areas on these maps show the regions from which the data discussed in the text were taken in 1922, 1924, 1925, and 1926. No infection was found in 1923, though more than 1,300 acres were examined. The fields examined in the other four years contained a total of 2,201 acres. (See page 36.)

THE STEM RUST ON BARLEY

Very few records of the occurrence of stem rust on barley have been made in Illinois south of the north third of the State. So far as the annual epidemic on barley is concerned, only the northern third of the State needs to be considered, not only because of the rarity of the rust southward but also because of the scarcity of the crop there. Because of the limited range of the crop and the limited acreage devoted to it, records of its diseases are much fewer than those for more common and more widely grown cereals.

In 1922 infection was found in the five counties shown in Figure 34. Data were obtained from eight fields which were representative of the barley district. Stem rust appeared to be completely absent in 1923, but in 1924 the infection became very general in the north. During the latter season, one barley field was examined in each of the 15 counties shown in Figure 35.

In 1925, fields were examined in the four counties shown in Figure 36, and stem rust was found to be prevalent, though in a very light form, in each.

By the time the observer reached the barley region in 1926 the crop had been cut and was standing in shocks. Although examinations made under these conditions are not wholly satisfactory, one field in each of the three counties, Boone, DeKalb, and McHenry, was given a very careful examination; and the data taken from them may be considered typical of the stem rust infection in the barley region.

The indexes of prevalence and destructiveness secured from the computations made with field data are as follows:

Year	Acreage examined	Prevalence: Calculated percentage of stems infected with stem rust			Destructiveness: Calculated percentage of stem area occupied by rust		
		For the acreage examined	For the county acreage represented	For the State's acreage	For the acreage examined	For the county acreage represented	For the State's acreage
1922	52	14.1	48.1	45.5	5.8	12.3	12.4
1923	...	0	0	0	0	0	0
1924	194	5.6	6.9	8.0	.5	.5	.6
1925	65	15.7	11.3	11.1	.1	.2	.2
1926	60	100.0	....	....	28.7	....	....

The figures given above, which are reliable indexes of the seriousness of stem rust on barley during each of the five years 1922-1926, indicate definitely the relative importance, in each year and throughout the period, of this rust and the leaf rust (see page 26) as agents in reducing the barley yield, stem rust being in the main much the less significant.



FIG. 34 1922

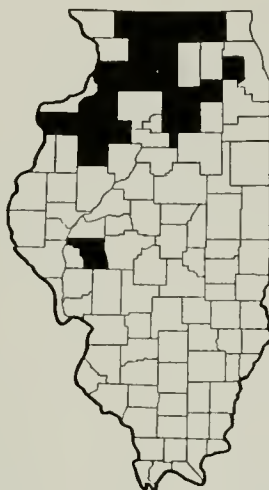


FIG. 35 1924



FIG. 36 1925

FIGS. 34-36. SOURCES OF STEM RUST DATA FOR BARLEY

The region from which data were taken in the years 1922, 1924, and 1925 are shown in black on these maps. In 1923, there was no stem rust infection. In 1926, 3 fields, one in Boone, one in DeKalb, and one in McHenry County, were examined. (See page 38.)

THE STEM RUST ON RYE

In spite of the wide distribution of rye in Illinois and the extensive use of it along newly placed hard roads, which might be expected to aid in distributing stem rust infection on the crop, it has been possible to secure but very little data on stem rust prevalence in rye fields. In 1922 only two fields, one in Mason and one in Grundy County, were found infected. No infection was recorded in 1923. In 1924 data were secured from 10 fields located in the seven counties shown in Figure 37. During the two subsequent years, 1925 and 1926, no instance of infection was seen in any of the fields examined, though

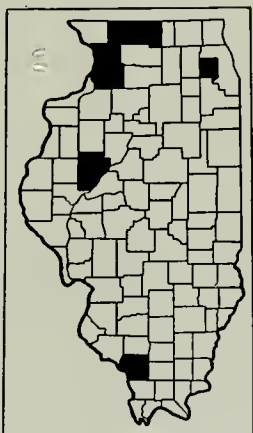


FIG. 37. SOURCES OF STEM RUST DATA FOR RYE IN 1924

In the seven counties shown in black, 10 fields containing a total of 70 acres furnished data on the stem rust attack of 1924.

infected rye plants were found occasionally in wheat fields and along roadsides. The data on the severity of stem rust on rye for the years covered by the survey are as follows:

Year	Acreage examined	Prevalence: Calculated percentages of stems infected with stem rust			Destructiveness: Calculated percentage of rye stem area occupied by stem rust		
		For the acreage examined	For the county acreage represented	For the State's acreage	For the acreage examined	For the county acreage represented	For the State's acreage
1922	70	50.0	50	50	28.5	22.5	25.5
1923	217	0	0	0	0	0	0
1924	70	7.7	18.1	25.9	3.9	9.1	13.9
1925	230	0	0	0	0	0	0
1926	23	0	0	0	0	0	0

Comparison of stem rust infections on the cereal crops subject to its attack

With stem rust, as with leaf rust, both the degree of prevalence and the degree of destructiveness have varied from year to year. These variations, which have not been of the same relative amounts for each of the crops, are best shown graphically.

The indexes of prevalence on each of the cereals, for each year from 1922 through 1926, are shown in Figure 38. A common trend is shown by all except wheat. In 1922 stem rust was moderately prevalent on barley, rye, and oats, but only mildly so on wheat. The following year prevalence dropped practically to zero on the first three crops, but on wheat it increased considerably. The crop season of 1924 saw a marked increase on all the cereals except wheat, while in 1925 prevalence was less on oats and rye, but more on wheat and barley.

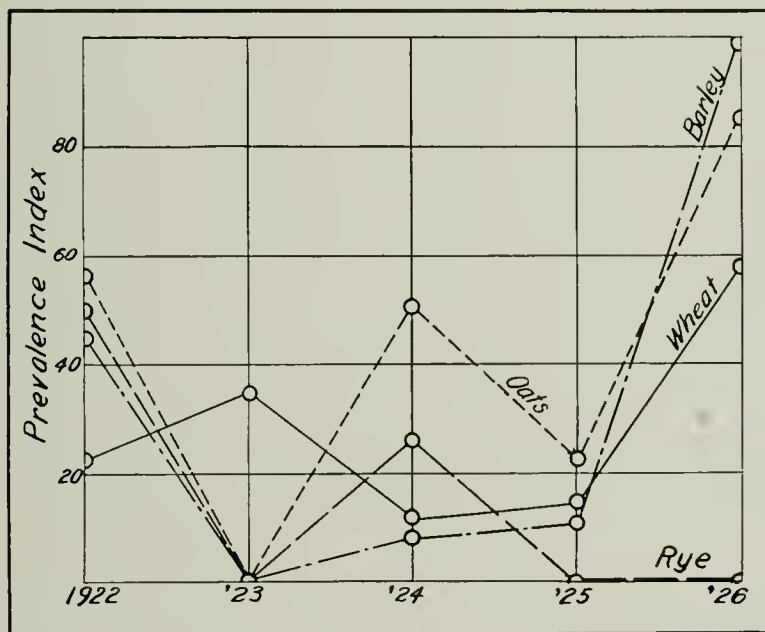


FIG. 38. PREVALENCE OF STEM RUST ON THE CEREAL CROPS, 1922-1926

The indexes of prevalence computed from field data and given in tables in the text are shown graphically here. There is a greater uniformity of prevalence trend from year to year on all crops than was true with the leaf rusts (compare with Fig. 23); but in contrast with the prevalence of the leaf rusts, stem rust reached its highest point in 1926.

than the year before. In 1926 it increased markedly on all except rye, reaching the greatest degree recorded during the survey. It is evident from an inspection of Figure 38 that the climatic conditions of any one year have not affected the prevalence of stem rust to the same extent, or in the same way, on every crop.

The intensities of attack, as indicated by the indexes of destructiveness calculated from the field data, are shown in Figure 39. Practically the same tendencies are exhibited on all the crops, wheat alone showing a marked divergence. In 1924, when the trend of destructiveness was upward on the three other crops, it declined very markedly on wheat.

There has been a distinct parallel between prevalence and destructiveness throughout the five seasons, the only break in it being the attack on wheat in 1923, in which year the increase in prevalence over the previous season was accompanied by a large decrease in destructiveness

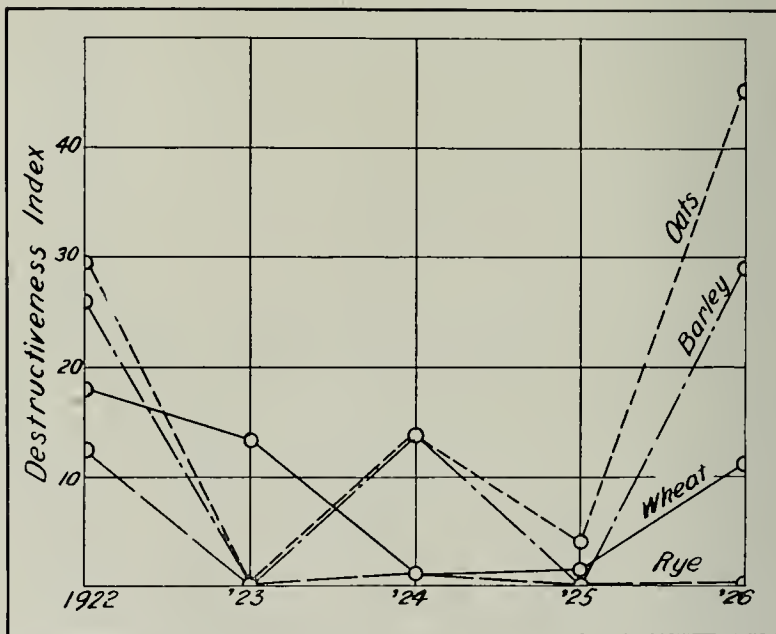


FIG. 39. DESTRUCTIVENESS OF STEM RUST ON THE CEREAL CROPS, 1922-1926

The indexes of destructiveness given in tables in the text are shown graphically here. The trend of destructiveness from year to year follows very closely the trend of prevalence (compare with Fig. 38), being greatest in 1926 and 1922, and generally very low in the other years.

CEREAL SMUTS

All of the cereal crops are subject to diseases classed under the general name, smut; but the smuts, like rusts, are different on the different crops, exhibiting different symptoms and being possessed of different means of spread and infection. On wheat there are three; on barley, two; on oats, two; on rye, two; and on corn, one. According to their appearance, they can be classed as "loose", "covered", and "stripe" smuts. In general, "covered" smuts are much less abundant than "loose" or "stripe" smuts. The covered smuts of oats and barley, because of their rarity, have not furnished sufficient data to deserve inclusion in this discussion; and the limited range of the "stripe", or "flag", smuts on wheat and rye precludes their inclusion.

The outstanding characteristic of all the smuts, except the one on corn, is that they nearly always destroy completely, either directly or indirectly, the head or the grain. The loose smuts replace the grain and the floral glumes with a mass of smutty powder, the covered smuts replace the grain and often the floral glumes as well, and the stripe smuts produce such malformations of the leaf and head that diseased stems rarely are productive. As a result, the prevalence of a smut is also a direct measure of its destructiveness.

WHEAT LOOSE SMUT

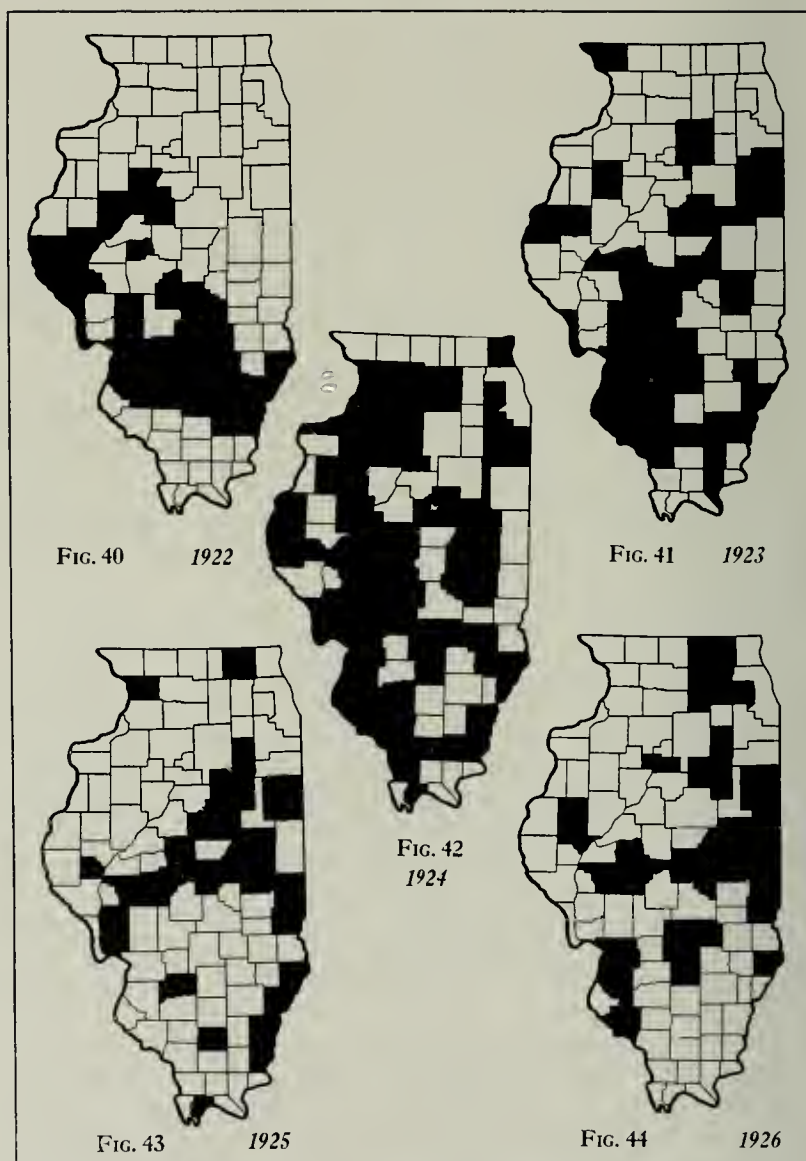
Caused by *Ustilago tritici* (Pers.) Rostr.

This is the least important of the common cereal smuts. Though distributed throughout the wheat fields of the State and conspicuous enough to be classed among the common diseases, its means of accomplishing infection, which is limited to the very short time the wheat flowers are open, prohibits it from becoming abundant, at least under Illinois conditions. For the same reason, the extreme fluctuations exhibited by other diseases will not be found with it.

During 1922, loose smut was seen in wheat fields located in the 29 counties shown in Figure 40. Wheat harvest was already so far advanced when the examinations were made that only the northern fields furnished data.

Data secured in 1923 from 81 fields located in the 38 counties shown in Figure 41 were representative of the loose smut infection of the season, not merely because of the large wheat-acreage from which they were taken but also because of their extensive distribution and their location in regions both of intensive and less intensive wheat culture.

The most abundant data obtained in any of the five years of the survey were procured in 1924. In the 58 counties shown in Figure 42, 145 wheat fields aggregating 5,661 acres were examined. The wheat grown in the counties represented by the field records aggregates 1,754,835



FIGS. 40-44. SOURCES OF DATA FOR THE LOOSE SMUT OF WHEAT, 1922-1926

The black areas on these maps show the regions from which data were taken in each year of the period. The fields examined in these five years contained a total of 16,425 acres. (See page 43.)

acres, which is slightly more than 16 per cent of the State's acreage for that year.

Data were obtained in 1925 from 51 fields located in the 26 counties shown in Figure 43. Although the acreage they contained was only about one third as great as in the previous year, the total county acreage of which they were representative constituted nearly 29 per cent of the State's acreage.

In 1926, data were obtained by examining 48 wheat fields located in the 29 counties shown in Figure 44. Though somewhat less representative with respect to size of acreage and wideness of distribution than the records of the previous two years, the increased care employed in obtaining them makes them the most dependable of all the estimates obtained.

During these five seasons, data have been taken from 349 wheat fields containing a total of 13,425 acres. The indexes of prevalence obtained from the analysis of the data compare as follows:

Year	Acreage examined	Prevalence: Calculated percentage of wheat heads infected with loose smut		
		In the acreage examined	In the county acreage represented	In the State's acreage
1922	433	1.37	1.28	89
1923	4,421	1.41	1.54	1 39
1924	5,661	.44	.44	.45
1925	1,725	.67	.69	70
1926	1,185	.94	....	....

WHEAT BUNT

Caused by *Tilletia laevis* Kuehn.

Wheat bunt, known more commonly as stinking smut, is much less prevalent than loose smut in the wheat fields in Illinois. Usually only a comparatively small number of wheat fields in a county are infested, and they often are grouped together in a small region. In the infested fields bunt may be the most costly disease, for it not only destroys the heads on infected stems but gives so bad an odor to the harvest from the field that large discounts, called dockage, from the market price are applied when the grain is sold.

