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COMPARATIVE RESISTANCE OF VARIETIES OF OATS TO CROWN AND STEM RUSTS

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The Comparative Resistance of Varieties of Oats to Crown and Stem Rusts

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INTRODUCTION

Numerous instances of the production of disease-resistant crops may be noted in this and other countries, but comparatively little work has been done on the problem of resistance of oats to stem rust (*Puccinia graminis* Pers.) and crown rust (*P. coronata* Corda.)[1] Many of the published records on the rust resistance of oats are observations covering but a single season and too often with no determination of the species of rust present. The use of resistant varieties, however, appears to be the most hopeful method of combating these rusts. This paper is chiefly an account of studies conducted to determine which of the existing varieties are resistant to either or both of the rusts mentioned above.

In order to reach a more definite understanding of the problem, our investigations were begun with a view of determining the degree of infection and of perfecting methods of producing maximum infection at will. Supplementary to this was a consideration of the relation of amount of inoculum applied to the degree of infection and also an inquiry into the relation of the period of rust incubation, and of time of sowing to resistance of oats to both stem rust and crown rust. A comparative study of rust resistance of oats grown in the greenhouse and field was also made.

REVIEW OF EARLIER WORK

Among the earliest observations on the variation in susceptibility of oat varieties to rust are those of Eriksson and Henning (6)[2] in Sweden. These writers state that it was impossible to observe any definite difference in the susceptibility of oat varieties. They considered it an open question whether the differences observed actually represented constant, inherent resistance or were dependent on soil conditions, proximity to other rusted plants and other factors of environment.

McAlpine (12) states that stem rust alone is peculiar to oats in Australia and that the wild oat, *Avena fatua*, is generally severely affected.

Sower (25) published figures on the rust resistance of oat varieties grown at Cedara, South Africa, stating that both crown and

[1] For a discussion of the nomenclature of this rust, see Research Bull. Iowa Agr. Exp. Sta. 49: 134-141. Feb., 1919.

[2] Reference by number is to the Bibliography.

stem rusts occur, tho it is quite apparent from his data that only crown rust was present. It is noteworthy that three varieties belonging to the red oat group (*Avena sterilis*) were found to be most resistant. He also points out a relation between the anatomical differences of the group and their relation to rust resistance and seems to consider these differences as being intimately connected with the causes of resistance and susceptibility. Lamont (10), Peacock (20) and McConnell (13) likewise refer to the rust resistance of certain representatives of the red oat group, tho they fail to specify whether the resistance is to stem or crown rust.

Litwinow (11) made a study of rust resistance of oat varieties in Russia, using 50 pure lines belonging to several species and varieties. He found that all of them, with the exception of the very latest maturing ones, were finally very heavily infected with crown rust.

Vavilov (28, 29, 30) made extensive tests on some 350 lots of cultivated and wild oats to determine their reaction to both stem and crown rust. From these experiments he concludes that there is little probability of finding varieties resistant to stem rust. In the case of crown rust, however, tho the majority of cultivated and wild oats were found very susceptible, many more forms showed resistance.

The different varieties of side oats, *Avena orientalis*, were very susceptible, as were those forms of *A. fatua*, *A. ludoviciana* and *A. sterilis* closely related to the culivated oats. Of the 323 lots of *A. sativa* examined, five, belonging to the varieties *A. cinerea* Keke. and *A. grisea* Keke., proved to be "relatively very immune" from crown rust. The majority of the lots which he described as "less susceptible" and "relatively very immune" belong to varieties with black or gray glumes and, in general, are morphologically different from susceptible races. *A. brevis* Roth., *A. strigosa* Schreb. and *A. nuda* L. var. *biaristata* Aschr. and Gr. also show relative immunity from this rust. Vavilov further discusses the origin of cultivated oats and shows that their reaction to the rust fungi is often correlated with morphological differences and with their supposed genetic relationships.

In this connection Jakushkina and Vavilov (9) studied the size, number and distribution of stomata in both resistant and susceptible varieties of oats, but found that there was little or no correlation between variations in these structures and the physiologic character of rust resistance inherent in the variety.

It is interesting to note that probably one of the earliest American records of rust resistance in oats was that of Speer (26), who reported the results of his observations on the occurrence of rust on the oat varieties growing on the Iowa Agri-

cultural Experiment Station plats. Tho no mention is made of the species of rust concerned, he states that the oats all rusted so badly that they were nearly worthless, with the exception of Improved American, Everett (a side oat), Lackawanna, and Giant Yellow French (also a side oat). Observations on the resistance or susceptibility of oat varieties to rust have since been made by Pammel (18), Plumb (21), Carleton (4), Bolley (2), Shepherd and Ten Eyck (24), and McWethy (14).

Norton (17) published definite experimental results on oat-rust resistance and distinguished clearly between crown and stem rust. He found that "the *Avena sterilis* forms are nearly free from crown rust, while stem rust attacks them very badly."

Burnett (3) found that the amount of leaf rust infection on Red Rustproof (Red Texas) was much less than on other varieties.

Reed (22) tested 46 varieties and strains of oats under greenhouse conditions, only one of which seemed to possess any degree of resistance to crown rust. His field observations coincide with those made in his greenhouse experiments. The same author (23), in a later report, states that in the field one lot of *A. barbata*, two of *A. brevis*, three of *A. fatua*, one of *A. ludovicina*, three of *A. nuda*, twenty-two of *A. sativa*, nine of *A. sativa orientalis*, seven of *A. sterilis*, and one of *A. strigosa* were studied. Practically all of them proved highly susceptible to crown rust. Even those varieties known to be nearly or quite immune under ordinary conditions proved susceptible under the conditions of the experiment. One lot each of *A. brevis*, *A. ludoviciana*, *A. trisperma* and *A. sativa* showed some evidence of resistance.

Parker (19) studied the resistance of oat varieties to leaf and stem rusts under greenhouse conditions, using seedlings and plants at time of heading. White Tartarian and Ruakura were the only varieties which showed unquestionable resistance to stem rust. Several varieties of the red oat group (*Avena sterilis*) were found to be resistant to crown rust. Among these were strains of Burt, Cook, Appler, Italian Rustproof, Red Rustproof and Turkish Rustproof. The Ruakura oat and certain other species of Avena also gave indications of resistance to crown rust.