The field prevalence of bunt is not easy to determine. The heads on diseased stems, though often very characteristically malformed and discolored, are yet so nearly like the normal heads that even a trained eye does not recognize them readily. Moreover, the characters by which they can be recognized do not develop fully until a field is nearly ripe. As a result, data on prevalence rarely is obtained earlier than a

few days before harvest. The fields in which it is found are, therefore, both small in number and not representative in distribution, and the data obtained from them are, very probably, understatements of the amount of infection. The only means of supplementing the field counts is to obtain reports from wheat dealers on the marketing of smut infested wheat.

In analyzing data on bunt prevalence, the procedure is not quite the same as for other diseases. The smallness of the amount of data secured from fields, together with their limited distribution, renders them incapable of complete analysis. As a rule the only figure which can be computed is an index of prevalence in the acreage known to have been infested. It can be considered only as typifying the amount of infection prevailing in the crop found by other means to have been infested.

The most useful data on bunt prevalence have been obtained in reports from grain dealers. Circular letters were sent annually to the dealers in the State, requesting reports of the number of bushels purchased and offered that were smutted; and the replies received, which have been more numerous than is usual with circulars, are believed to be especially dependable because the dealers were asked to reply only when such lots had been offered them.

The data secured in this way, being in terms of bushels rather than acres, require a treatment somewhat different from that accorded acreage statistics. The following short section taken from the analysis of the 1922 reports shows the method.

Sheet	County	Bushels reported as infested	County yield	Percentage of the county yield infested
1	Adams	0	1,011,030	0
3	Champaign	0		
4	Champaign	2,000		
5	Champaign	0		
6	Champaign	622		
7	Champaign	0		
		2,622	518,315	.506
8	Douglas	1,500		
9	Douglas	0		
		1,500	392,632	.382
30	Piatt	2,000		
31	Piatt	500		
		2,500	581,600	.430
32	Putnam	2,000	203,381	.983
	Total	8,622	2,706,958	.318

The dealers' reports are assigned places in the permanent file with other disease records. These for each year are kept in separate folders,

the sheets being assorted by counties as are the other reports, and the sheets of each folder numbered serially. In the calculations made with the data, only one tabulation is made. In the first column, the number of the report sheet is entered; in the second column, the county from which it came; and in the third column, the number of bushels of smut-infested wheat. When this is completed, the number of bushels infested is obtained for each county and for all the reports by summing the items in column 3. In column 4, opposite each county total, the county yield given in the agricultural statistical reports already mentioned is entered. The total yield of all the counties concerned in the report is the sum of these entries. By dividing the county yields by the county totals of infested wheat, a percentage, shown in column 5, is obtained which represents the proportion of smut infestation for each county; and by dividing the sum for column 3 by that for column 4 a percentage is obtained which represents the average proportion of smut infestation for all the counties in the tabulation. The percentages are carried to the third place beyond the decimal for the reason that the percentages dealt with in this disease are always very small and the maximum of accuracy is desirable.

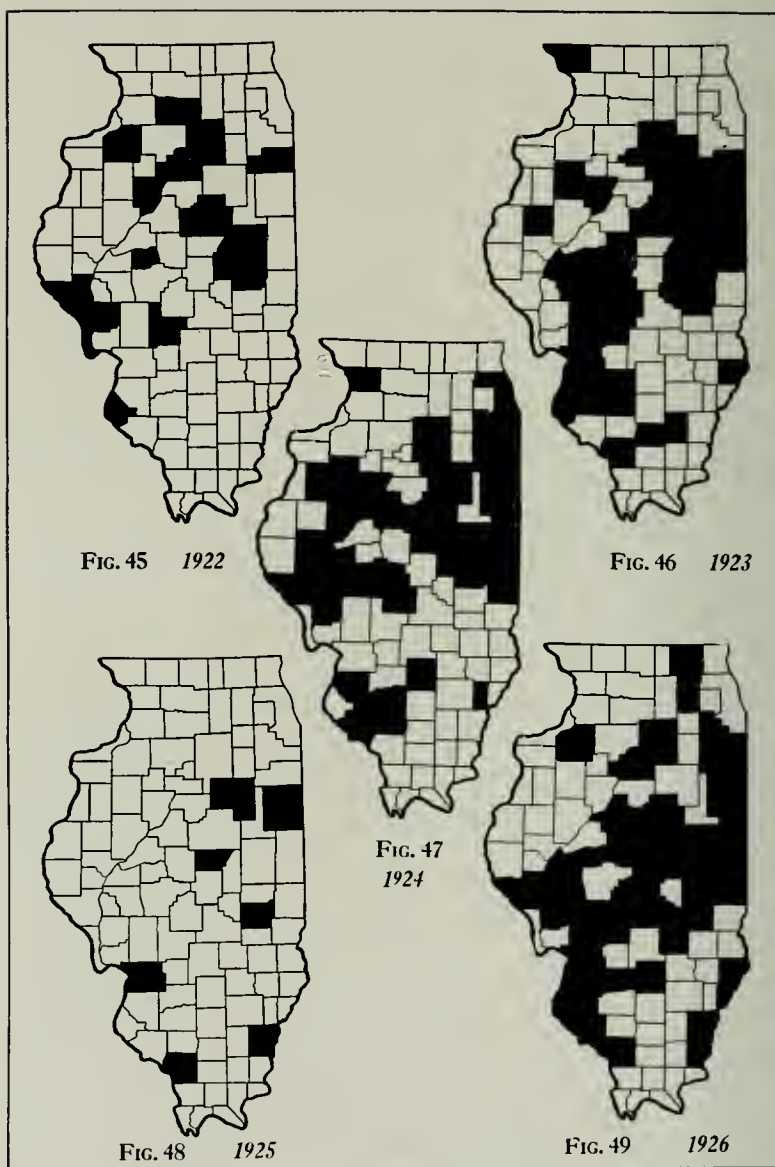
No further manipulation of these data is permissible. They must be considered as representative of the entire territory from which they came, and the complete lack of data from other territories prohibits further calculations.

The figures secured by this method are empirical in that they represent prevalence less directly than definite field data. A more definite conception of prevalence can be obtained if the results of field examinations and of dealers' reports are taken together. For example, dealers' reports show that, in 1922, .311 per cent of the State's yield was infested, the fields in which the infestation occurred having, according to the results of field examinations, 1.2 per cent of the heads bunt-infested.

During 1922 data on field prevalence were secured in six counties. These, together with dealers' reports, gave information from the 17 counties shown in Figure 45. The infestation present in 30.8 per cent of the State's yield of 55,432,000 bushels is represented.

The field data secured in 1923 are the most extensive obtained during the survey. Definite records were taken in 40 fields located in 24 widely distributed counties; but the acreage of these fields—2123 acres in all—is less than .2 per cent of the total acreage in the counties in which they were located, emphasizing again the lack of general prevalence. Grain dealers' reports received from 48 counties, give data on 64.7 per cent of the yield of the State. The counties in which bunt was shown to have occurred, by field examinations and dealers' reports, number 35 and have the distribution shown in Figure 46. From the two sets of data, it may be inferred that fields furnishing .317 per cent of the State's yield were bunt-infested to the average extent of 2.5 per cent.

Field examinations made in 1924 revealed the presence of bunt in 14 widely scattered counties. Reports for this year were received from



FIGS. 45-49. SOURCES OF WHEAT BUNT DATA, 1922-1926

The black areas on these maps show the territory from which data were taken in each year of the period. The data for this disease are obtained in part by direct examinations of fields, and in part from the reports supplied by grain dealers. During the five years of survey, data were taken from fields aggregating 2,785 acres. The dealers' reports applied to from 30.8 per cent to 64.7 per cent of the State's annual yields. (See pp. 45-47.)

grain dealers in 46 counties. The total distribution of bunt included the 34 counties shown in Figure 47.

The lack of adequate assistance in the survey during the summer of 1925 made it inadvisable to circularize the grain dealers, but data were secured by carefully examining seven bunt-infested fields in the seven widely scattered counties indicated in Figure 48. Although the number of fields is small and their acreage almost negligible, their wide distribution and the variation in degree of infestation which they exhibited justify considering the data as representative.

Field examinations showing bunt prevalence in 1926 were limited, including five fields, all of which were in four centrally located counties. However, grain dealers' reports were abundant. Responses to inquiries were received from 193 purchasing stations, the crop directly represented by these reports constituting a very large percentage of the State's yield. The range of bunt infection for the year, compiled from dealers' reports and field examinations, is indicated in Figure 49, which shows this disease to have occurred in 44 counties.

Summaries of the data showing field prevalence and the infestation of harvested grain are given in the table below.

Year	Prevalence, as shown by:			
	Field examinations		Grain dealers' reports	
	Acres examined	Average percentage of heads diseased	Bushels of marketed wheat represented	Percentage of marketed wheat smut-infested
1922	107	1.20	17,085,896	.371
1923	2,123	2.50	128,104	.317
1924	310	4.03	25,150,705	1.043
1925	105	1.43	.....	.....
1926	140	.45	.....	.....

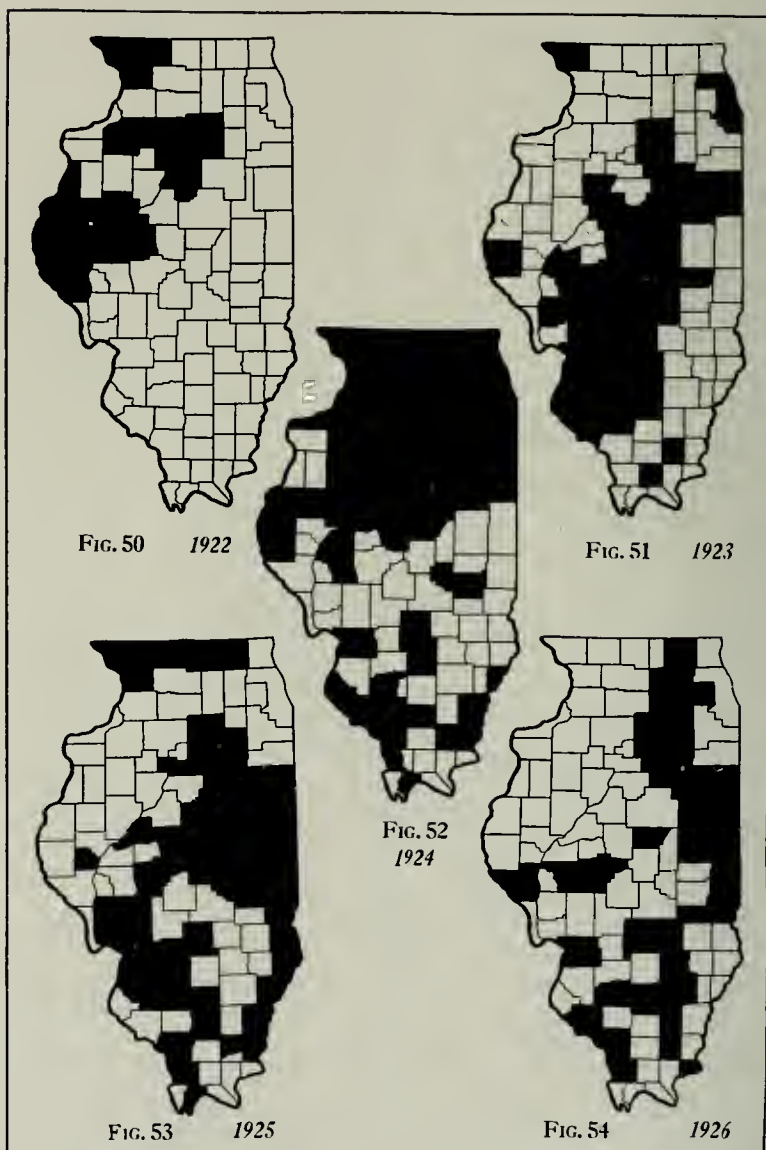
OATS LOOSE SMUT

Caused by *Ustilago avenae* (Pers.) Jens.

The loose smut of oats, though having a life history different from that of the loose smut of wheat, appears much the same in the field. It destroys the spikelets, leaving in their stead masses of smutty powder. Its abundance is measured simply as the percentage of smutted heads.

During 1922, dependable records of its prevalence were secured from 39 oat fields located in the 20 counties shown in Figure 50. It is unfortunate that all of these records should come from the northwest quarter of the State, but some dependence may be placed upon them because their number, distribution, and their varying acreages seem to indicate conditions typical of a very large part of the State.

Data showing loose smut prevalence in 1923 were secured from 88 fields aggregating 1,695 acres and distributed among the 36 counties



FIGS. 50-54. SOURCES OF DATA FOR OATS LOOSE SMUT, 1922-1926

The black areas on these maps show the territory from which data were taken in each year. In all, fields totaling 7,667 acres were examined, the smallest acreage (723) being examined in 1922, and the largest (2,412 acres) in 1924. (See page 49.)

shown in Figure 51. The extent of the regions from which the records were taken make them much more representative than those of 1922.

An acreage still larger than that of 1923 furnished data on oats smut prevalence in 1924. In all, 135 fields containing 2,412 acres were examined. They had the distribution shown in Figure 52, which includes 57 counties so widely scattered as to be typical of the entire state. The acreage in these counties constitutes 64.7 per cent of the State's acreage.

The acreage examined for smut in 1925, though less than that of 1924, was close to 2000. In the 48 counties shown in Figure 53, data were taken from 104 fields, which may be considered typical of the infection throughout the state even though a considerable territory in the northwest is not represented directly.

In 1926, 41 oats fields were examined for smut prevalence. Though their total acreage was small when compared with previous years, they were widely distributed and were directly representative of the oats crop grown in the 32 counties shown in Figure 54. These counties are so distributed as to be typical of the entire state.

The indexes of prevalence, which in these cases are also indexes of destructiveness, obtained from the field data are given below for each of the 5 years.

Year	Acreage examined	Prevalence: Calculated percentage of smut infected oats heads		
		For the acreage examined	For the county acreage represented	For the State's acreage
1922	723	6.94	4.44	5.62
1923	1,695	4.96	3.58	3.08
1924	2,412	5.43	5.21	5.20
1925	1,967	3.65	3.83	3.49
1926	870	3.40	....	....

BARLEY LOOSE SMUT

Caused by *Ustilago nuda* (Jens.) K. & S.

Although barley is subject to attack by both loose and covered smuts, the latter is found so rarely in Illinois and is recognized in the field with such difficulty that it has been impossible to secure adequate data bearing on its prevalence. As a consequence, only the data on loose smut will be presented.

In the first year of survey, 1922, no data were obtained, but in 1923 a considerable quantity of specific and general data was secured relating to infection in the 11 counties shown in Figure 55. Insofar as the field data are amenable to analysis, they indicate a prevalence of 6.3 per cent.

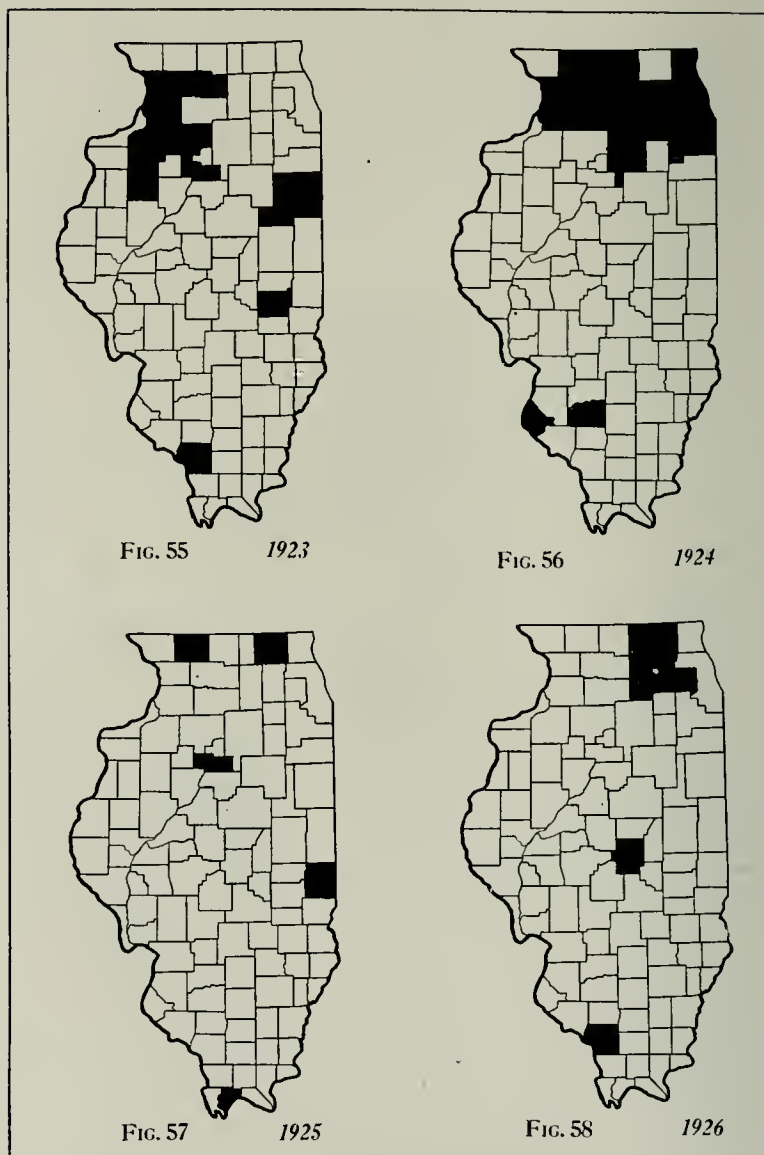


FIG. 55-58. SOURCES OF DATA FOR BARLEY LOOSE SMUT, 1923-1926

The black areas on these maps show the territory from which data were taken in each of the four years. The acreage furnishing the records was not large, in comparison with other cereals, but the concentration of barley in the northern part of the State makes small acreages quite representative. (See page 16.)

More abundant data were secured in 1924. Barley fields—32 in number—scattered among the 17 counties shown in Figure 56 were given careful examination. All but two were located in the northern barley district, their wide distribution among the northern counties resulting in a typical sampling of smut prevalence.

In 1925, records were taken from only 5 fields. They were located in the five counties shown in Figure 57. The seven fields examined in 1926 were located in the seven counties shown in Figure 58. Although not so widely scattered as the fields examined in previous years, the uniformity of the data secured from them indicates a typical representation of the northern infection.

The prevalence of barley loose smut, as shown by calculations made from field data, is shown below, year by year.

Year	Acreage examined	Prevalence: Calculated percentage of smutted barley heads		
		For the acreage examined	For the county acreage represented	For the State's acreage
1923	49	5.30	....	....
1924	400	1.71	1.67	1.64
1925	60	3.07	3.86	4.11
1926	125	5.00	....	....

CORN SMUT

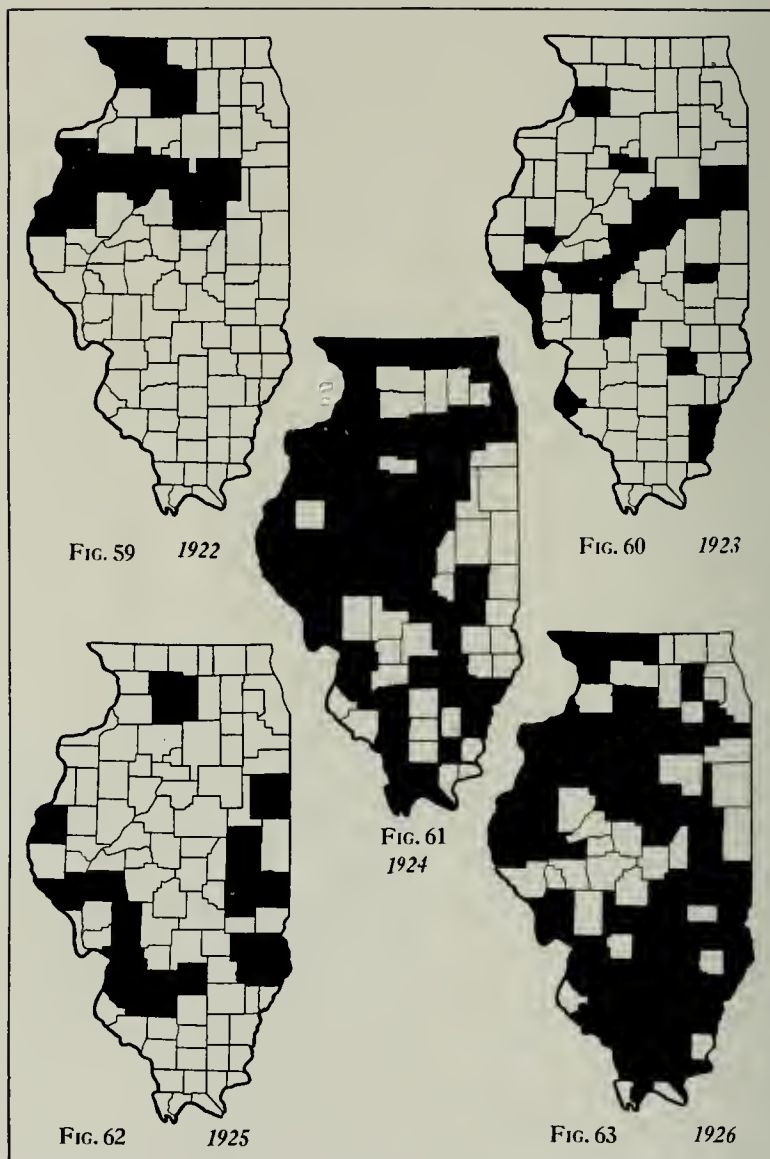
Caused by *Ustilago zeae* (Beckm.) Unger.

The smut of corn differs from the other cereal smuts in that when it attacks its host it affects localized regions, such as leaf bases, undeveloped buds in the axils of the low leaves, ears, and tassels. At least one, sometimes all, of these forms of attack may be seen on an infected stalk. Prevalence of smut, determined as for other cereals, alone is discussed in the paragraphs which follow. Destructiveness would have to be measured for each of the modes of attack; and it has not been possible, with the facilities at hand, to undertake these measurements.

In 1922, data on prevalence were obtained from 49 fields, aggregating 503 acres and representing the 17 counties shown in Figure 59. Though located entirely in the northern half of the state, and chiefly in the west, these counties are all heavy corn producers; hence, the fields examined may be considered typical of the corn fields of the state.

Data were taken in 1923 from 19 fields which were located in the 18 counties shown in Figure 60. Though fewer, these fields were more widely scattered than those examined in 1922 and contained a greater total acreage. The data secured from them are also more representative than those obtained in 1922.

The most abundant data were obtained in 1924. In the 68 counties shown in Figure 61, 141 fields were examined. The 5,546 acres which



FIGS. 59-63. SOURCES OF CORN SMUT DATA, 1922-1926

The black areas on these maps show the territory from which data were taken in each of the five years. The prevalence of smut was recorded, during these years, in 244 fields which contained a total of 8,866 acres. (See page 53.)

they contained represented directly 6,164,400 acres of corn—68.9 per cent of the State's acreage.

Twenty-four fields, distributed among the 21 counties shown in Figure 62, were examined in 1925. The data secured from them are not as typical as might be desired, for the reason that the large, centrally located corn region including McLean County is not represented. However, the universal occurrence of smut and the evident similarity of infections in widely separated regions both lend authenticity to the data.

Records of prevalence were taken in 1926 from 84 fields distributed among the 70 counties shown in Figure 63. The data secured are representative, not merely because of the extensiveness of the fields, which contained 1,574 acres, nor because of their very wide distribution, but especially because greater care was used than in previous years.

The indexes of prevalence for corn smut, determined from the field data, are as follows:

Year	Acreage examined	Prevalence: Calculated percentage of infected stalks		
		For the acreage examined	For the county acreage represented	For the State's acreage
1922	503	4.73	5.48	5.33
1923	678	5.91	9.40	11.56
1924	5,546	4.75	4.46	4.33
1925	565	3.00	3.53	3.16
1926	1,574	2.90	....	....

Summary of all data on cereal smut prevalence

The increase or decrease in prevalence from one year to another of the various cereal smuts is compared in Figure 64. There does not appear to be any definite agreement in the fluctuation exhibited by any two of these smuts throughout the period covered by the Survey's data. Neither is there any agreement in trend from one year to the next between smuts having either similar life histories or similar means of producing infection. The closest parallel is shown by the loose smut of oats and wheat bunt, both of which were moderately prevalent in 1923, increased greatly in 1924, fell off decidedly in 1925, and fell off still more in 1926. A less striking parallel existed between the loose smuts of barley and wheat, both showing in 1923 a high degree of prevalence which fell off very markedly in 1924, increased in 1925, and again in 1926; but in this case the very large variations exhibited by the barley smut stand in strong contrast with the lesser variation of the wheat smut.

The most remarkable fact illustrated is the directly opposed reactions of certain of the smuts in certain years. Oats smut showed very high prevalence, as opposed to the low prevalence of the two wheat smuts, in 1922; but in 1923 it decreased, while the wheat smuts increased. In 1924, the prevalence of wheat bunt and oat smut both increased, but that of wheat loose smut fell off, as did also that of barley smut. The high

prevalence of the two first named is in very decided contrast with the low prevalence of the last two. A similar distinct contrast is exhibited in the years 1925 and 1926, the loose smuts of both wheat and barley showing decided increases in prevalence, the loose smut of oats and wheat bunt showing decreases. The curve for corn smut conforms to no other.

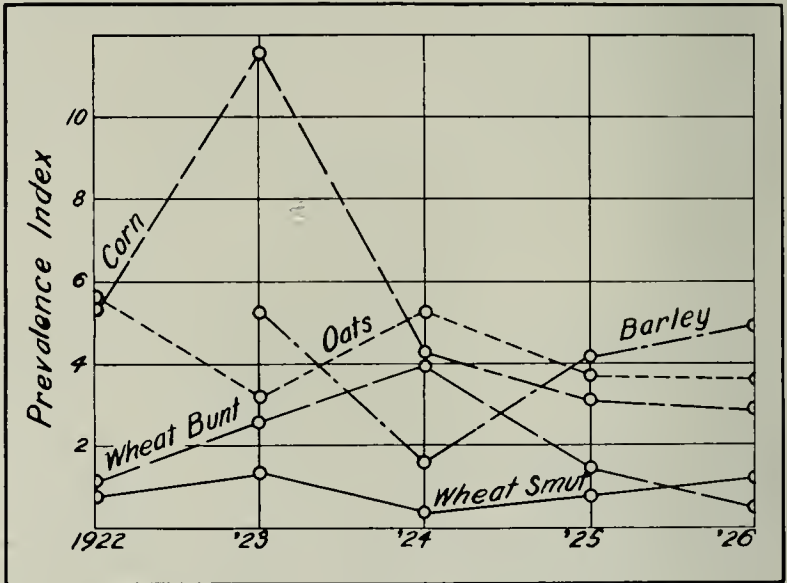


FIG. 64. PREVALENCE OF CEREAL SMUTS, 1922-1926

The year-to-year trend of prevalence for the entire period covered by the data is not the same for any two of these smuts. The closest similarity is exhibited by oats smut and wheat bunt, which followed the same trend in 1924, 1925, and 1926. Another similarity is shown by the trends of the loose smuts of wheat and barley from 1923 to 1926, but the large variations of the barley smut contrast sharply with the small variations of the wheat smut. Corn smut prevalence appears to be completely independent of the others.

SCAB OF CEREALS

Caused by *Gibberella saubinetii* (Mont.) Sacc.

As considered here, the disease commonly known as scab will be limited entirely to the effects its causal fungus produces upon the heads or spikes of the crops which it attacks. Measurement of its prevalence is accomplished in the same way as for other diseases of cereals, and its destructiveness, which might be termed severity with more propriety, is determined by exact counts of the diseased spikelets occurring on diseased heads; these heads, selected at random as the prevalence counts are made, are examined and counted later with care.

SCAB ON WHEAT

Though probably more widely distributed than our records show, scab infection of wheat had such limited prevalence in 1922 that records were taken from only 9 fields. Located in the 4 counties shown in Figure 65, they contained a total of 193 acres and, as sample fields, represented directly the scab prevalence in 212,000 acres of wheat. The data for this year show prevalence only, no special counts having been made to show destructiveness.

Records were taken from a much larger number of fields in 1923, and the territory represented by them was also much more extensive. In this year, as in 1922, the data obtained showed prevalence only. In all, 56 fields located in the 26 counties shown in Figure 66 and including a total of 2,164 acres were subjected to examination. The total county wheat acreage, of which they were samples, constituted 35.3 per cent of the State's acreage.

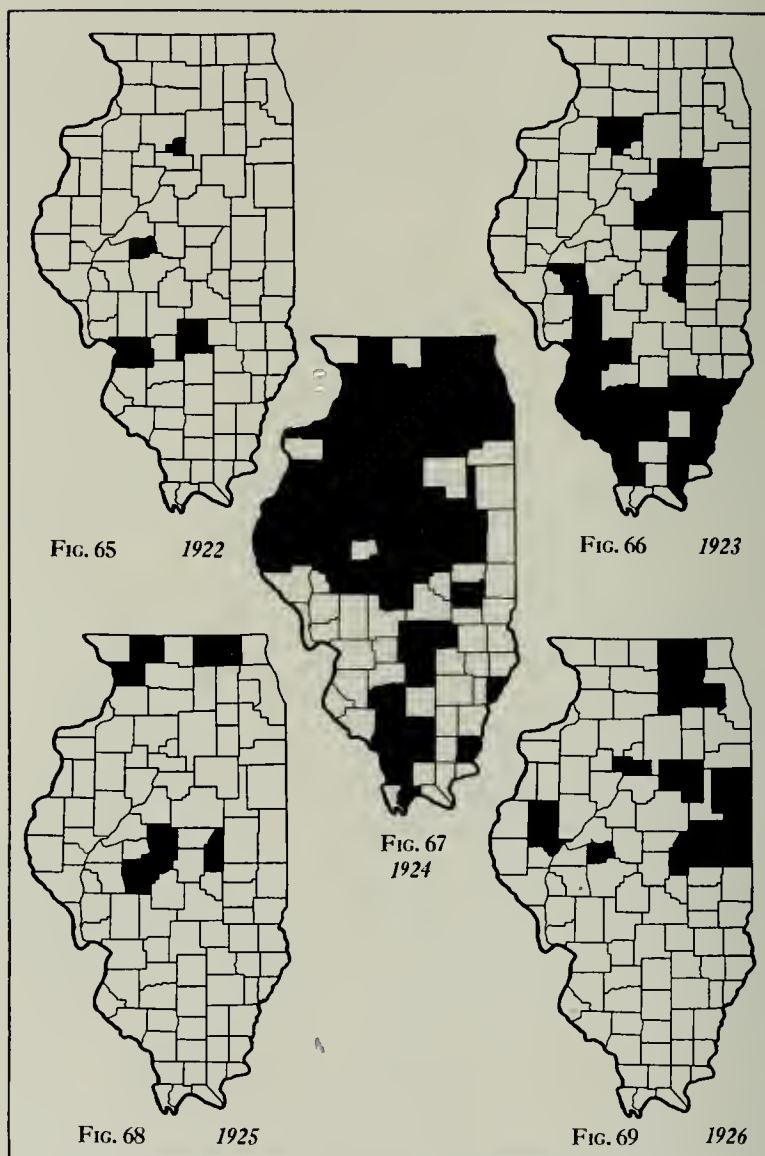
The season of 1924 gave the most abundant data, 116 fields located in the 59 counties shown in Figure 67 and containing a total of 3,166 acres being examined. It is unfortunate that, in this year of unusual prevalence, data bearing upon the destructiveness of the disease could not be secured. The 1,260,400 acres of wheat grown in the area shown in black in Figure 66, of which the sample fields were typical, constituted 54.6 per cent of the State's wheat acreage.

A very much smaller amount of data was secured in 1925, primarily because of the very late appearance of infections but also because the additional task of taking data on destructiveness required more time in each field. Only seven fields yielded data. They contained a total of 125 acres and were located in the 7 counties shown in Figure 68. A total of 173,010 acres of wheat—7.7 per cent of the State's acreage—was grown in these counties.

There was an increase in scab infection on wheat in 1926 which resulted in data being taken from 19 fields located in and representing the wheat acreage of the 11 counties shown in Figure 69. The data show both the prevalence of the disease and the destructiveness of the attack in a total of 435 acres.

The data taken from wheat fields to show the prevalence and destructiveness of scab are compared year by year in the following table:

Year	Acreage examined	Prevalence: Calculated percentages of wheat heads scab-infected			Destructiveness: Calculated percentages of wheat spikelets scab-infected		
		For the acreage examined	For the county acreage represented	For the State's acreage	For the acreage examined	For the county acreage represented	For the State's acreage
1922	193	8.84	2.54	2.43	.....	.....	.....
1923	2,164	4.22	5.65	8.82	.....	.....	.....
1924	3,166	6.18	4.16	3.46	.....	.....	.....
1925	125	16.36	34.74	21.20	14.51	34.34	20.5
1926	435	6.50	.....	.....	2.08	.....	.....



FIGS. 65-69. SOURCES OF DATA FOR SCAB ON WHEAT, 1922-1926

The black areas on these maps show the regions from which scab data were taken by direct examination of wheat fields in each year. A very large number of fields were examined, data being taken directly from a total of 6,083 acres (see page 57.)

SCAB ON OATS

Although large acreages of oats have been examined in each of the years of the survey, but few data have been accumulated on scab infection. During 1922 one infested field was found in Stephenson County, and in 1923 an infested field was found in Logan County. In 1924 scab was sufficiently prevalent to show, on the basis of the data taken from 5 fields located in the four counties shown in Figure 70, an average prevalence of .55 per cent and a destructiveness too small to be determined. The fields furnishing these estimates contained an even hundred acres.

In both of the two seasons, 1925 and 1926, scab was so rare on oats that it was neither collected nor recorded.