MATERIALS AND METHODS

Many of the varieties studied were obtained from the Minnesota Agricultural Experiment Station, while others were supplied by C. W. Warburton of the Office of Cereal Investigtions, Bureau of Plant Industry. The forms listed under the Latin names were obtained from Director Bubak of the Botanic Garden at Tabor, Bohemia, thru Dr. G. M. Reed, formerly of the

University of Missouri. The hybrids, and also the variety Early Ripe and one strain of Burt, were secured from Dr. H. H. Love of the Plant Breeding Department, Cornell University. Some of the White Russian strains were supplied by seedsmen, others came from field stations of the Bureau of Plant Industry, and still others from the Ashland (Wis.) Branch Experiment Station. L. C. Burnett of the Iowa Agricultural Experiment Station furnished seed of Iowa Numbers 103 and 105 and of several other varieties grown for the first time in 1918. The strains of Appler, also grown only in 1918, were obtained from the San Antonio (Texas) Experiment Farm.

In the study of varietal resistance of oats to both stem and crown rusts in the field, the seed was sown in 5-foot rows spaced one foot apart. The first year, three rows of each lot were sown; later, two rows; and finally, due to the increase in the number of lots, one row of each was sown. In every case a check was sown every tenth row and along the edges of the plots. The White Russian variety was used as a check the first year, and the Swedish Select in subsequent years.

To secure an epidemic of rust, it was the practice thruout the field experiments to inoculate the plots artificially with uredospores. This was done by spraying and dusting the plants with uredospores taken from stock cultures maintained thruout the winter in the greenhouse.

In carrying stock cultures of rust, seedling plants of Swedish Select oats, a highly susceptible variety, were grown in the greenhouse in 4-inch pots, sown 10 or 15 to a pot. In the 4-inch pots the plants were easily transferred to and from the moist chamber and when thinned would grow to maturity. These plants were infected with rust as described below and as the rust developed, other plants were infected, thus keeping the stock alive.

Thruout the winter about 100 pots were kept in lots of 10 to 20 in various stages of infection, some lots just inoculated, others just beginning to produce spores, others profusely sporulating, while still other plants were fresh and ready for inoculation. It was found that infected young plants would produce spores for a week or ten days, while older plants would bear spores for a month in great profusion. As spring approached, and at the time of seeding outdoors, the greenhouse stock was greatly increased, for it was desirable to time the spore production so that an abundance of spore material would be on hand for field inoculation. Surplus spores not used for increasing the greenhouse stock were saved in vials for subsequent use as inoculum in the field experiments. As shown by Melhus and Durrell (16), such uredospores could not only be stored for several weeks in a cool place without loss of viability, but

for a period of a few days or a week the percentage of germination increased, due to the ripening of immature spores.

Toward spring, when large quantities of spores were needed, inoculations were made on older plants, grown four to six in a pot, because stem rust was found to grow during a longer period on such plants. While the seedlings apparently were more readily infected and were easier to manipulate, yet the young shoots soon grew past the heavily infected leaves. These leaves then died, leaving only a small amount of spore material for subsequent inoculations. The leaves of the older plants were less easily killed by the rust, and an abundance of spore material was collected from the large stems and broader leaves.

Several different methods were used in making the inoculations. Spores gathered from greenhouse cultures were mixed with water and sprayed on the plants with a knapsack sprayer. Another method involved the artificial inoculation of individual plants here and there thruout the plots to start centers of infection. These two methods were later abandoned in favor of a third, in which the plot was thoroly moistened with a fine mist from a sprayer or hose. Dry uredospores were then blown on the plants by means of a blower (see fig. 1).

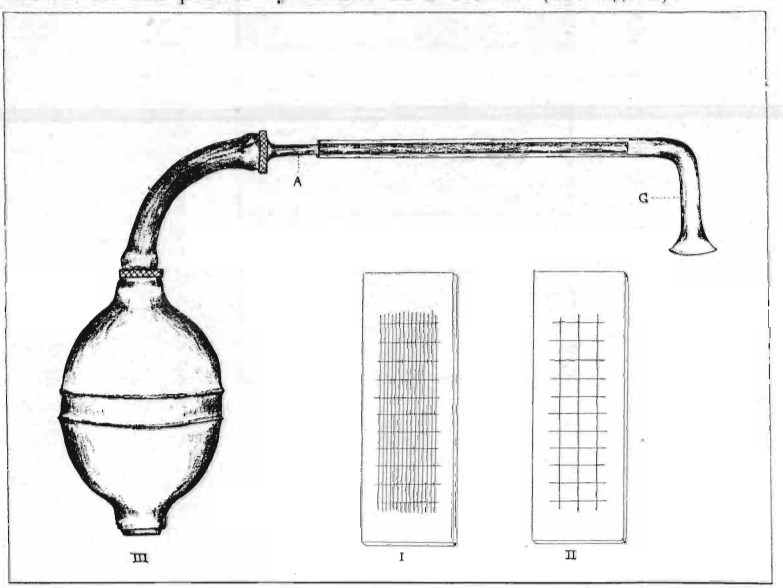

Fig. 1. Apparatus for dusting and counting spores in greenhouse inoculation work.

The spores are poured into the glass tube and expelled by a blast of air from the bulb. The crook in the tube aids in breaking up the spore masses and in producing a finely divided cloud of inoculum.

I. Slide, ruled in 1/20 cm. areas used in counting spores dusted on plants.

II. Slide, ruled in 1/4 cm. areas used in counting sori on leaves.

III. Blower used in dusting on spores. G, bent glass tube; A, small-bore brass tube soldered to blower.

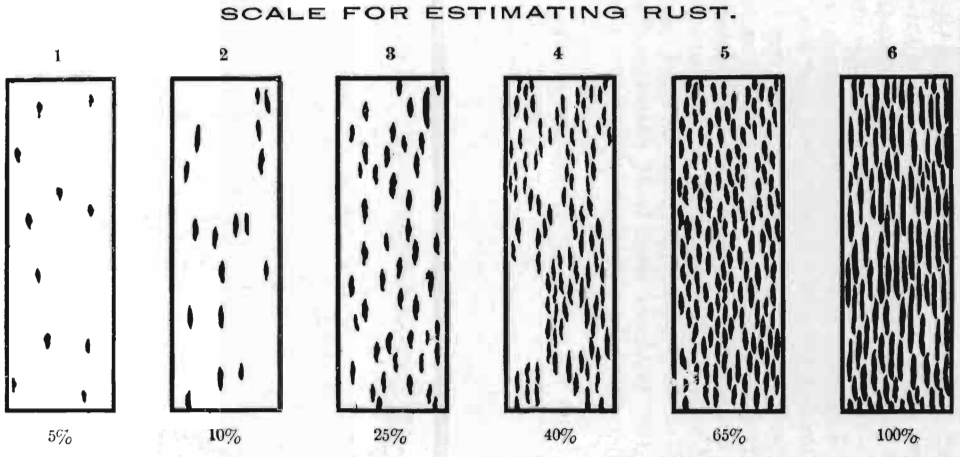

Fig. 2. Scale for estimating degree of rust, as devised by N. A. Cobb in Australia, and later revised and used in the office of Cereal Investigations, U. S. Dept. Agr. To eliminate as much as possible the personal equation in estimating rust, the comparisons with this scale were made by two persons, an effort being made to select representative samples from each variety.

The infection just described started when the oat plants were 6 to 8 inches tall and continued thruout the growing-season, until some of the earlier varieties had headed and ripened. The most severe infection was obtained in the rust nursery as a result of diligent application of spores in large quantities at intervals of one to two days during that part of the growing-period when the plants were making rapid vegetative growth.

Just prior to harvest the different varieties were closely examined for the amount of infection of both rusts. The degree of infection was estimated by comparison with the scale for estimating rust, (fig. 2).

As the different varieties matured they were harvested by pulling, so that individual plant selections could be made where necessary. The seed from these individual plants was threshed separately and samples saved for the following year's work.

EXPERIMENTAL RESULTS

COMPARISON OF METHODS OF INOCULATION

To obtain uniform exposure of plants to infection is difficult. Spores may be smeared over wetted leaves with a knife, shaken from the infected plants as suggested by Fromme (8), or sprayed on in water suspension as done by Melhus (15), and then incubated in a moist chamber. Any of these methods is applicable in carrying stock cultures of rust, but none has proved practical in comparing varietal resistance where large numbers of plants are used. Further, it was found that different methods of inoculation gave different results as to amount of resultant infection. Smeared inoculations resulted in severe infection of a nonuniform character, some parts of the leaf being covered with rust, while other parts remained free. Where many plants are to be tested or carried in stock this method is very laborious.

In spraying the spores onto the plants a more uniform distribution of the inoculum may be secured. To accomplish this even distribution, a blower was devised, as shown in fig 1, with which spores might be blown onto wetted plants. This dusting or blowing on of spores seems to offer the most favorable means of insuring rust infection, for it results in a rapid, uniform distribution of spores with minimum injury. To record the amount of spores applied to the plants, glass slides, ruled in 1-20 cm. areas, were distributed among the plants and spore counts were made on these slides. In estimating the amount of rust obtained on the infected plants the method

described on page 35 was used. A modification of this method was made, however, by laying glass slides, ruled in ¼ cm. areas, over the sori when first visible and by making definite counts of sori over a constant area.

To compare the methods referred to above with the one just described, the following tests were made. Spores were applied to 280 pots of oat plants of several varieties by the following methods: (1) Dusted from heavily rusted plants on the moist leaves of uninfected plants, (2) blown on with a spore blower, (3) smeared on with a knife, and (4) sprayed on in water suspension. The infection following inoculation by the first three methods was uniformly abundant, but in all cases where the spores in suspension were sprayed on, the infection was light. (See fig. 3). This low degree of infection was repeatedly noted on other occasions when spores in suspension were sprayed on. Apparently the spores are injured by the immersion in water, for even those of high germinating capacity, when so immersed not only produced scant infection, but showed a low percentage of germination in drop culture. On examination, these spores appeared to have experienced some internal disturbance, for the granular cell contents were shrunken to the center away from the cell wall and the whole spore seemed greatly increased in diameter.

The method of inoculation by blowing gives freedom from injury sustained by spores in suspension in water, and a very uniform distribution as well. When blown down on a beam of light, the cloud of spores is seen to be uniformly divided.

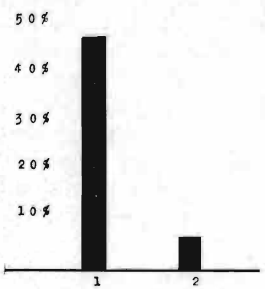

Fig. 3. Comparative degree of infection obtained by dusting and spraying on of uredospores of crown rust.

1. The average degree of sporulation (47 percent) obtained by blowing, dusting and smearing on of spores.

2. The average degree of sporulation (7 percent) obtained from spores sprayed on in water suspension.

The spore counts on ruled 1-20 square cm. areas on slides distributed among the plants in a moist chamber are shown in table 1. These data illustrate the uniformity of spore distribution by the spore-blower method. Such even distribution has never been obtained by any other method heretofore described. It should be mentioned that it is largely due to the use of this method, together with enormous quantities of spores, that the high percentage of infection was obtained in the varietal experiments in the rust nursery in 1917 and 1918.

METHOD OF ESTIMATING RUST INFECTION

The method of reading the degree of rust infection as customarily practiced

TABLE I—SPORE DISTRIBUTION IN MOIST CHAMBER BY SPORE BLOWER, AS SHOWN BY COUNTS OF SPORES WITHIN DEFINITE AREAS ON GLASS SLIDES*

Slide No.	Spores on 1/20 Square Cm. Areas	Spores on 1/20 Square Cm. Areas
	Moist Chamber No. 1	Moist Chamber No. 2
1	5, 5, 10, 5, 10, 7, 5	14, 8, 9, 9, 15, 11, 13
2	7, 5, 10, 12, 14, 8, 7	14, 10, 8, 14, 10, 9, 8
3	10, 5, 9, 7, 10, 14, 11	9, 12, 10, 15, 7, 13, 16
4	7, 11, 12, 9, 6, 12, 11	14, 10, 12, 11, 11, 8, 12
5	7, 6, 5, 9, 10, 8, 10	16, 12, 10, 11, 7, 10, 12
6	9, 10, 8, 12, 11, 10, 9	10, 10, 7, 11, 8, 8, 10
Average	9 spores per 1/20 cm. square	10 spores per 1/20 cm. square

* This table is a copy of a representative page from a notebook showing the distribution of blown spores caught on twelve slides ruled in areas of 1/20 square cm. and distributed in the four corners and center of the inoculation chamber. Such counts were made on slides scattered among the plants every time exposures to infection were made.

is to estimate the percentage on representative plants by comparison with the scale as described and shown in fig. 2. Glass slides etched in ¼ cm. areas were placed over infected leaves and stems of representative plants, and the actual number of sori counted in a centimeter space. By this means the degree of rust recorded is reduced to a more definite basis. Especially is this true in the greenhouse, where the rust can be observed as soon as it makes its appearance. It is also interesting to note that the figures obtained on the percentage basis coincide with those obtained by the scale method, as shown in table II.