The prevalence may be stated for the five years as follows:

Year	Acrea examined	Percentage of panicles infected
1922	723	Trace
1923	1,695	Trace
1924	100	.55
1925	1,967	0
1926	870	0

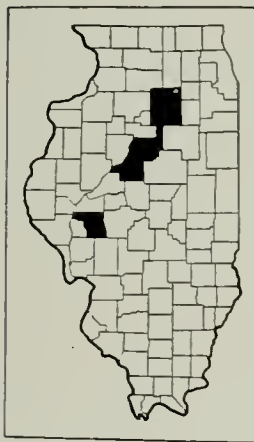


FIG. 70. SOURCE OF THE DATA FOR SCAB ON OATS, 1924

The black areas on this map show the regions from which scab data were taken by direct examination of oats fields in 1924. In the 5,355 acres of oats examined during the period 1922-1926, scab was practically absent, except in 1924.



FIG. 71. SOURCE OF THE DATA FOR SCAB ON BARLEY, 1924

Although a considerable acreage of barley was examined in each year of the period 1922-1926, data on scab were obtained only in 1924. In the other years infection was practically absent.

SCAB ON BARLEY

As was the case with oats, infection has been very light on barley during the years of the survey. Only in 1924 was it possible to secure positive data on its prevalence. In this season, 30 fields were examined. They were located in the 20 counties shown in Figure 71 and contained

a total of 392 acres. Their location in the northern counties of the State makes them typical of the barley region. In fact, the 209,780 acres of barley which they represented directly, were slightly more than 93 per cent of the State's acreage. In these fields, the data indicate a prevalence equal to 13.43 per cent; in the acreage directly represented, they indicate an average prevalence of 12.77 per cent; and in the State, of 12.86 per cent.

During 1925 and 1926 scab was so rare in barley fields that no records of it could be taken.

SCAB ON RYE

In contrast with the infections on oats and barley, scab on rye was most abundant in 1923, though the attack was too mild to measure. In the seasons of 1922, 1924, 1925, and 1926, infected rye was found only as mixtures in wheat fields.

Summary of data on cereal scab

The data obtained in field examinations, though much less voluminous than those for other cereal diseases, indicate the variations in prevalence among the individual crops from 1922 through 1926 and the intensity of the attacks in 1925 and 1926. The summaries of prevalence only, arrived at by methods previously outlined and given above for each of the crops, are compared in Figure 72.

Besides indicating that, of the four cereals commonly attacked by scab, wheat and barley alone have had serious epidemics, Figure 72

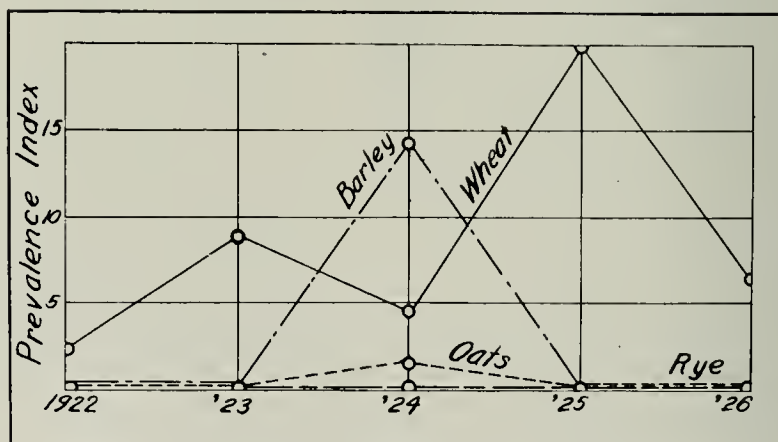


FIG. 72. PREVALENCE OF SCAB ON CEREALS, 1922-1926

The prevalence indexes for scab calculated from field data and given in the text are shown graphically here. Wheat and barley have had serious infections, and wheat alone is diseased every year.

shows that scab, like other diseases, finds conditions in a given year more favorable for spread on one crop than on another. Thus, in one season it may be very prevalent on wheat but practically absent from the other crops. Wheat appears to be the only crop consistently susceptible. There was an increase in prevalence on oats and barley in 1924; but, in contrast, the prevalence on wheat diminished. The slight rise in prevalence on rye in 1923 was accompanied by an increase on wheat. Except for these two coincidences, the tendency toward an increase in scab prevalence on one crop appears entirely independent of that tendency on another.

LEAF SPOT AND LEAF STRIPE DISEASES

Besides the common and conspicuous diseases just discussed, there is in Illinois at least one disease of each of the cereals, excepting corn, which attacks its host by entering the leaves, damaging the plants, and reducing yields by killing parts of the leaves. Barley is subject to a leaf stripe which not only results in a reduction in the amount of leaf but also generally kills the stem it attacks. Wheat is affected by "speckled" leaf blotch, which shows first as small spots but later kills large parts of the leaf. Rye is subject to a leaf spot much like the wheat leaf spot, but its occurrence in Illinois is very rare.

BARLEY STRIPE

Caused by *Helminthosporium gramineum* Rabh.

Stripe prevalence and stripe destructiveness are practically equivalent, for diseased stems die early, rarely maturing any grain. In obtaining data for this disease it is necessary, therefore, only to determine prevalence.

No data were taken in 1922 and 1923; but the lack of data from the many fields examined during these years should not be construed as showing the disease to have been absent.

In the summer of 1924 data were taken from 43 fields containing 683 acres. They were distributed among the 21 counties included in the black area of Figure 13 and, as samples of the 215,215 acres of barley grown in the area shown, were directly representative of 95.7 per cent of the State's acreage.

The records for 1925 were taken from five fields only, one in each of the five counties shown on Figure 14. Though containing a total of only 80 acres, they were representative of 56,320 acres of barley—46.2 per cent of the State's acreage.

In 1926 data were taken from 6 fields located in the 6 counties shown in Figure 15. These fields, which contained 120 acres, were located mainly in the northeast corner of the state, in a region devoted to barley production, and may be considered as typifying the prevalence of stripe infection.

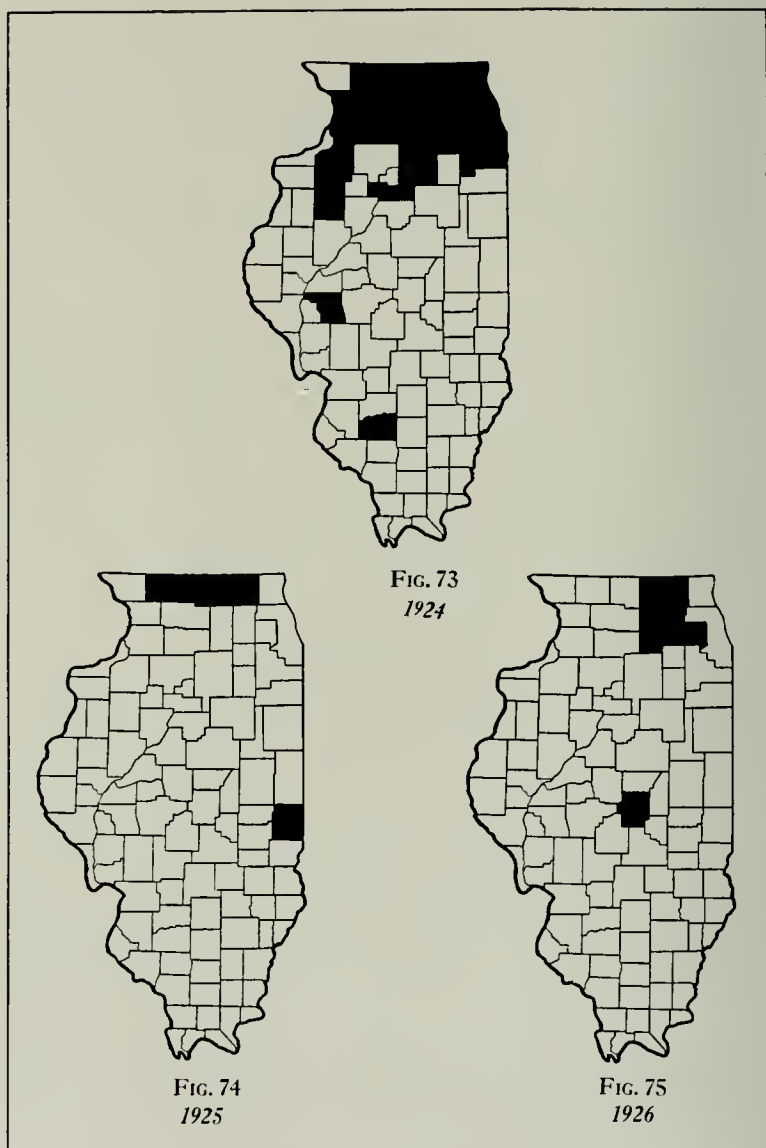


FIG. 73-75. SOURCES OF BARLEY STRIPE DATA, 1924-1926

The black areas on these maps show the regions from which data were taken by direct examination of barley fields in each year. No data were taken in 1922 and 1923, but the fields examined in 1924 were representative of 95 per cent, and in 1925 of 46 per cent of the State's acreage (see page 61).

The data accumulated show, when subjected to analysis, the following degrees of prevalence and destructiveness.

Year	Acreage examined	Prevalence and Destructiveness: Calculated percentages of stripe-infected barley culms		
		For the acreage examined	For the county acreage represented	For the State's acreage
1924	683	1.69	1.90	1.76
1925	80	4.49	4.21	4.16
1926	120	2.25	....	....

The indexes in this table are representative of stripe infection, except that the index for 1926 is somewhat low, being unduly lowered through the influence exerted in the calculations by a large field of 40 acres in Macon County. Were statistics available for 1926, this index would approximate 3.37 per cent in the two columns now vacant. This figure will be used in the summary to be made later.

SPECKLED LEAF SPOT OF WHEAT

Caused by *Septoria tritici* Desm.

Wheat plants are killed by the leaf spot only in rare instances; but in almost every season the disease is sufficiently abundant to cause serious damage to growing and maturing plants. Its prevalence is measured in terms of the number of stalks bearing spotted leaves; but since the spotting on the leaves varies in quantity, leaf by leaf and plant by plant, a special scale for determining destructiveness has been devised, a reduced replica of which is shown in Figure 16.

Such diagrams representing wheat leaves present, in a graded series, readily distinguishable degrees of leaf spot injury. Abundance of leaf spot infection, though in some measure correlated with the amount of injury, is not often the same, a fact explained through the ability of a spot located on the lower part of a leaf to cause the death of a large amount of leaf tissue extending upward beyond it. The examples in the scale indicate distinguishable degrees of injury as percentages of leaf area destroyed. They are also typical of types of injury commonly encountered in the field.

In making use of the device, the observer collects a generous leaf sample at random, while he is making prevalence counts. As the sample will contain leaves with no infection, with light infections, and with heavy infections, it should represent the average amount of leaf injury present on disease-bearing stalks. Either then, or later in the laboratory, the parts of the sample—fresh in the field, but pressed and dried in the laboratory—are compared individually with the standardized diagrams by fitting each part between the two standards which it most closely resembles. The intermediate value of the sample part is not determined, for

to do so involves personal judgment to an extent certain to result in gross error. Instead, each part of the sample is considered as falling in the class represented by the scale diagram having the lower value of the two between which it falls. A record is made on the field data sheet of the number of parts of the sample falling in each class, and the average amount of leaf spot injury shown by the sample is determined in the manner described on page 19.

An analysis of the data on prevalence and destructiveness then is made in the manner described in the first part of this paper (see pages 8-14).

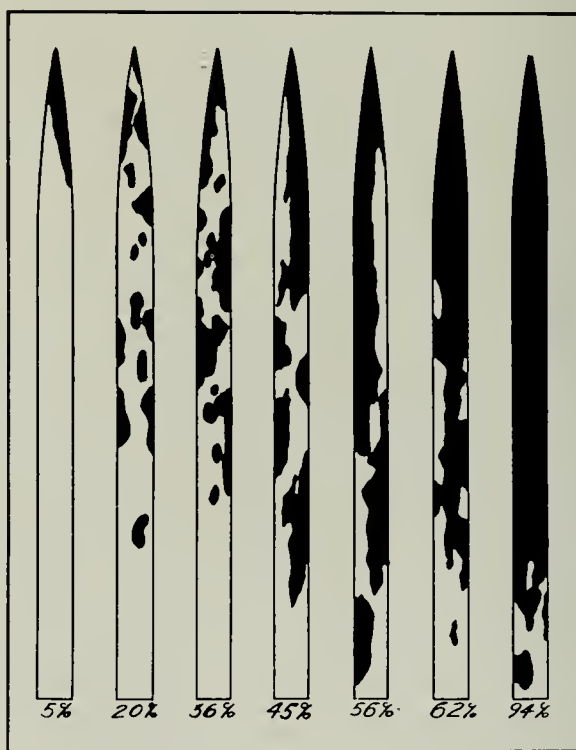
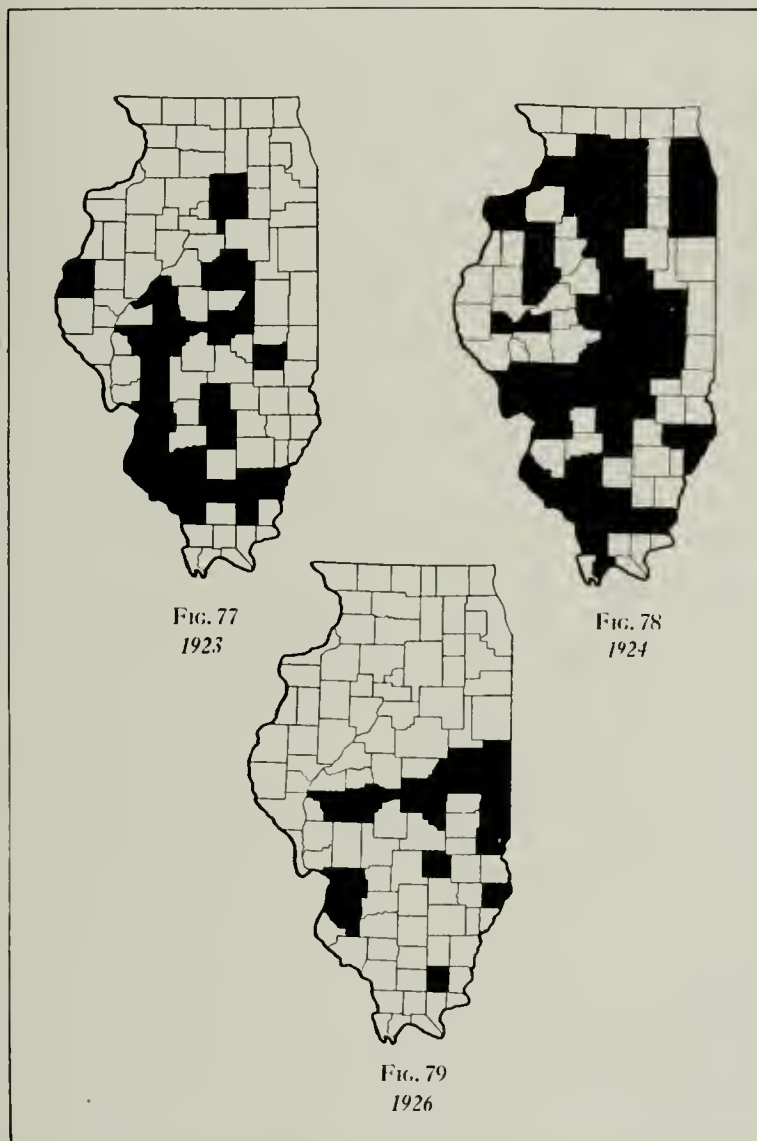


FIG. 76. STANDARD FOR MEASURING THE DESTRUCTIVENESS OF THE SPECKLED LEAF SPOT OF WHEAT

The black areas on each diagrammatic leaf represent the tissue killed by the leaf spot fungus. The area of the black spots has been measured and is given as a percentage of the entire leaf area for each diagram. Random samples taken in each field are compared with this scale, and the destructiveness of the disease is computed in terms of leaf area destroyed (see page 63).



FIGS. 77-79. SOURCES OF THE DATA FOR THE SPECKLED LEAF SPOT OF WHEAT IN 1923, 1924, AND 1926

The black areas on these maps show the regions from which data were taken by direct examination of wheat fields in each year. During the period 1922-1926 fields containing a total of 12,787 acres were examined for this disease, 862 acres showing none of it in 1922 and 3,225 acres having only a trace in 1925.

Due in a large measure, perhaps, to the exceedingly heavy attack of leaf rust in 1922, leaf spot appeared practically absent from wheat fields. No positive data on its prevalence were secured that year. In 1923, however, a considerable quantity was obtained from 41 fields located in the 24 counties shown in Figure 77. The fields examined contained 2,428 acres and were representative of 40.3 per cent the State's wheat acreage.