As the infection appears on the host plants, every point of rust invasion is indicated by a light-colored spot, or fleck, shortly followed by the appearance of a sorus in the center. In a large majority of cases but one sorus appears in each etiolated area. (fig. 4). Out of 833 areas attacked by rust, 748 produced at first but one sorus, 67 produced two, and 15 produced three. A summary of the results of over 200 lots studied in the greenhouse shows further that from an average of 27 flecks per square cm., an average of 37 sori per square cm. were borne at the beginning. If estimates of rust are taken at this time,

TABLE II—COMPARISON OF METHODS OF RECORDING INFECTION OF CROWN RUST (*PUCCINIA CORONATA*) ON OATS*

Source of data	All varieties		Checks	
	Pustules per sq. cm.	Rust estimated, Percent	Pustules per sq. cm.	Rust estimated, Percent
First greenhouse records	22	32	36	46
Ten days after first records	32	40	46	65
Seedlings in greenhouse	37	40	54	56
Early sown plot in rust nursery	40	40	42	43
Late sown plot in rust nursery	38	35	40	37
Average	33	37	43	49

* This table gives the averages for all varieties studied in the greenhouse and in the rust nursery in 1918.

they will indicate quite accurately the relative degree of infection of plants when exposed to like conditions and opportunities for infection. Later, as illustrated in table III, the number of sori per infected area increased 56 percent. For comparative results, where the number of sori is used as an index of rust infection, estimates of rust should be made at equal lengths of time following the first appearance of the sori.

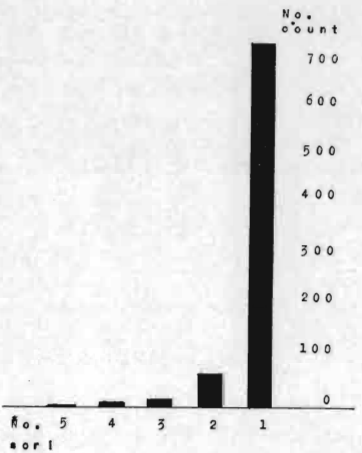

Fig. 4. Graph showing the number of pustules produced by each of 833 areas attacked by rust, indicating that in the majority of cases each fleck produced one pustule.

RELATION OF DOSAGE TO DEGREE OF INFECTION

The appearance and character of the etiolated areas or flecks produced at first by rust invasion, would suggest that each one represents a point of invasion by a germinating spore. This assumption in general is true. There is a relaton between the number of viable spores applied to a host plant and the resulting number of sori, but the relation is not direct. Fig. 5 shows graphically the results of tests on 994 pots of oats, illustrating the relation of number of viable spores applied to the resulting infection, evidenced by the number of sori produced. In these studies, when both seedlings and plants at time of heading were inoculated with crown rust, the number of spores applied and the resulting sori were counted as previously described. The degree of infection was found not to correspond directly to the amount of inoculum applied to the host. At the lowest figures, 0-15 spores per square cm., 17 sori resulted; between 15-50, 24 sori, and so on, with a constantly increasing rate up to 1,000 spores per square cm. From this point to 6,000 spores

TABLE III—INCREASE IN THE NUMBER OF RUST SORI DURING AN EIGHT-DAY PERIOD

Source of data	No. of sori per sq. cm. at first reading	No. of sori per sq. cm. 8 days later
Varieties infected with *P. coronata* at time of heading	22	32
Checks infected with *P. coronata*	36	46
Varieties infected with *P. graminis*	17	(a)
Checks infected with *P. graminis*	26	(a)
Average	25	39

(a) The sori became confluent to such an extent that the number could not be determined definitely.

the increase is only 18 sori per square cm. and the curve shown in fig. 5 becomes flattened.

It is a physical impossibility to get more than a certain number of sori on a square centimeter, say about 100, or one to each square mm. It therefore makes little difference whether 1,000 or 6,000 spores germinate on a leaf; only a certain amount of infection is manifest as sori. The matter of degree of infection appears to be largely one of available nutrition. With the application of many spores, their germination and resultant invasion of the host soon exhaust the food supply, the leaf turns yellow, and the sori resulting from the infection, tho numerous, are small, or dried and undeveloped. Where only a few spores are applied to the leaf the resulting mycelium has little competition. Being well nourished, it produces numerous sori in concentric and successive circles about the original point of eruption. These symptoms of leaf rust infection have been constantly observed thruout the studies described in this paper. On large, rank leaves of maturing plants, where the centers of infection were scattered and the rust received plenty of food without taxing the host leaf, sori have been kept for over a month, all the time producing fresh crops of spores while slowly invading the leaf tissues. In seedlings, however, the progress of infection of the tissues is more rapid than in the case of older plants, and the leaves are soon killed by the rust when the infection is severe.

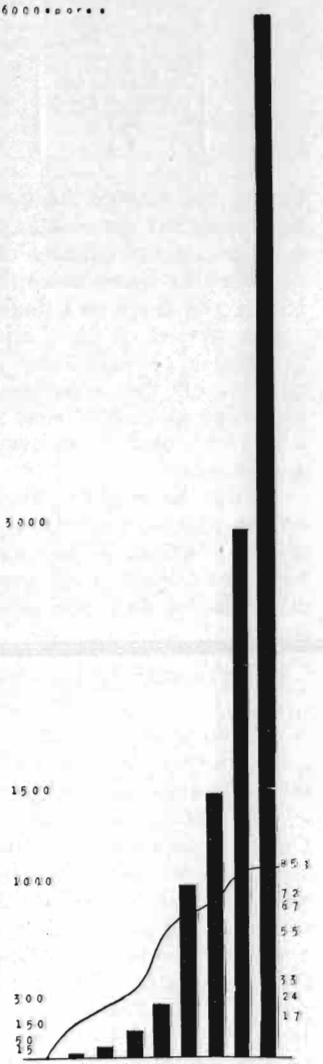

Fig. 5. Graph showing the relation between the number of spores applied to a leaf and the resulting sporulation. Columns represent the number of viable spores applied (from 15 to 6,000 per square cm.) curve represents the number of sori produced per sq. cm. (17 to 85) by the different amounts of spores applied.

COMPARATIVE SUSCEPTIBILITY OF SEEDLINGS AND OLDER PLANTS

The greater susceptibility of seedlings is indicated not only by the greater degree of rust infection obtained with equal spore applications,

TABLE IV—COMPARISON OF TIME OF INCUBATION OF CROWN RUST ON SEEDLINGS AND OLDER PLANTS

Source of data	Older plants		Seedlings	
	No. days from exposure till flecks appear	No. days from exposure till sori appear	No. days from exposure till flecks appear	No. days from exposure till sori appear
Varieties	8.2	10.1	5.8	8.9
Checks...	7.4	9.5	4.9	7.8

but by the shorter incubation period. The degree of rust infection obtained on seedlings as compared with older plants submitted to equal chances of infection indicates that the seedlings are slightly more susceptible than the older plants, producing 18 percent more sori than the latter.

The period of incubation of the rust in the leaf also points to greater susceptibility of seedlings. Table IV shows a comparison of the incubation periods of seedlings and older plants as averaged from 26 sets of checks of the variety Swedish Select, and from over 200 other lots of oats tested in the greenhouse.

It will be noted in table IV that the incubation period of crown rust is two days shorter on seedlings than on older plants. Whether this difference is due to greater and more readily available food supply in the younger plants or to some other factor or combination of factors, is a question yet to be answered.

RESISTANCE OF DIFFERENT VARIETIES AND STRAINS TO CROWN AND STEM RUSTS

Of the many varieties of oats, some mature before rust becomes severe, others resist slight attacks of rust, while still others exhibit a definite resistance even under the stress of a severe attack. In order to determine the reaction of the different varieties of oats to rust, a large number of varieties and selections of oats was sown in the rust nursery in the field for five years and exposed to severe attacks of rust induced by artificial methods. Thus it was made possible to compare the resistance and susceptibility of these varietes to both crown and stem rust. The data obtained on lots grown during all or a part of the five-year period from 1914 to 1918 are presented in tables V to IX, inclusive. Table VIII gives data on hybrids grown in one or more years from 1916 to 1918, and table IX includes lots grown only in 1918.

In tables V, VI and VII the percentages of crown and stem rust shown by the different varieties are given for each year. The letter "T" indicates a trace of rust, insufficient in amount to grade numerically. The average of all varieties and the number of varieties included in the test for each year are

shown at the foot of the tables. Maximum percentages attained during the period are indicated by blackface type.

Table V presents data on the varieties and strains of the red oat group (*Avena sterilis*) commonly grown in the Southern States. Table VI includes those varieties which belong to the common oat group (*Avena sativa*). These are grown in the northern states and for the most part have white or yellow glumes. Table VII includes the various botanical species and races of *Avena* under their Latin names. Few, if any, of these are grown commercially in this country. In table VIII are recorded the results of tests with certain hybrids between varieties of the *A. sterilis* and the *A. sativa* groups. These crosses were made at Cornell University, and the seed was furnished the writers by Dr. H. H. Love of the Plant Breeding Department.

Before discussing the response of the individual varieties and strains to the rust resistance tests, some general relations will be pointed out, particularly the comparison between the *A. sativa* and *A. sterilis* groups. The summary figures are given in table X for ready comparison.

Table X shows that in each of the five years the average percentage of crown rust was lower in the *A. sterilis* derivatives

TABLE V—PERCENTAGE OF CROWN RUST AND STEM RUST INFECTION ON VARIETIES OF OATS IN THE RUST NURSERY AT AMES, 1914-1918, *AVENA STERILIS**

Name of variety	Number or Source	Perc'age crown rust[2]					Percentage stem rust[2]				
		1914	1915	1916	1917	1918	1914	1915	1916	1917	1918
Appler	C. I. 695	20	**40**	12	30	20	3	10	15	5	**75**
Burt		30	**40**	25	35	10	15	20	T	8	**25**
Burt	Cor.			10	**45**	30			10	5	**85**
Burt	C. I. 710	30	**45**	10	40	30	1	5	12	10	**80**
Culberson	C. I. 651	25	40	**65**	35	50	10	T	3	0	**65**
Early Ripe	Cor.			15	**45**	25			12	5	**50**
Fulghum	C. I. 694	30	40	15	**65**	50	5	10	3	0	**90**
Golden Rustproof	Class 1796	35	35	5	**55**	25	25	10	10	5	**65**
Italian Rustproof	C. I. 409	20	50	25	**55**	45	T	20	20	15	**85**
Red Rustproof	C. I. 261	35	40	25	**90**	35	5	30	20	10	**80**
Red Rustproof	C. I. 518	35	30	1	**85**	5	3	25	12	12	**40**
Red Rustproof	C. I. 700	20	45	15	**80**		2	20	12	**25**	
Turkish Rustproof		35	40	60	**75**	50	15	5	3	5	**85**
Turkish Rustproof	C. I. 627	25	30	60	**70**		5	35	7	T	**85**
Turkish Rustproof					65	35					**65**
No. of varieties		12	12	14	15	13	12	12	14	14	14
Average percentage		28.3	39.6	24.5	58.0	31.5	7.5	15.8	9.9	7.5	69.6

* In all of the tables the varieties are arranged alphabetically and, in addition to the name, certain identification numbers are given. "C. I." refers to the Office of Cereal Investigations. "S. P. I." to the Office of Seed and Plant Introduction of the United States Department of Agriculture. The abbreviation "Cor." stands for "Cornell." The abbreviation "Minn." refers to the accession numbers of the Minnesota Agricultural Experiment Station, and the Cornell numbers are those of the hybrid series of the Department of Plant Breeding. The abbreviation "Class" refers to a series of numbers assigned by C. W. Warburton to those varieties being grown in his classification nursery.

[2] Figures in blackface type indicate maximum percentage of infection obtained on the variety during the five years.