The season of 1924 furnished the largest accumulation of leaf spot data of any of the seasons covered by the survey. Examinations were made in 149 fields distributed in somewhat varying numbers among 53 counties. They furnished a representative sampling of leaf spot prevalence and intensity for the region shown in black in Figure 78. The fields themselves contained 5,667 acres, while the region which they represent grew 1,389,975 acres—60.3 per cent of the State's 2,307,000 acres of wheat.

Speckled leaf spot was rare in 1925. In 3,225 acres examined, only four instances of infection were found, one each in Clark, Crawford, Pulaski, and St. Clair counties. Though sufficient to give samples for laboratory diagnosis, they were so light that they could not be estimated, either in prevalence or severity. The infection for 1925 is to be considered, therefore, as only a trace.

In 1926, leaf spot was prevalent in fields throughout the central and southern parts of the state, but was not found in the northern third. Records of prevalence and severity were taken from 23 fields, which contained 605 acres and were located in the 14 counties shown in Figure 79. The data obtained were representative only of the infection in the southern half of the state, and the prevalence and intensity of the attack, expressed respectively by indexes of 11.0 and .39 calculated from these data, will be reduced considerably when 1926 acreage statistics become available for further calculations.

The fluctuations in prevalence and intensity of attack, as shown by the field data when subjected to analysis, are as follows:

Year	Acreage examined	Prevalence: Calculated percentage of wheat stalks with diseased leaves			Destructiveness: Calculated percentage of wheat leaf area destroyed		
		For the acreage examined	For the county acreage represented	For the State's acreage	For the acreage examined	For the county acreage represented	For the State's acreage
1922	.....	0	0	0	0	0	0
1923	2,428	88.7	88.3	89.2	26.2	23.2	21.8
1924	5,667	58.3	53.2	54.2	9.06	8.03	9.5
1925	3,225	T	T	T	T	T	T
1926	605	11.0	....	....	.30	....	....

OATS HALO BLIGHT

Caused by *Pseudomonas coronafaciens* (Elliott) Stev.

Though the symptoms presented by the halo blight of oats are quite different from those shown by the leaf spot of wheat discussed above, the method of estimating its destructiveness is much the same. Its prevalence is determined, of course, as the percentage ratio of disease-bearing stalks. For estimating the intensity of the attack, a special scale, shown with considerable reduction in Figure 80, has been devised. The effect produced by halo blight in destroying leaf tissue appears to be considerably less than the similar effect of the wheat leaf spot. The degrees of destructiveness are more readily distinguishable, which permits the use

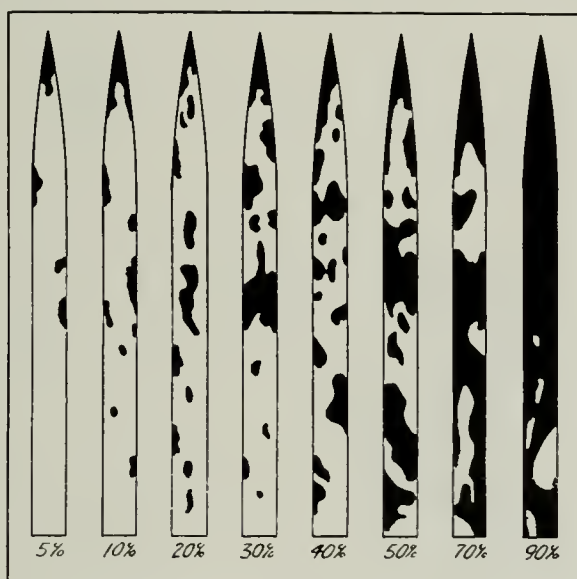


FIG. 80. STANDARD FOR MEASURING THE DESTRUCTIVENESS OF OATS HALO BLIGHT

The black spots on each diagrammatic leaf represent the tissue killed by the halo blight bacterium. The area of the spots has been measured and is given as a percentage of the entire leaf area for each diagram. Random samples taken in each field are compared with this scale, and the destructiveness of the disease is computed in terms of leaf area destroyed (see page 69).

of a larger number of individual standards in the scale and results in a considerably greater degree of accuracy in the estimates. Otherwise, the methods of obtaining field data are the same as those previously discussed.

During 1922, with halo blight of oats as with several other cereal diseases, data were recorded exclusively in the northern half of the State. Definite records were taken in 5 fields which contained a total of 9½ acres and were located in the 4 counties shown in Figure 81. Although their combined acreage is not impressively large, their wide

separation together with the constancy of the data endows them with a certain degree of dependability.

In 1923 only two records of halo blight were obtained. A small field of 5 acres in Macoupin County, examined June 20, yielded the information that 65 per cent of the stems bore leaves having an average of 50 per cent of their area destroyed. In another small field of 3 acres in Fayette County, examined June 12, 3 per cent of the stalks bore leaves having 17.5 per cent of their area destroyed. In view of these facts, the prevalence and destructiveness of halo blight in 1923 were too light to be estimated.

In 1924 data were taken from 78 fields which contained a total of 1,291 acres. They were distributed among the 43 counties which make up the black areas of Figure 82. The oats grown in these areas, 1,906,500 acres, make up 43.5 per cent of the State's acreage.

Again in 1925 abundant data were obtained. The fields examined, 56 in number, contained 1,189 acres and represented the infection prevailing in the 31 counties shown in Figure 83. These counties contained 2,237,510 of the State's 4,724,000 acres devoted to oats production. The data, therefore, apply directly to 47.4 per cent of the State's acreage.

Much less abundant in 1926 than in the two preceding seasons, halo blight was, nevertheless, widely prevalent. Records were taken in the 9 counties included in the black areas of Figure 84.

Prevalence and destructiveness, as shown by data obtained by the survey, are given in the following table:

Year	Acreage examined	Prevalence: Calculated percentage of oats culms bearing blighted leaves			Destructiveness: Calculated percentages of oats leaf area destroyed by halo blight		
		For the acreage examined	For the county acreage represented	For the State's acreage	For the acreage examined	For the county acreage represented	For the State's acreage
1922	97	77.90	78.30	67.70	14.20	14.80	13.60
1923	1,306	T	T	T	T	T	T
1924	1,291	61.33	46.45	47.87	8.27	8.27	7.30
1925	1,189	47.06	47.62	44.59	11.93	11.93	5.76
1926	315	3.00	.....	.....	T	.....	.....

Summary of leaf spot and stripe data

The variations in prevalence indicated for the individual diseases in the foregoing tables are brought into graphical comparison in Figure 85, while the differences in destructiveness are shown in Figure 86.

So far as available data show, the trends of both prevalence and destructiveness are the same for each disease; but there are marked differences in these trends for the different diseases. In 1922, both in prevalence and destructiveness, halo blight of oats stood high, while the speckled leaf spot of wheat was very low. In the succeeding year,

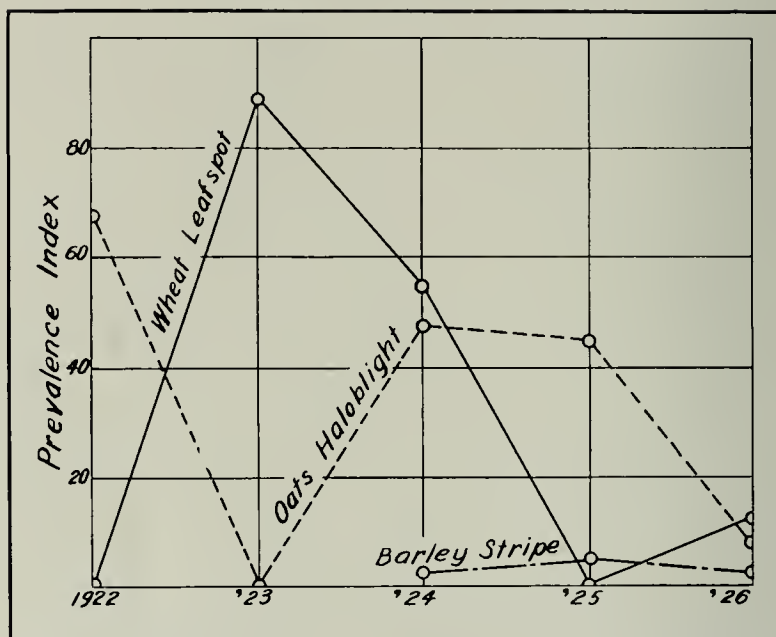


FIG. 85. PREVALENCE OF THE LEAF SPOT AND STRIPE DISEASES, 1922-1926

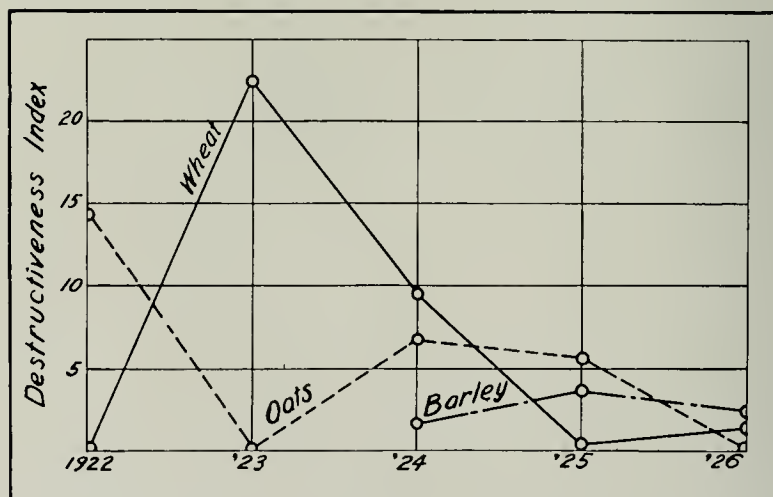


FIG. 86. DESTRUCTIVENESS OF THE LEAF SPOT AND STRIPE DISEASES, 1922-1926

1923, their positions were reversed, the former being low and the latter very high. The summer of 1924 was marked by a sharp decline of speckled leaf spot and a sharp rise of halo blight, the two being very nearly equal in prevalence and in destructiveness. In 1925 both diseases stood below their marks of the previous years, but the decline of halo blight was slight and that of leaf spot great, leaving the former still serious and the latter insignificant. In contrast to these two, there was a slight rise in the prevalence of barley stripe. Finally, in 1926, halo blight and barley stripe exhibited declines in both prevalence and destructiveness, which contrasted sharply with the increase shown by the speckled leaf spot of wheat.

SUMMARY OF ALL DATA SHOWING PREVALENCE AND DESTRUCTIVENESS

All of the diseases considered in the previous pages have been of a kind which attacks and destroys above-ground parts of the plant. When considered in relation to their effects, they are of three types: destroyers of stem tissue, of leaf tissue, and of heads. One only, the smut of maize, commonly attacks all parts of the plant. Data on at least one of each of these types of disease have been given for each of the cereal crops for nearly every one of the five seasons. In any season an individual plant of any of these crops may bear one, and is likely to bear two or even more, types of disease. This fact is not particularly significant with respect to the prevalence of the several diseases, but it is very important in determining the destructiveness resulting from disease attack.

The prevalence indexes previously given for the several types of disease are brought together in the following tables in closer relation to the individual crops. For each crop, the indexes of the several diseases are added together to give an index of total prevalence for each year; and averages are obtained for the entire period of the survey. This gives a fairly exact comparison of the five seasons.

Disease	Prevalence:					
	in 1922	in 1923	in 1924	in 1925	in 1926	Average
Leaf rust	94.10	89.70	68.30	52.60	57.24	72.38
Stem rust	22.06	35.70	11.10	14.90	57.80	28.31
Loose smut	.89	1.39	.45	.70	.94	.88
Bunt	1.20	2.50	4.03	1.43	.45	1.92
Scab	2.43	8.82	3.46	21.20	6.50	8.48
Septoria	0	89.20	54.20	T	11.00	30.88
Total	120.68	227.31	141.54	90.83	133.89	142.85

On wheat, as shown in the first table, the total prevalence, as well as the prevalence of each disease, fluctuates from year to year. The season

of 1925 ranks lowest, 1922 next, then 1926 and 1924, and finally 1923 at the peak with a total prevalence of 227.31.

The prevalence of oats diseases is given in the following table:

Disease	Prevalence:					
	in 1922	in 1923	in 1924	in 1925	in 1926	Average
Crown rust	67.00	83.10	64.3	27.00	70.40	62.36
Stem rust	56.90	0	45.5	21.60	85.50	41.90
Loose smut	5.62	3.08	5.2	3.49	3.40	4.58
Scab	T	T	.75	0	0	.15
Halo blight	67.70	T	47.87	44.50	3.00	32.63
Total	197.22	86.18	163.62	96.68	162.30	141.20

The average prevalence of disease for the survey period is 141.2, which, when compared with the index for wheat, 142.85, shows how similar in average prevalence the diseases of the two crops are. The variation in prevalence, season by season, is as evident as in the case of wheat diseases, and the differences in prevalence shown by the individual diseases are also evident.

The barley data, though in general much less abundant than those of wheat and oats, furnished indexes of prevalence which compare as follows:

Disease	Prevalence:					
	in 1922	in 1923	in 1924	in 1925	in 1926	Average
Leaf rust	25.0	100.0	100.0	34.6	76.10	67.14
Stem rust	45.5	0	8.0	11.1	100.00	32.92
Loose smut	....	5.30	1.64	4.11	5.00	4.01
Scab	....	....	12.86	T	T	4.29
Stripe	....	....	1.76	4.16	2.25	2.72
Total	70.5	105.3	124.26	53.97	183.35	107.47

The prevalence indexes of rye diseases, though computed like those for barley, from rather limited data, give the following comparison.

Disease	Prevalence:					
	in 1922	in 1923	in 1924	in 1925	in 1926	Average
Leaf rust	99.1	50.3	22.2	44.5	19.1	47.04
Stem rust	50.0	0	25.9	0	0	15.18
Scab	T	T	T	T	T	T
Total	149.1	50.3	48.1	44.5	19.1	62.22

Although only three diseases are considered, instead of the five or six diseases of the crops just discussed, similar seasonal variations in prevalence are evident.

For corn, the number of diseases treated is of necessity small, and the information secured concerning them, due to conditions imposed, has often been inadequate. Yet the indexes of prevalence obtained show the following comparisons:

Disease	Prevalence:					
	in 1922	in 1923	in 1924	in 1925	in 1926	Average
Rust	34.6	3.0	62.6	33.3	11.4	28.98
Smut	5.33	11.56	4.33	3.16	2.9	5.46
Total	39.93	14.56	66.93	36.46	14.3	34.44

In order to show clearly the fluctuations from season to season of the total infections by the diseases discussed, the totals from the above tables are shown in Figure 87. The same lack of agreement is evident when the prevalence of the diseases attacking one crop is compared with those attacking another. Of the five years covered by our survey, there is not one in which disease prevalence was uniformly either

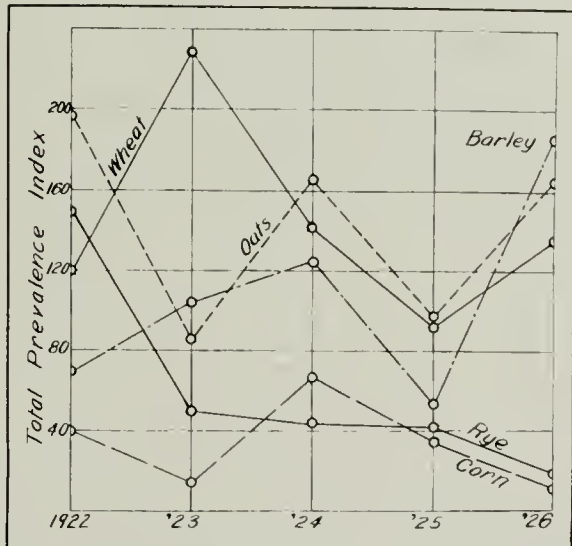


FIG. 87. TOTAL DISEASE PREVALENCE FOR EACH CROP, 1922-1926

There was not one year among the five in which disease prevalence was uniformly high or low on all the cereals, nor was prevalence constant in amount on even one crop throughout the period.

heavy or light on all of the five cereals. The closest approach to such a condition occurred in 1925, the total prevalence of disease in that year being, for each of the five crops, less than the year before. Beginning with the wide range of total prevalences displayed in the season of 1922, the trend was downward for rye, corn, and oats diseases, but upward for those of barley and wheat in 1923; down for wheat and rye diseases but up for those of oats, barley, and corn in 1924; down for the diseases of all five crops in 1925; and in 1926 down for corn and rye, but up to relatively high points for wheat, oats, and barley diseases.