TABLE VI—PERCENTAGES OF CROWN RUST AND STEM RUST INFECTION ON VARIETIES OF OATS IN THE RUST NURSERY, AMES, 1914-18, *AVENA SATIVA*

Name of variety	Number or Source	Percent crown rust					Percent stem rust				
		1914	1915	1916	1917	1918	1914	1915	1916	1917	1918
Abundance	Minn. 272	20	50	42	65	55	10	15	12	T	80
Do	C. I. 796				75	40				30	75
Alberta	Class. 1797	35	65	25	50	55	35	5	7	12	75
American Banner	Minn. 275	35	55	40	45	40	3	15	9	15	70
Archangel	Minn. 280	25	55	40	45	40	5	5	4	5	80
Archangel x Early Gothland	Minn. 305	25	60	55	55	55	3	15	5	15	85
Banner	Minn. 348	35	35	25	60	45	5	15	3	5	70
Do	C. I. 806				65	50				10	70
Big Four	Minn. 354	30	45	15	60	55	20	20	4	8	65
Black Anthony	Class. 1804	20	60	35	85						
Black Beauty		30	50	32	90						
Black Tartarian					70	25					
Bumper Crop	Class. 1791	35	50	65	75	55	20	T	5	5	85
Challenge	Minn. 273	30	55	25	65	30	5	15	5	10	85
Clydesdale	Class. 1729	30	65	40	60	60	15	5	8	10	80
Do	Class. 1793	35	40	25	68	15	25	10	7	20	95
Colorado No. 9	Minn. 386	25	50	55	90	65	10	15	3	5	80
Conqueror	Class. 1798	20	65	40	80	60	20	25	6	T	90
Danish	C. I. 798				75	45				20	80
Danish Giant	C. I. 672	30	50	25	68	50	5	10	15	5	85
Early Gothland	Minn. 26	40	40	50	65	50	10	10	3	8	90
English Wonder	Class. 1807	25	60	42	65	50	2	20	12	5	65
Garton No. 5	C. I. 730	35	70	65	70	50	20	5	5	5	70
Garton No. 396	Minn. 405	35	65	55	65	45	20	5	10	5	95
Garton Black Rival					85.	60				8	75
Garton Record	C. I. 801				78	40				20	85
Garton Abundance	C. I. 802				72	55				12	75
Goldmine	Class. 1805	30	55	38	50	20	5	T	5	T	75
Green Mountain	Class. 1799	30	60	50	50	40	20	20	4	T	85
Green Russian	Brookings, S. D.				40	50				0	10
Do	Minn. 350	30	50	25	25	10	10	20	2	5	65
Johnson	Class. 1808	25	60	40	45	50	1	5	3	5	70
Junghans	Class. 1800	35	50	30	35	45	15	10	5	5	90
King Oscar	Minn. 341	39	55	35	35	40	10	15	4	7	90
Ligowa	Minn. 6	40	50	40	40	30	10	15	12	10	90
Lincoln	Minn. 340	30	55	38	60		15	15	3	5	
Pickett	Class. 1728	30	65	45	60	40	10	T	3	7	90
Roosevelt	Minn. 391	35	40	25	65	30	20	15	3	8	90
Ruakura Rust-resistant	C. I. 701	30	50	15	40	30	2	5	T	T	10
Do	C. I. 701				65	25				25	25
Do	C. I. 701				25	15				25	35
Do	C. I. 701				60	30				15	35
Shadeland Challenge	C. I. 680	35	65	55	65	30	8	T	2	15	90
Shadeland Climax	C. I. 681	30	40	30	60	25	10	10	12	5	75
Shireff	Minn. 285	30	40	40	55	20	2	10	5	5	85
Siberian				40	70	25					
Silvermine					70				6	5	60
Sixty-day	C. I. 165			35	50				10	0	30
Sparrowbill	C. I. 804				72	30				10	85
Storm King		25	60	60	75	35	10	5	2	5	75
Stube		35	65	40	65	35	10	T	6	10	75
Swedish Select	Minn. 271	30	50	45	65	45	5	15	12	12	65
Do	Minn. 271				60	40				18	60
Vilmorin Black Hybrid	C. I. 830				30	40				5	
White Bonanza	Minn. 403	30	45	25	65	30	25	25	4	10	40
White Russian					40	50				T	80
Do					45	30				T	1
Do					30	35				0	20
Do					40	30				0	5
Do					40	45				0	5
Do	C. I. 551				55	40				0	2
Do		35	50	50	40	60	10	0	T	0	5
Do				20	42	25				0	5
Do	C. I. 300				60	25				0	5
Do	C. I. 800				70	25				T	5

Name of variety	Number or Source	Percent crown rust					Percent stem rust				
		1914	1915	1916	1917	1918	1914	1915	1916	1917	1918
White Wonder	Minn. 299	30	65	30	70	25	3	10	5	T	80
Yielder	C. I. 799				78	40				10	90
(Unnamed)	C. I. 601	30	65	40	60	45	5	10	8	10	75
Do	C. I. 603	30	63	50	68	50	15	10	10	12	60
Do	C. I. 609	5	65	40	35	30	1	5	4	T	60
Do	C. I. 749	35	40	50	68	35	20	5	T	T	50
Do	C. I. 749				70	35				T	30
Do	C. I. 749				68	40				T	10
Do	Minn. 343	25	60	32	80	25	5	15	2	T	75
Albion	Iowa 103			55	60	25			3	0	40
Do	Iowa 103				60	10				0	60
Richland	Iowa 105			65	68	10			T	0	70
No. of varieties		45	45	50	77	72	43	43	47	73	71
Average percentage		29.6	54.4	39.6	59.6	38.0	11.2	10.5	5.5	6.7	61.1

than in those of *A. sativa.* The figures are certainly significant, for the number of varieties is representative in both species, and the constancy of their relation in each of the five years leaves no doubt that a greater degree of resistance to crown rust exists in the varieties of *A. sterilis* than in those of *A. sativa.* This fact was suggested by the junior author (19) as a result of greenhouse studies made in 1915-1916.

The occurrence of the maximum figures for crown rust in 1917 requires some explanation. In that year special attention was given to crown-rust infection. Large quantities of spores were put on the plots daily or every other day during the growing season. Abundant infection resulted, with the consequence that the percentage figures were frequently higher

TABLE VII. PERCENTAGES OF CROWN RUST AND STEM RUST INFECTION ON OATS IN THE RUST NURSERY, AMES, 1914-18
MISCELLANEOUS SPECIES

Name	S. P. I. Number	Percent crown rust					Percent stem rust				
		1914	1915	1916	1917	1918	1914	1915	1916	1917	1918
A. barbata	25354	10	30	5	T	2	3	25	7	30	10
A. brevis			40	0	10	10		10	15		40
A. fatua		30	30	65	90	60	15	5	12	T	95
A. nuda					65	25					25
A. orientalis flava			75	40	65	45		T	T	5	50
A. orientalis mutica			70	40	40	30		T	T	0	5
A. orientalis obtusa			65	25	30	25		10	2	5	80
A. purpurea	25357				75	40				T	45
A. tartarica			70	40	50	30		10	8	5	70
A. tartarica tristis			80	40	70	50		10	8	8	50
A. sativa	25356				75	40				5	40
A. sativa aristata			40	40	80	50		10	7	10	40
A. sativa aurea			80	20	70	30		10	3	25	65
A. sativa brunnea			55	65	90	55		10	3	8	85
A. sativa grisea			60	70	80	5		10	T	0	0
A. sativa Krausei			75	30	50	25		10	4	20	85
A. sativa montana			75	30	85	40		5	3	10	70
A. sativa mutica			65	31	53	38		20	6	7	71
A. sativa nigra			40	65	60	25		5	T	5	75
A. sativa praegravis			57	45	86	57		13	4	1	82
A. sativa setosa			75	45	67	45		10	3	8	85
A. sativa trisperma			30	20	5			30	35	10	85
No. of varieties		2	19	19	22	21	2	19	19	20	22
Average percentage		20.0	58.5	37.7	58.9	34.6	9.0	10.7	6.3	8.1	57.0

TABLE VIII. PERCENTAGE OF CROWN RUST AND STEM RUST INFECTION ON HYBRIDS OF *AVENA SATIVA* AND *AVENA STERILIS* OBTAINED IN THE RUST NURSERY, AMES, 1916-18

Parentage	Cornell No.	Percent of crown rust			Percent of stem rust		
		1916	1917	1918	1916	1917	1918
Burt x Sixty-Day	2501	20	70	30	7	T	65
Early Ripe x Sixty-Day	514	10	60	0	5	5	20
Do	514	10	75	0	3	T	
Do	514		60	25		T	15
Do	514	5	62	15	15	T	15
Do	514	5	60	20	20	10	50
Do	514		65	5		5	30
Do	514		65	10		5	50
Early Champion x Early Ripe		10	60	25	12	8	70
Do		15	72	5	8	5	70
Do		10	70	20	14	5	60
Do				30			85
Early Ripe x Black Mesdag	535	20	70		10	T	50
Do	535	5	70	30		T	70
Do	535	5	72	15		T	70
Do	535	5	75	25	18	8	85
Do	535	8	70	10	10	5	
Do	535	5	72	30	12	T	80
Do	535		78	20		15	80
Do	535		75	15		5	75
Do	535		75	40		10	80
Do	535			15			90
Do	535			25			80
Swedish Select x Early Ripe	543	5	65	25	10	5	25
Do	543	5	65	20	12	20	60
Do	543			25			80
Do	543	5	62	20		20	40
Do	543			25			65
Do	543		65	20		20	50
Do	543			15			50
Do	543			40			80
Do	543			35			50
Do	543		30	65		15	55
Do	543			40			50
Do	543		65	25		30	65
No. of varieties		17	26	34	14	26	33
Average percentage		8.4	66.4	22.5	11.1	7.5	59.4

than in other seasons. In 1918, the same methods were followed with stem rust, and with the same result.

The 1918 season was the only one in which the attack of stem rust was severe enough to prove conclusively the resistance of the White Russian oat, tho the results in previous years had suggested it. The maximum percentage of infection with stem rust is, therefore, a safer criterion of the resistance of any variety than the five-year average.

In the case of crown rust, the five-year averages probably furnish a fairly correct idea of what might be expected of a given variety or group of varieties under normal field conditions. The maximum figures serve to show what may be the reaction of any variety under the most severe rust attack. Fewer varieties can be described as resistant on the basis of the maximum figures than when the averages are used as criteria. Fig. 6 shows graphically frequencies of the different maximum percentages on all the varieties during the five years.

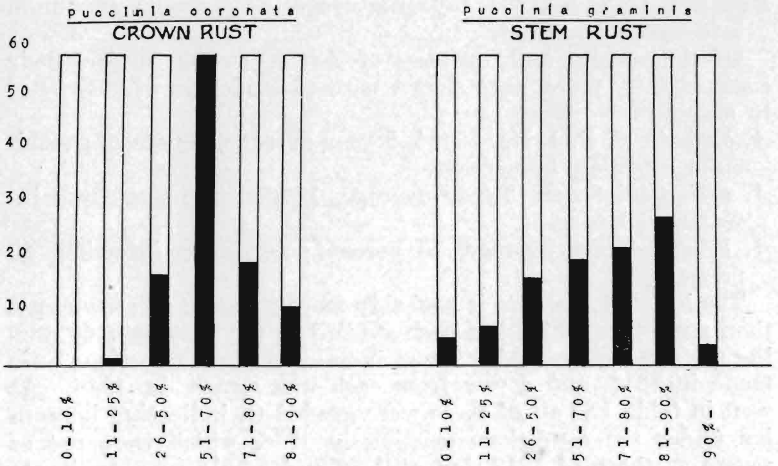

Fig. 6. The frequency of the different maximum percentages of crown and stem rusts occurring in the varietal experiments.

From this graph it will be seen that few varieties show a low degree of rust infection. In the case of crown rust, the greatest number became rusted from 50 to 70 percent, while in the case of stem rust, the greatest number were rusted from 50 to 95 percent.

Only a few varieties are outstandingly resistant to either rust and none, with the possible exception of Ruakura and *Avena barbata,* show marked resistance to both rusts.

It has been shown that, as a whole, the *A. sterilis* group is distinctly more resistant to crown rust than the *A. sativa* group. Of the varieties of red oats, the following are of particular interest, because of their relatively low averages of crown-rust infection:

Appler, C. I. No. 695, 5-year average, 24 percent; maximum infection, 40 percent.