The average total prevalence over the period of years covered by the survey is remarkably characteristic for each of the five crops. This fact is illustrated in Figure 88, in which the five-year index averages given in the foregoing five tables are shown graphically. The high prevalence of infection on wheat and oats is indicative of the fact that these crops suffer most from diseases of their above-ground parts. The

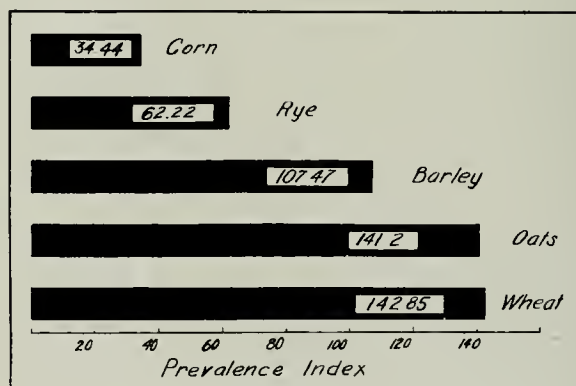


FIG. 88. AVERAGE DISEASE PREVALENCE FOR EACH CROP

The indexes of prevalence given in the text for the diseases of each crop have been added and averaged in order to show the normal prevalence of diseases on each crop in Illinois.

lesser prevalence shown for barley and rye result, in part at least, from the limited range of culture of the first crop and from the scattering cultivation accorded the latter. In the case of corn, however, the very low average prevalence may be considered as directly correlated with the relatively minor ranks held by smut and rust among corn diseases.

It is not possible to gain a clear-cut conception of the destructiveness of diseases through the simple process of adding the indexes, as has been done for prevalence. The types of injury caused by the various

diseases are dissimilar and, therefore, require a more complicated treatment.

From the data previously given to show the comparative intensity of attack, those relating to wheat are selected and shown together in the following table:

Disease	Destructiveness:														
	1922			1923			1924			1925			1926		
	Stem injury	Leaf injury	Head injury	Stem injury	Leaf injury	Head injury	Stem injury	Leaf injury	Head injury	Stem injury	Leaf injury	Head injury	Stem injury	Leaf injury	Head injury
Leaf rust	...	50.3	...	...	31.3	...	...	19.1	...	...	17.1	...	...	11.2	...
Stem rust	17.8	...	...	8.0	...	...	...	.6	...	1.2	...	...	11.2	...	...
Loose smut	...	...	89	...	...	1.39	...	...	45	...	...	70	...	...	94
Bunt	...	1.20	...	...	2.50	...	...	4.30	...	...	1.43	...	...	...	45
Scab	...	T	...	...	T	...	...	T	...	...	20.50	...	...	...	2.08
Leaf spot	...	0	...	...	21.8	...	...	9.5	...	...	T	...	...	3	...
Total	17.8	50.3	2.09	8.0	53.1	3.89	.6	28.6	4.75	1.2	17.1	22.63	11.2	11.5	3.47

Disease attack injures or kills parts of the wheat stem, leaf, or head, thereby interfering with the ability of the plant to produce grain. The degrees of disease severity shown by the totals in the above have more or less commensurate effects upon the ability of the wheat to yield in each year; but a real understanding of the total destructiveness in one year with that in another is not readily attained by examining the table.

In order to gain a clearer picture of the meaning of the figures, one may imagine, first, a wheat stalk, unattacked by disease, with stature and proportions of leaf and spike such as those illustrated by the standard in Figure 89. The effect of disease attack upon such a stalk, through the injury it causes, would be to cut down the amount of stem, leaf, and spike in proportion to the severity of the attack, leaving only the healthy parts to produce the harvest. Yield from a diseased stalk might be expected to compare closely with the yield of a healthy stalk having the same proportions as those left healthy on the diseased stalk. The effect of disease attack may be appreciated, then, by imagining five wheat stalks, one for each of the years covered by our survey, reduced in the size of their parts, as shown in Figure 89, in the exact proportions (insofar as they can be depicted) indicated by the figures in the foregoing table.

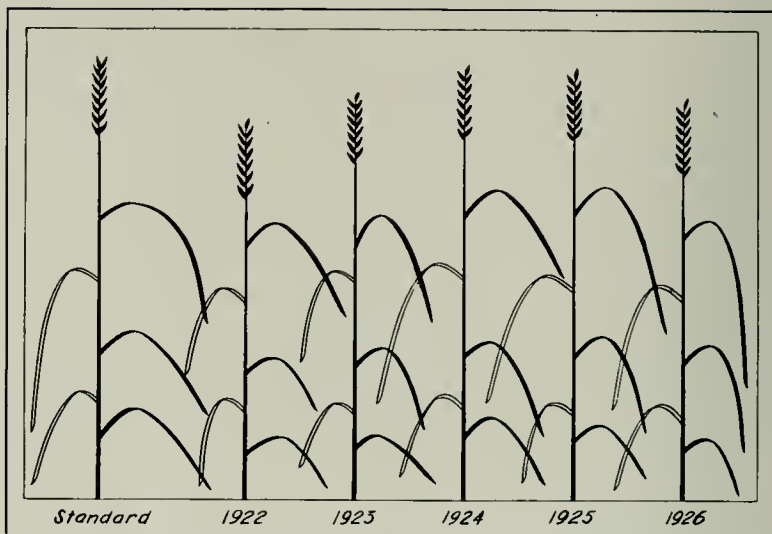


FIG. 89. DESTRUCTIVENESS OF WHEAT DISEASES, 1922-1926

The effect of disease attack upon the stems, leaves, and heads of wheat, as indicated by the indexes of destructiveness given in the text, is shown for each year of the period 1922-1926 in comparison with an average healthy stalk.

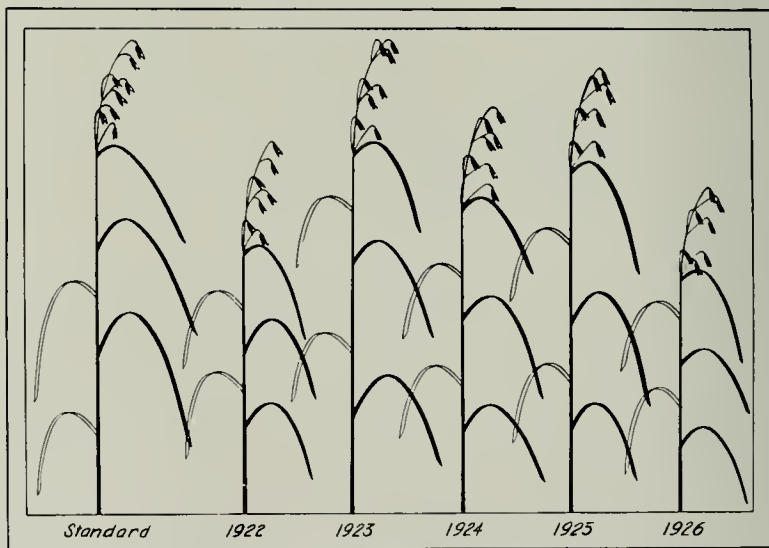


FIG. 90. DESTRUCTIVENESS OF OATS DISEASES, 1922-1926

The effect of disease attack upon the stems, leaves, and panicles of oats, as indicated by the indexes of destructiveness given in the text, is shown in comparison with an average healthy stalk. See the text on page 75 for further explanation.

The destructiveness of the diseases of oats, barley, and rye may be regarded in the same way as the diseases of wheat. A statement of their destructiveness may be made, consequently, by omitting summarizing tabulations like that given above for wheat diseases and using, in their stead, illustrations similar to Figure 89.

In Figure 90, the total effect of disease attack on oats, as indicated by the indexes of destructiveness given in previous pages, is illustrated for each year in comparison with an undiseased stalk of average proportions. The stature of the stalk is shown reduced 29 per cent by stem rust attack in 1922, not at all in 1923, 13.8 per cent in 1924, 4.5 per cent in 1925, and 42.7 per cent in 1926; the normal leaf complement is illustrated as being reduced 40.9 per cent by the combined attacks of crown rust and halo blight in 1922, 30.6 per cent in 1923, 19.2 per cent in 1924, 6.4 per cent in 1925, and 9.9 per cent in 1926; and the spikelets are depicted as reduced 5.62 per cent by scab and loose smut in 1922, 3.08 per cent in 1923, 5.95 per cent in 1924, 3.49 per cent in 1925, and 3.4 per cent in 1926.

The destructiveness indicated by the indexes given previously for barley diseases is shown in Figure 91. In comparison with a barley stalk



FIG. 91. DESTRUCTIVENESS OF BARLEY DISEASES, 1922-1926

The effect of disease attack upon the stems, leaves, and panicles of barley, as indicated by the indexes of destructiveness given in the text, is shown in comparison with an average healthy stalk. See the text on pages 75-77 for further explanation.

of normal proportions, stem rust is shown to have reduced the stature 12.4 per cent in 1922, not at all in 1923, .6 per cent in 1924, .2 per cent in 1925, and 28.7 per cent in 1926; the normal leaf complement is reduced 5 per cent by the combined attacks of leaf rust and stripe in 1922, 5 per cent in 1923, 6.16 per cent in 1924, 9.16 per cent in 1925, and 9.25 per cent in 1926; and the heads are reduced 5.3 per cent by loose smut in 1923, 1.64 per cent in 1924, 4.11 per cent in 1925, and 5.0 per cent in 1926.

The destructiveness effect of rye diseases is illustrated in Figure 92. In comparison with an undiseased stem of average proportions, the diagram illustrating the disease injury of 1922 has 25.5 per cent less stem and 55.1 per cent less foliage; for 1923 the stem is normal and the foliage 8.2 per cent smaller for 1924 the amount of stem of 13.9 per cent less, and the foliage 2 per cent less; for 1925 the stem is normal, the foliage .9 per cent less; and for 1926 the stem is normal but the foliage is 19.1 per cent less. In every season, the heads are drawn at normal size, as the data accumulated for head smut, scab and ergot showed no appreciable general reductions from their attack.

No similar depiction can be given of the effect of smut and rust on corn, for no satisfactory method of estimating their destructiveness has been devised.



FIG. 92. DESTRUCTIVENESS OF RYE DISEASES, 1922-1926

The effect of disease attack upon the stems, leaves, and panicles of rye, as indicated by the indexes of destructiveness given in the text, is shown in comparison with an average healthy stalk.

SOME RELATIONS OF DISEASE TO WEATHER AND CLIMATE

There is abundant evidence in the experience of the farmer and the disease specialist that a vital relation exists between the occurrence of disease epidemics such as those described in the preceding pages and the accompanying weather conditions. Particular combinations of temperature and rainfall have been observed to accompany—even to condition—severe attacks, and the absence of them generally is attributed to a corresponding absence of favorable weather. The climate of a region, also, appears to determine to a very large extent what the relative importance of particular diseases shall be, or whether any disease shall be important.

In the main, these interrelations have not been defined. With respect to weather, they have been generalized into the four categories, hot and wet, hot and dry, cold and wet, and cold and dry, each combination being reported to have a particular influence over particular diseases. Since they refer, almost without exception, to departures from the average conditions of localities or limited regions familiar to the observers who make the statements, it is not surprising that a list of their reported effects contain incongruous diversities of opinions, among which the only apparent agreement often is that weather has had a dominating influence. This applies particularly to diseases which attack plants above the ground; for a number of diseases that are soil borne or attack the parts of plants that are in the soil have been subjected to extensive investigation in the laboratories of the Wisconsin Agricultural Experiment Station*, where many of their relations to temperature and soil moisture have been ascertained. But, with diseases attacking as well as spreading to and from aerial plant parts, the conditions which govern infection are chiefly those of the atmosphere, though it must be recognized that concurrent soil conditions may so hasten or delay the plant's growth that even under ideal atmospheric conditions heavy infection does not occur.

The difficulties which attend the artificial duplication of out-of-door weather in the limited space of a laboratory demand that the main facts of the disease-and-weather relation shall be determined by observing the two as they occur naturally. The conclusions arrived at may be subjected later to experimental verification and refinement; but the principles worthy of practical application to the problems of the farm certainly will be those derived by observing natural phenomena.

It is not within the scope of this paper to define exactly any of these principles, for the chief intention has been to describe ways of measuring disease phenomena; but a small contribution may be made by showing some of the ways in which disease data may be correlated

* Jones, L. R., James Johnson, and James G. Dickson. Wisconsin studies upon the relation of soil temperature to plant disease. Wis. Agr. Exp. Sta. Research Bull. 71. 1926.

with weather. As this material is presented mainly by way of example, it will be limited to the leaf rust of wheat, leaving the fuller treatment of it and other diseases to later papers.

RELATION TO MEAN ANNUAL TEMPERATURE AND TOTAL ANNUAL RAINFALL

The yearly history of wheat leaf rust may be considered to extend from about the first of July to the end of the following June. During this time, there are various periods of rest and active growth, the sum of which is expressed in the degree both of prevalence and destructiveness reached by the rust at harvest. There is, first, a period of meagre existence in shocks, on stubble, in straw stacks, and on volunteer plants. Following it there often is a short period of very rapid multiplication upon the young, fall-sown wheat, which is terminated by the arrival of the winter months with their low temperatures. Finally, there is the spring and early summer, when the rust that was overwintered, aided by an accretion of wind-blown infection from the south, develops with exceeding swiftness, step by step with the wheat, to harvest.

The success with which the rust-producing organism passes these various periods is determined by many factors, including temperature, rainfall, humidity, wind, and light, each of which is changing continually and independently. While varying greatly in individual seasons, the most important of these factors—temperature and rainfall—vary remarkably little, as a rule, from year to year. The normal yearly mean temperature for Illinois, according to weather records extending back to 1878, is 52°, and the average yearly rainfall is 36.42 inches. During the years covered by the disease survey reported here (1922-1926), the mean temperature of a year has never been more than 2.3° above nor more than 1.4° below the normal mean, and the rainfall of a year has never been more than 1.57 inches above nor more than 3.59 inches below the normal total.

Striking correlations ought to exist, therefore, between very small annual departures and the large annual variations in rust attack. The indexes of wheat leaf rust are given in comparison with the mean temperature and total rainfall for each rust year, that is for the period July through June rather than January through December, in the following table:

Year	Prevalence index	Destructiveness index	Mean temperature of the rust years	Total rainfall of the rust years
1922	94.1	50.3	54.8	41.73
1923	89.7	31.3	53.1	32.69
1924	68.3	19.1	51.9	38.74
1925	52.6	17.1	53.0	31.15
1926	57.2	11.2	51.3	35.15

No complete parallels exist between either phase of the rust attack and mean temperature or total rainfall for year-long periods, but they are observable when temperature and rainfall are considered together. In 1922, when the rust indexes were highest, both mean temperature and total rainfall were highest; while in 1923 the rust indexes, the mean temperature, and the total rainfall were distinctly lower. The destructiveness index was greater in 1925 than in 1926, and the combinations of mean temperature and total rainfall for these two years stood in the same relation.

These facts, and the deductions to be drawn from them, are shown more clearly by diagram in Figure 93. The horizontal scale represents inches of total annual rainfall; the vertical scale, degrees of mean annual temperature. The heavily-lined axes are drawn from the points of average mean annual temperature and average total annual rainfall for Illinois. The points labeled A, B, C, D, and E are the combinations of temperature and rainfall listed in the preceding table for the consecutive years 1922-1926. In the upper half of the diagram, a trend of rust increase from points B and D to point A is indicated by a dotted line; and in the lower half a similar trend is indicated by the dotted line drawn through points E and C. These two lines are nearly parallel,

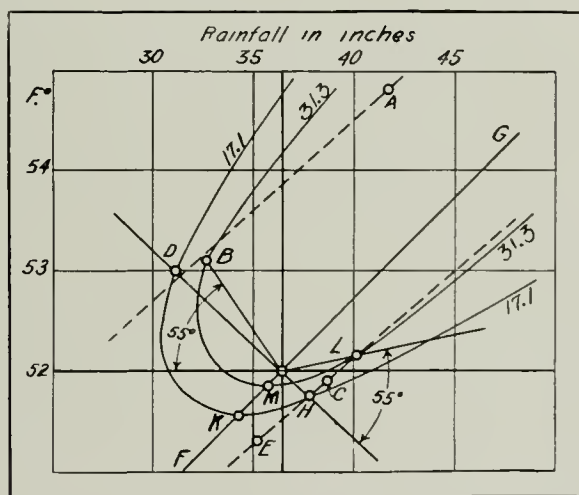


FIG. 93. RELATION OF COMBINATIONS OF MEAN ANNUAL TEMPERATURE AND TOTAL ANNUAL RAINFALL TO DESTRUCTIVENESS OF THE LEAF RUST OF WHEAT

The hyperbolic lines, drawn as explained in the text, pass through all the combinations of mean annual temperature and total annual rainfall capable of producing rust attacks with destructiveness indexes of 17.1 and 31.3. When enough data have been obtained, hyperbolas can be determined for every degree of rust attack, and the facts so learned can be used in predicting the intensity of attack in a given season.

running upward at an angle very close to 45° . The trends which they indicate suggest strongly that rust destructiveness increases when both the mean annual temperature and the total annual rainfall increase. Although these lines are determined by a very small number of points, the fact that they run upward at an angle so close to 45° is strongly indicative of a certainty of correlation between increasingly heavy rust attacks and combinations of increasingly high mean annual temperatures and totals of annual rainfall.

If it is assumed that this correlation is perfect, the line F-G may be drawn at a 45° angle through the intersection of the temperature and rainfall axes. Starting at the lower end, it should pass through points representing combinations of temperature and rainfall which would result in rust attacks with indexes rising steadily from 0 to 100.

Certain of the indexes theoretically included in this line are shown, however, actually to have been produced by temperature-rainfall combinations not crossed by the line, thus suggesting that rust attacks measured by a given index may result from an infinite number of such combinations. To determine them exactly requires data for a period of years much greater than is now available; but a method for determining them approximately is suggested in the following:

Point D is so situated that a line drawn from it to the intersection of the axes stands nearly at a right angle to the line F-G and, when continued, cuts the dotted line E-C at H. The point H lies about at the place between E and C where an index of 17.1 would be expected from inspection, and it may be given that value. By rotating either point D or point H about the intersection of the axes in conformity with the known values indicated by points already placed, a hyperbolic line may be drawn through the points D, K, and H, which theoretically runs through all the possible combinations of temperature and rainfall resulting in a rust attack having an index of 17.1.

A line drawn from point B to the axis intersection departs at an angle of 55° from the temperature axis. If a line is drawn from the intersection, departing from the line F-G at the same angle, to cross the line E-C, it will determine the point L, to which may be assigned the index of point B, 31.3. By rotating either point B or point L as directed above for D, the hyperbola L, M, B is obtained, which runs through all of the combinations of temperature and rainfall capable of producing a rust attack of the index 31.3.

From so small a number of points, the proper location of the hyperbolic lines can be only suggested; but with the accumulation of data year after year, it will be possible to determine them with great precision for every magnitude of rust attack. Practically, the delineation of a set of hyperbolic bands for predetermined ranges of rust indexes will be more serviceable than hyperbolic lines in predicting intensity of rust attack, for the absolute regularity of the line, which is determined

only by temperature-rainfall combinations, will be shattered by the occurrence of varied atmospheric saturation deficits, light intensities, and other minor factors not readily subjected to quantitative measurement.

RELATIONS OF DISEASE TO SEASONAL TEMPERATURE AND RAINFALL

It has been pointed out that the leaf rust of wheat exists under quite diverse conditions during different periods of its year. Since these periods correspond to a certain extent, but not wholly, with the seasons of the year, it is necessary to visualize the points of difference and similitude among various years in order to determine the extent and characteristics of the rust seasons.

Making use of diagrams constructed according to the method suggested by Taylor¹, the mean temperature and total rainfall for each month of the years included in the survey may be so represented as to be compared easily, year with year and month with month. This is done in Figures 94-99, in which the vertical scale represents Fahrenheit degrees of mean monthly temperature and the horizontal scale, inches of total monthly rainfall. The combination of mean temperature and total rainfall occurring in any month is shown by a point placed at the intersection of the proper temperature and rainfall lines, and the month is designated by an arabic numeral (1=January, etc.). Figure 94 shows the progress of a "normal" year in Illinois, beginning with July and ending with the following June, the normal mean annual temperature and the normal total monthly rainfall for the state being indicated by the heavy, dotted lines. Figures 95-99 are diagrams of the years 1922-1926, in which, to facilitate comparison, the mean annual temperature and total monthly rainfall of a normal year are indicated as in Figure 94.

These diagrams show that no one of the years with which we are dealing approaches a normal year very closely. The outstanding fact illustrated by all of them is that the rust year is divided roughly into halves, the first of which is characterized by falling, and the second by rising, temperatures. This we may take to be a characteristic of every rust year, to which we should attach only this very broad and obvious significance: From July through December the rust organism is being subjected to increasingly rigorous temperatures and is decidedly on the down-grade, while from January through June the general upward trend of temperature has an increasingly favorable influence upon its rate of propagation. Lacking definite names, the terms "fall trend" and "spring trend" may be given to these periods.

When a fall trend or a spring trend in any one of these years is compared by means of these diagrams with its counterpart in any other year, distinct differences are evident. Keeping in mind the variations in rust attack stated previously, the observable differences suggest at once that

¹The settlement of tropical Australia. By G. Taylor in *Geog. Rev.* Vol. 8, pp. 84-115. 1918.

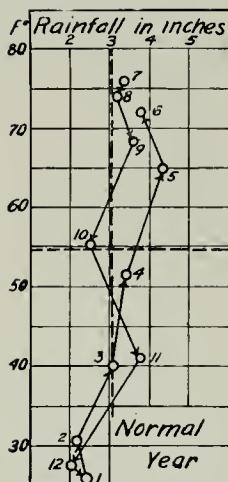


Fig. 94

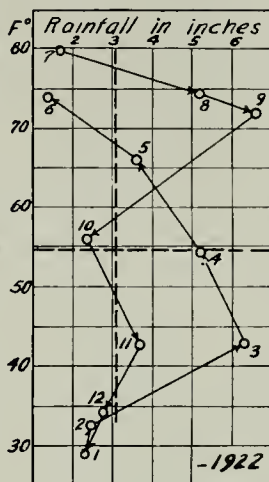


Fig. 95

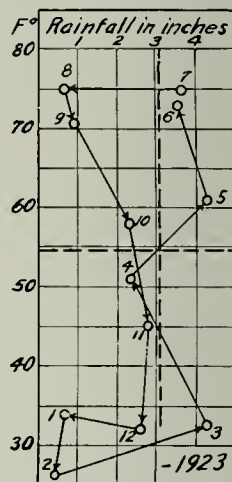


Fig. 96

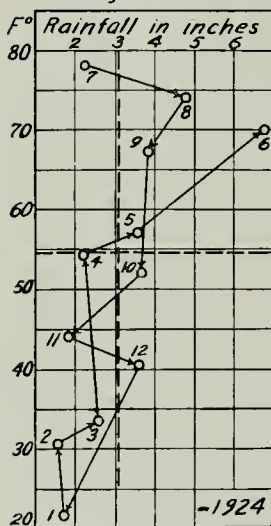


Fig. 97

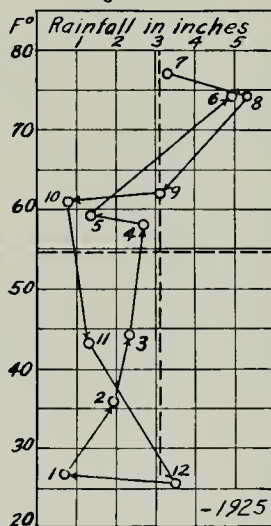


Fig. 98

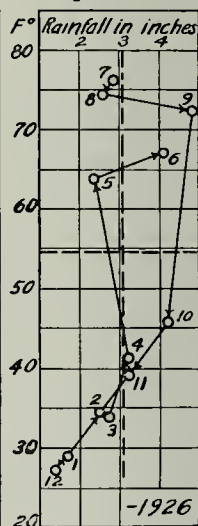


Fig. 99

FIGS. 94-99. TEMPERATURE-RAINFALL DIAGRAMS OF A NORMAL WHEAT LEAF RUST YEAR AND OF THE RUST YEARS 1922-1926 IN ILLINOIS

The rust year begins with July, after the previous crop has been harvested, and extends through the following June. The trends of temperature and rainfall, given as monthly means and totals, respectively, are shown for a normal year and for each year for which rust data were procured. These diagrams show that each rust year consists of two parts, the first of which has falling,

rust abundance is related to the mean temperature of the fall trend and the total rainfall of the spring trend rather than to the rainfall of the fall trend and the temperature of the spring trend or combinations of the two.

The following table emphasizes these points.

Year	Destructive- ness index	Mean temperature		Total rainfall	
		Fall trend	Spring trend	Fall trend	Spring trend
1922	50.3	59.8	49.3	22.59	19.14
1923	31.3	59.3	47.0	15.01	17.78
1924	19.1	59.0	44.9	20.24	18.52
1925	17.1	56.1	49.9	17.27	13.91
1926	11.2	56.2	46.4	18.97	16.19

No parallel can be found between the variations in rust destructiveness and either the spring temperatures or the amounts of fall rain given in this table, or between combinations of the two, whether the years be taken successively or grouped according to high and low rust indexes. Variation in the mean temperature of the fall trends and in the total rainfall of the spring trends, however, follows very closely the rise and fall of the rust indexes. How closely they follow one another is shown better by Figure 100.

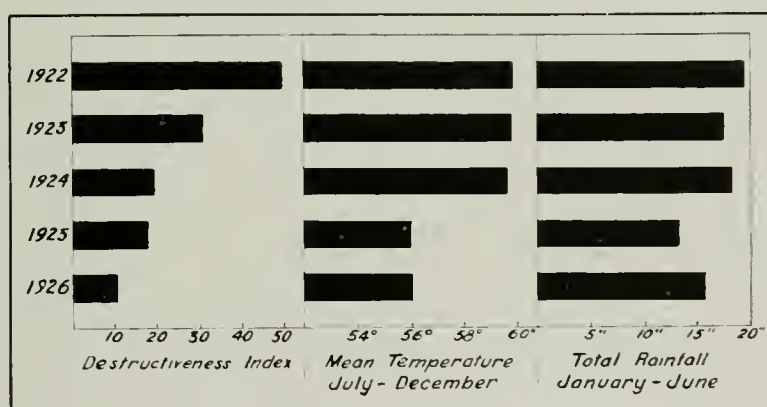


FIG. 100. COMPARISON OF RUST INTENSITY WITH JULY-DECEMBER TEMPERATURE AND JANUARY-JUNE RAINFALL, 1922-1926

and the second rising, temperatures (see page 83). The rust year may be divided also into three parts: an autumnal season, July-September; an hibernal season, October-March; and a vernal season, April-June (see page 83).

Practically, we are lead to believe that, whenever a fall trend has rain exceeding 15 inches in amount, abundant rust is probable the following spring, if the mean temperature of the fall is 59°F. or more; but if the temperature is around 56°, light rust is to be expected. A spring trend with a mean temperature of 45° or more may be expected to be productive of a heavy rust epidemic when it follows a fall trend of 59°, if its rainfall is in excess of 17.5 inches, and of a light rust attack when it follows a fall period of 56°, if its rainfall is less than 16.2 inches.

Records of the weather in Illinois are available since 1818, making it possible to estimate the frequency with which years favorable and unfavorable to leaf rust may be expected to occur in the future, on the basis of their occurrence during the past 48 years. Favorable, intermediate, and unfavorable fall and spring trends, alone and in various combinations, have occurred the number of times shown in the following table:

Combinations of temperature and rainfall, classified with respect to rust development	Number of times occurring in 48 years	Comparative frequency of occurrence
Fall trend alone		
favorable	7	1/6.857
intermediate	23	1/1.086
unfavorable	18	1/2.666
Spring trend alone		
favorable	32	1/1.500
intermediate	6	1/8.000
unfavorable	10	1/4.800
Both fall and spring trends		
favorable	4	1/12.000
intermediate	3	1/16.000
unfavorable	6	1/8.000
Fall trend favorable		
spring trend intermediate	0	0/48.000
spring trend unfavorable	3	1/16.000
Fall trend intermediate		
spring trend favorable	19	1/2.526
spring trend unfavorable	1	1/48.000
Fall trend unfavorable		
spring trend favorable	9	1/5.333
spring trend intermediate	3	1/16.000

Stated more concretely, the expectation with respect to any fall is only 1 in 7 that it will be favorable to rust, nearly 1 to 1 (even chances) that it will be intermediate, and only 3 in 8 that it will be unfavorable; and with respect to any spring the chances are 2 in 3 that it will be favorable, 1 in 8 that it will be intermediate, and 1 in 4 that it will be unfavorable. The probability of a favorable spring following a favorable fall is only 1 in 12, and of an unfavorable spring following an unfavorable fall only 1 in 8; but the likelihood of intermediate falls and

springs occurring together is approximately 4 in 5. Stated in terms of leaf rust attack, it is probable that on an average only one year in twelve will be productive of a severe epidemic and only one year in eight of a very light epidemic, while four years in every five should have moderate rust attacks. This statement, however, should not be expected to apply rigidly to any small number of years; it is significant only for a period of half a century or more.

Referring again to Figures 94-99, three divisions of the year may be distinguished, including first the months July, August, and September, next the months October through March, and finally the months April, May, and June. For convenience, these periods may be designated respectively as aestival, hibernal, and vernal, these terms applying not only to periods of the year but also to distinct phases in the rust organism's history. The mean temperatures and total precipitation of each of these periods for the years during which rust observations were made are compared in the following table, with the indexes of rust destructiveness.

Year	Destructiveness index	Aestival period		Hibernal period		Vernal period	
		Mean temperature	Total precipitation in inches	Mean temperature	Total precipitation in inches	Mean temperature	Total precipitation in inches
1922	50.3	75.5°	13.58	39.0°	18.02	64.7°	10.13
1923	31.3	73.4	7.33	38.7	15.19	61.7	10.27
1924	19.1	72.5	11.02	37.5	15.21	60.3	12.53
1925	17.1	69.3	11.60	39.2	10.50	64.2	9.08
1926	11.2	74.5	10.47	35.4	15.18	59.8	9.51

The variations of the rust indexes is not correlated throughout the five years with either the temperature or precipitation of any season; but the heavy and light rust years, as groups, find striking counterparts in the heavy and light precipitations of their corresponding vernal seasons. It is evident, also, that the effect of precipitation in these seasons is intimately related to that of temperature. The 15.18 inches of rainfall in the hibernal season and the 9.51 inches in the vernal season of the light rust year of 1926 approach very closely the corresponding amounts in the heavy rust year of 1923, but the expectation of heavy rust from this cause is counterbalanced by low mean temperatures in both seasons. An illustration of the opposite relation occurred in the light rust year of 1925, when the mean temperatures of both the hibernal and the vernal periods, which were almost as favorable as those of the heavy rust year of 1922, were offset by very low precipitation totals.

The relative effects of various mean temperatures and totals of precipitation upon the amount of rust infection could be determined by making numerous comparisons like the foregoing; but at the present stage of our inquiry the details in our possession are not sufficiently abundant

to furnish satisfactory conclusions. We might assume, for example, that the influences of temperature and rainfall are cumulative and that their total effect is expressed in the amount of rust eventually produced. On this basis, we could develop a linear equation for each year and, by comparing the equations, arrive at average effects to be assigned to each degree of mean temperature and each inch of rainfall for each of these seasons.

Actual tests of this process with the data at hand have yielded results which, though very suggestive, are still too indefinite to be presented, except in generalizations. They suggest that there is a well defined minimum temperature below which rust infection can not occur, and that above this threshold the amount of rust produced increases more and more rapidly as the temperature increases.

The months of May and June should be regarded as the most critical of the year in the development of a leaf rust epidemic, for at this time the infections that have survived the rigors of the previous months begin to grow anew, producing new spores and starting the new epidemic. As the days pass, infection is increased not only from the local sources of spore supply but also by spores blown in on the wind from fields to the southward. Even under the most adverse circumstances, sufficient infective material is present in the fields of this State to produce a very destructive epidemic. Whether it remains mild, as it did in 1925 and 1926, or becomes serious, as in 1922, 1923, and 1924, depends very largely upon the spring temperature and rainfall. A comparison of rust indexes and the weather of May and June is given below.

Year	Destructiveness index	Weather conditions of May and June	
		Mean temperature	Total rainfall
1922	50.3	70.2	5.08
1923	31.3	67.0	7.88
1924	19.1	63.4	10.35
1925	17.1	67.0	6.42
1926	11.2	66.5	6.39

It is evident that neither temperature alone nor rainfall alone in these months is related to heavy or light infections. The mean temperature in 1925, the year of lightest rust, was the same as in 1923, when there was a rather heavy rust attack; and the rainfall of 1922, the year of heaviest rust, was less than in either of the two light rust years, 1925 and 1926. The degree of rust attack must be determined, consequently, by the condition produced by the mean temperature and total rainfall combined. It is not possible to see, in the foregoing table, what interrelations such combinations may have, but if a diagram, as in Figure 101, is drawn and the different years properly plotted upon it, they may

be made clear. The normal mean temperature for the May-June period in Illinois, 67.1° , is shown by the heavy horizontal line, and the normal total rainfall, 8.08 inches, by the heavy vertical line. The point at which these lines cross represents the normal mean temperature and total rainfall condition for the May-June period. The actual combinations for the years in question are shown on the diagram, circled dots marking years of heavy rust and circled crosses marking years of light rust.

It is remarkable that the points representing heavy rust lie in a nearly straight, diagonal line running from the upper left to the lower right corner of the diagram, while those for light rust lie close together near the middle of the upper part of the cold, dry quarter.

The number of seasons for which there are records are far too few to permit complete acceptance of the relations the diagram suggests; but in view of the principles underlying mathematical correlation, it is quite probable that the general trend, at least, of the May-June mean temperature-total rainfall combinations likely to produce heavy rust attacks is indicated.

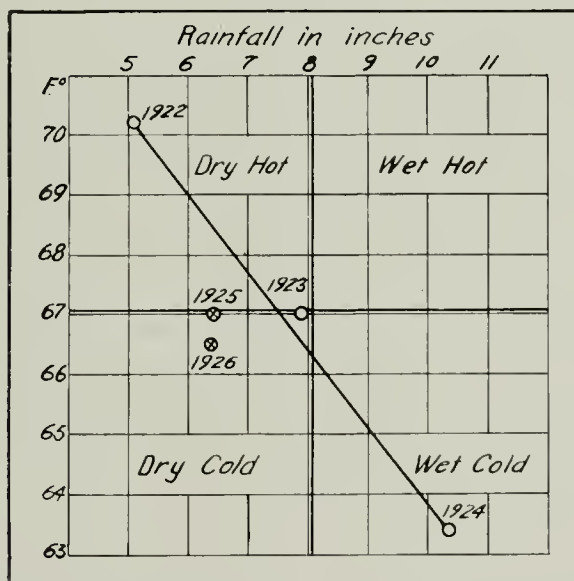


FIG. 101. CORRELATION BETWEEN THE DESTRUCTIVENESS OF WHEAT LEAF RUST AND THE MEAN TEMPERATURE AND TOTAL RAINFALL OF THE MAY-JUNE PERIOD

Circles mark the May-June weather in years of destructive rust and circled crosses in years of light rust. The line connecting the circles suggests that, contrary to the usual opinion, dry, hot weather will produce the heaviest attacks. Damp, cool weather produces moderately serious disease, and rather dry weather with usual temperatures results in mild attacks.

**The geographical occurrence of dates of first spring infection, and
the temperature relations governing the subsequent
development of an epidemic**

It has been said that there is always sufficient infective material present to produce a destructive epidemic if conditions are favorable. Although, as has just been shown, several distinguishable parts of the year, as well as the year as a whole, influence very definitely the intensity of disease attack, the fact remains that each year's epidemic is independent, in a measure, of all the seasons of the year except the spring, for then spores of the rust organism blown from distant places by strong winds serve to introduce new infection. For this reason, it is worth while to inquire into the time when spring infection is likely to occur and the conditions under which various grades of intensity are developed.

The earliest appearance of rust in Illinois, as shown by our survey records, varies considerably according to locality. The late start on field work in 1922 failed to furnish any such records for that year, but in the years 1923, 1924, and 1925 a number of dates of earliest infections were secured. In 1923, five such observations were made; in 1924, 8; and in 1925, 11. Arranged roughly from south to north, they are given by counties in the following table under the "observed date."

County	Observed Date	Theoretical date	County	Observed Date	Theoretical date
1923			1925		
Bond	June 5		Madison	June 4	
Coles	June 8	June 7- 8	Greene	June 4	June 4- 5
Macon	June 9	June 9	Clark	June 9	June 8- 9
LaSalle	June 15	June 14-15	Coles	June 10	June 9-10
Cook	June 30	June 18	Edgar	June 10	June 10-11
1924			Macon	June 12	June 9-10
Calhoun	June 6	June 4- 5	Piatt	June 11	June 10-11
Jersey	June 6	June 4- 5	Champaign	June 11	June 11-12
Macoupin	June 4	June 4- 6	Logan	June 12	June 10-11
Champaign	June 15	June 11	McLean	June 13	June 12-13
Moultrie	June 17	June 11-12	Iroquois	June 19	June 15-17
Piatt	June 17	June 12			
Kankakee	June 25	June 18-19			
Will	June 25	June 19-20			

Upon inspection of this list, it is apparent that, though the dates for comparable localities differ year by year, the first rust infection is always earlier in the south than in the north and for, the same latitude, earlier in the west than in the east. This suggests that rust infection occurs in close conformity in the spring with Hopkins' Bioclimatic Law¹, which

¹ Hopkins, A. D. Periodical events and natural laws as guides to agricultural research and practice. U. S. Dept. Agr. Weather Bureau, Monthly Weather Review, Supplement 9, 1918.

states, essentially, that "other conditions being equal, the variation in the time of occurrence of a given periodical event . . . is at the general average rate of 4 days to each 1 degree of latitude, 5 degrees of longitude and 400 feet of altitude, later northward, eastward, and upward in the spring and early summer, and the reverse in late summer and autumn."

In accordance with this view, the State of Illinois has been divided into the sections shown in Figure 102, which represent theoretical time variates of periodical events in harmony with adjacent states. The slanting longitudinal lines represent a difference of approximately four-fifths

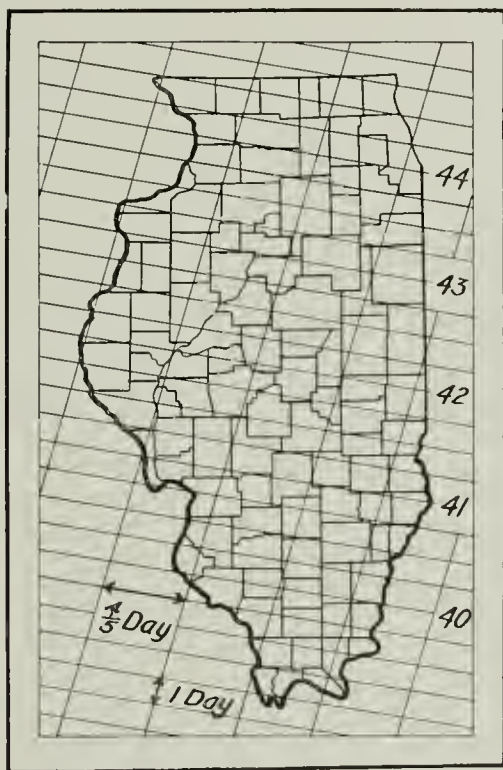


FIG. 102. THEORETICAL TIME-VARIATE LINES FOR ILLINOIS, ACCORDING TO HOPKIN'S BIOCLIMATIC LAW

The earliest wheat leaf rust infection occurs in the south, and at a given latitude infection occurs earlier in the west than in the east. The seasonal progress of infection is in the northeasterly direction taken by the longitudinal lines. The horizontal lines represent, from south to north, a difference of one day, and the longitudinal lines a difference of four-fifths of a day, from west to east, in the appearance of first rust infections. When the first infection is observed in the south, the date of its appearance in any more northern region can be predicted accurately.

of a day, and the somewhat slanted horizontal lines a difference of approximately one day in the occurrence of a given event.

Selecting the first date given in the foregoing table for each year, it is possible to compute from Figure 102 a theoretical date of first infection for the other counties listed. As an example, in 1923 rust was first seen in Bond County June fifth, but it was not seen in Coles County until June eighth. Referring to Figure 102, it is readily determined that, by the provisions of the law just stated, rust should have appeared through the southern part of Coles County June seventh and through the northern part June eighth. There is a practical coincidence of observed date (June 8) and theoretical date (June 7 and 8). Theoretical dates so determined are given in the preceding table for each of the observed dates.

A comparison of the observed and theoretical dates shows in all cases a very close agreement. The statement seems warranted that, when the appearance of rust has been observed in the southern part of the State, an accurate prediction can be made of the date on which initial infections will occur in any part further north.

The dates of spring infection influence the total amount of disease subsequently produced. If they are early, there are longer periods of multiplication; but if they are late, the periods of multiplication are shorter. This, however, is probably much less important than the temperature and rainfall of the multiplication period, for it is commonly observed that low temperatures inhibit the development of infection, though prolonging somewhat the growing period of wheat, while high temperatures not only inhibit infection but greatly curtail the growing season of the crop and consequently the multiplication period of the disease.

As temperature appears to be the controlling factor, it is to be expected that certain average temperatures occurring through periods of given extent should result, other conditions being equal, in definite amounts of infection. These other conditions will not be equal, of course; but when a large territory is included, the variations they cause should fluctuate about the general trend of the temperature effects.

The amount of rust observed at a certain time in a certain field may be considered, therefore, to be in the main an expression, somewhat modified by other factors, of the effect of the temperatures accumulated from the time of the initial infection to the time of examination. A statement of the accumulated temperatures may be obtained by adding the daily mean temperatures recorded by the nearest Weather Bureau station. In the following table, these totals as well as the average mean daily temperature during rust development are given in connection with amounts of rust observed in 1926.

It should be stated that the first infection was observed June 2 at Paris. From it, theoretical dates of first infection were determined, by the prediction method just described, for instances not definitely observed.

OBSERVED RUST INFECTIONS, COINCIDENTALLY ACCUMULATED TOTAL MEAN DAILY DEGREES, AND AVERAGE MEAN DAILY TEMPERATURES FROM FIRST INFECTION TO DATE OF EXAMINATION

County	De-structive-ness index	Mean daily degrees accumulated	Average mean daily temperature during rust development	County	De-structive-ness index	Mean daily degrees accumulated	Average mean daily temperature during rust development
Boone	14.0	4,105.0°	66.2	Macon	2.0	453.5°	64.8
Champaign	33.6	2,051.5	70.7	Madison	6.0	2,040.0	68.0
Champaign	20.0	2,209.5	71.3	Marion	trace	1,529.5	72.8
Champaign	25.0	2,478.0	70.8	Marion	trace	573.5	71.6
Clark	10.0	1,019.5	67.9	Marion	1.0	1,529.5	72.8
DeKalb	15.0	3,373.5	68.8	Marshall	30.0	3,589.0	70.3
DeKalb	10.0	2,934.5	68.2	McDonough	35.0	3,379.0	71.8
Douglas	32.0	2,012.5	67.1	McHenry	15.0	3,355.5	68.4
DuPage	11.0	3,149.0	68.4	Menard	30.0	3,407.5	72.5
DuPage	17.0	3,512.0	67.5	Monroe	trace	1,007.5	71.9
Edgar	32.0	2,055.5	70.8	Morgan	trace	826.0	68.8
Edgar	32.0	2,115.5	70.5	Moultrie	trace	1,499.5	68.1
Effingham	5.0	846.0	70.5	Moultrie	16.6	1,499.5	68.1
Fayette	6.2	544.5	68.1	Platt	35.0	439.5	73.2
Grundy	16.0	3,758.0	70.9	Randolph	10.0	2,362.5	73.8
Iroquois	17.0	2,373.5	71.9	Saline	17.0	2,778.5	75.1
Iroquois	17.0	2,373.5	71.9	Sangamon	trace	676.5	67.6
Kane	15.0	3,272.5	66.7	St. Clair	trace	1,231.5	72.4
Kane	29.0	3,200.5	66.6	St. Clair	4.1	1,231.5	72.4
Lawrence	4.5	372.5	74.5	Schuyler	20.0	3,712.0	71.4
Livingston	30.0	3,653.0	70.0	Vermilion	25.0	1,783.5	71.3
Livingston	60.0	4,154.5	72.8				

Upon examining this table, many wide discrepancies may be observed between the amounts of rust developed and the accompanying accumulated temperatures. For example, the development of a 32 per cent infection in Edgar County required from 2,055° to 2,115°, while southward, in Saline County, a much greater accumulation, 2,778°, was required for a 17 per cent infection; and northward, in McHenry County, 3,355° were required for a 15 per cent infection. In Edgar County, however, the average mean daily temperature was 70.5° to 70.8°, in Saline County it was 75.1°; and in McHenry County, 68.4°. This indicates that, in the field, there is a certain mean daily temperature, apparently between 70° and 71°, which may be termed the optimum, at which the rust organism can develop and spread most rapidly, and that if the mean daily temperature for any considerable number of days either falls much below or greatly exceeds this optimum the development and spread of the rust will be correspondingly inhibited.

The items in the preceding table fall into three groups, corresponding in the main to geographic sections of the state. In the south and in the north large accumulations of temperature are required for small percentages of infection because the mean daily temperatures are in excess of and less than the optimum, respectively; but through the central part

of the state mean daily temperatures are close to the optimum. For convenience, these parts of the state may be designated as lying south of the line numbered 41 in Figure 102, between lines 41 and 43, and north of line 43. The relation between the rapidity of rust development and accumulated temperatures in these districts is illustrated in Figure 103.

These differences in rapidity of rust development may be explained further, in view of their geographic locations, on the seasonal characteristics of the region in which they occur. Spring and summer come earlier and endure longer in the south. There, optimum temperatures for rust development may occur before the wheat can be infected readily and may be succeeded by temperatures above the optimum before the epidemic has progressed appreciably. In the central section, optimum temperatures appear somewhat later and endure through much of the growing season. Northward, unfavorably low temperatures, characteristic of

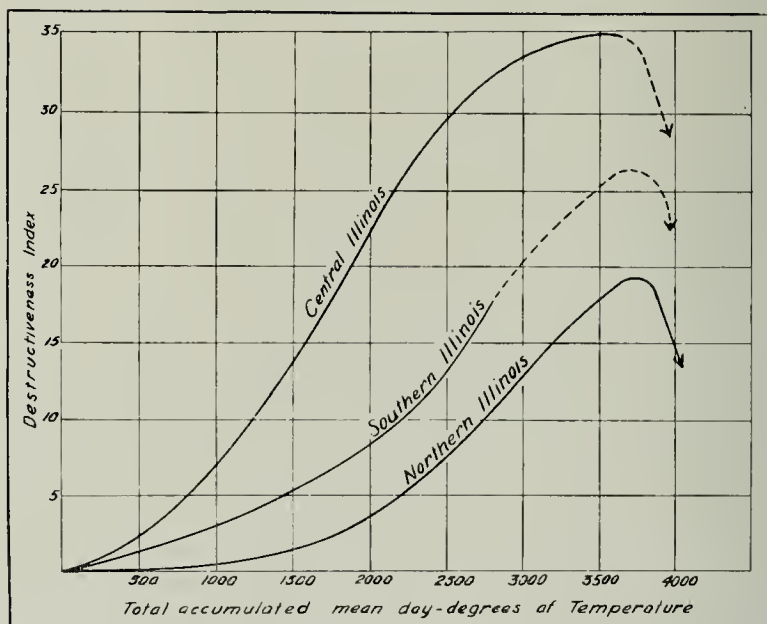


FIG. 103. EFFECT OF TEMPERATURE UPON THE DEVELOPMENT OF A WHEAT LEAF RUST EPIDEMIC, FOLLOWING THE OCCURRENCE OF FIRST INFECTION

The destructiveness indexes given in the table on page 93 are shown graphically here with their corresponding accumulations of mean daily degrees of temperature. They fall into the three rather distinct groups indicated by the three curved lines. The line of greatest rustiness is obtained from observations made in central Illinois; the intermediate line, by observations in southern localities; and the line of least rustiness, in northern localities.

the early growing season, are succeeded for a short period by optimum temperatures as the crop nears maturity, and immediately are followed by the high temperatures of summer.

The curves shown in Figure 103 suggest that a more complete analysis (not possible with the data we now possess) would show that temperatures could be classed as effective or non-effective in the development of an epidemic and that exact values could be assigned, in terms of velocity of disease development, to effective temperatures, which would make it possible to predict with a high degree of accuracy the ultimate intensity of attack in any season. This problem, however, requires data much more extensive, detailed, and complete than have been obtained thus far.

SUMMARY AND CONCLUSION

With strikingly few exceptions, attempts made heretofore to estimate variations in disease attack have resulted, with respect to commercial crops, in statements so patently generalized, both as to prevalence and damage, as to be far from convincing. Based on inexact observations and evaluated from memory or from too brief and inadequate notes, they have dealt too much with reductions in yield and money losses, neither of which can be estimated fairly with our present knowledge. While such estimates have been, as a rule, far too conservative, placing losses inordinately low, the fact remains that an abundant yield is determined chiefly by soil, weather, and proper cultivation. It is only in the exceptional season that yield is determined by disease attack alone.

The methods for collecting data on disease outlined in the preceding pages take into account the effect of disease upon the individual plant and its parts rather than upon yield. Disease prevalence and disease destructiveness have been observed directly, in accordance with definite rules, in fields selected at random, in order that representative samples might be secured; statistical methods of a relatively simple nature have been devised and used in evaluating the data thus secured; and indexes have been computed which represent the disease attack as it actually occurred. Because they do not involve the necessity of comparing or evaluating indirectly estimated reductions in yield or money losses, these indexes furnish the most satisfactory means now available for comparing disease attacks, year with year, or region with region. They also provide a means of visualizing the effect of disease upon the crop subjected to attack, as was illustrated in Figures 89-92.

The use that is to be made of exact data collected by studying and measuring epidemics under natural conditions has been exemplified, though briefly, with some of the wheat leaf rust data. It has been shown that there is a well defined relation between intensity of attack and annual mean temperatures and yearly totals of rainfall; that in the July-December period of the year temperature has a greater influence than rainfall,

while in the January-June period rain is the more important, in determining the destructiveness of a year's rust attack; that there is a possibility of predicting with reasonable accuracy the date upon which the first spring infection will occur in any part of the State in any year; that during the months of May and June the correlation between disease development and weather conditions lies mainly with temperature; and that the degree of destructiveness which an epidemic, once started, is likely to attain may be predicted from the rapidity with which degrees of mean daily temperature accumulate.

Such results as these outline only the broadest of the principles which underlie the yearly development of disease epidemics on the crops grown on the farms of Illinois. Although they have no immediate application to the problems of the farm, they are the general laws from which the rules of practice must be drawn. What has been learned in the case of wheat leaf rust must be learned also for the other diseases of wheat, and for the diseases of other crops; the laws pertaining to all must be refined by further observations and analyses; and the practical rules at last determined must be subjected to final tests, before the task is finished.