Burt, 5-year average, 28 percent; maximum infection, 40 percent.

Burt, C. I. No. 710, 5-year average, 31 percent; maximum infection, 45 percent.

Early Ripe (Cornell) 3-year average, 28 percent; maximum infection, 45 percent.

Golden Rustproof, Class No. 1796, 5-year average, 31 percent; maximum infection, 55 percent.

Of the varieties of *A. sativa* showing resistance to crown rust, only two deserve special mention. These are:

Green Russian, Minn. No. 350, 5-year average, 28 percent; maximum infection, 50 percent.

Ruakura, C. I. No. 701, 5-year average, 33 percent; maximum infection, 50 percent.

Of the species and varieties of Avena grown under their Latin names, three have shown marked evidences of resistance to crown rust. They are:

A. barbata, S. P. I. No. 25354, 5 year average, 9 percent; maximum infection, 30 percent.

A. sativa trisperma, 3-year average, 18 percent; maximum infection, 30 percent.

A. brevis, 4-year average, 15 percent; maximum infection, 40 percent.

The lot of *A. barbata* is probably more resistant to crown rust than any other which has been studied in the rust nursery during the five-year period. Three individual plant selections were made in 1917, and a row from each was grown in 1918. As seen in table IX, all of these were graded O, indicating immunity under the conditions existing in 1918, which were not as severe as those of 1917, but still offered ample opportunity to distinguish resistant strains from susceptible ones.

TABLE IX. PERCENTAGE OF CROWN RUST AND STEM RUST INFECTION ON VARIETIES AND SELECTIONS TESTED ONLY IN 1918 IN THE RUST NURSERY AT AMES

Name	Selection No.	Cr'wn rust	Stem rust
Bicknell		40	90
Black Mesdag		10	80
Black Tartarian			85
Daubeney		35	70
Early Champion		20	60
Early Gothland		40	
Green Russian		50	25
Do		45	
Do		45	10
Do		50	5
Joanette		40	50
Probsteier		55	55
Siberian		5	60
Sixty-Day		5	35
Swedish Select		30	65
White Russian		50	
Do		15	
Do		20	2
Do		30	10
Do		15	2
Do		10	40
Do		20	10
Do	98-2	55	0
Do	98-3	45	10
Do	98-4	40	1
Do	98-5	30	2
Do	99-2	40	2
Do	99-3	30	10
Do	99-4	35	10
Do	101-2	40	10
Do	101 1/2-2	45	2
Do	101 1/2-3	50	30
Do	101 1/2-4	40	5
Do	101 1/2-5	40	5
Do	102-2	30	1
Do	102 1/2-2	35	5
Do	102 1/2-3	30	5
White Russian	102 1/2-4	30	2
Do	102 1/2-5	35	5
Do	102 1/2-6	25	2
Do	102 1/2-7	30	5
Do	103-2	45	5
Do	103-3	45	5
Do	103-4	30	10
Do	103-5	40	10
Do	106-2	30	10
Do	106-3	35	5
Do	106-4	30	10
Do	107-2	25	40
Do	107-3	25	5
Do	108-2	30	10
Do	108-3	30	10
Appler		55	80
Do		50	80
Do		65	80
Do		35	75
Do		30	65
Do		25	75
Do		40	85
Do		40	80
Do		50	90
Do		65	85
Italian Rustpr'f		25	90
Red Rustproof		40	85
Turkish Rustp'f			65
Avena barbata		0	20
Do		0	10
Do		0	10
Do		0	15
Avena fatua		40	50
Avena ludoviciana		25	75
No. of varieties		69	67
Average percentage		33.1	32.8

In 1918 (table IX), a number of varieties then grown for the first time had low percentage figures, but as the epidemic was not an extremely severe one, these results cannot be taken as final. The strains of Appler obtained from San Antonio (Texas) Experiment Farm did not manifest a high degree of resistance to crown rust, altho three of them had relatively low percentages of infection, 35, 30 and 25 percent, respectively, as compared with some of the others, which ran as high as 65 percent.

It has been shown that the comparisons of group averages of resistance to crown rust do not hold for stem rust. It is also true that none of the individual varieties of *A. sterilis* have shown resistance to stem rust, tho one strain of Burt and several selections of *A. sativa* and *A. sterilis* hybrids have averages slightly lower than the group average, probably due to their rust-escaping character, which results from their early maturity.

Altho the number of *A. sterilis* varieties studied was not large, it represents fairly well those types commonly grown in the United States, and certainly does not suggest that we should look for, or expect, resistance to stem rust among the red oats.

Among the species and botanical varieties of Avena tested, there are three which deserve special mention because of their resistance to stem rust. These are:

A. barbata, S. P. I. No. 25354, 5-year average, 15 percent; maximum infection 30 percent. Four individual plants of this strain selected in 1917 produced progenies in 1918 which graded 20, 10, 10, and 15 percent, all showing marked resistance in a season when the infection was abundant.

A. orientalis mutica, 4-year average, 1.25 percent; maximum infection, 5 percent. This strain showed infection only in the severe rust year, 1918, the infection then being only 5 percent. This variety, a side oat, well exemplifies the extreme resistance, amounting almost to immunity, exhibited by certain other varieties of side oats.

A. sativa grisea, 4-year average, 2.5 percent; maximum infection 10 percent. An individual plant selection made in 1916 was free of stem rust in both 1917 and 1918. Under the 1918 conditions this is quite remarkable, and indicates an abilty to withstand an extremely severe rust attack.

TABLE X. AVERAGE PERCENTAGE OF CROWN RUST AND OF STEM RUST INFECTION RECORDED IN RUST NURSERY STUDIES OF *AVENA STERILIS* AND *A. SATIVA* GROUPS OF OATS AT AMES, 1914 TO 1918

Group	1914	1915	1916	1917	1918	Average
			CROWN RUST			
A. sterilis	28	39	24	58	31	36
A. sativa	30	54	39	59	38	44
			STEM RUST			
A. sterilis	7	16	10	7	69	22
A. sativa	11	10	5	6	61	19

Most of the varieties of *A. sativa* are susceptible to stem rust, but certain varieties show well defined resistance. Among these are:

Green Russian, Minn. No. 350, 5-year average, 19 percent, maximum infection, 65 percent. Flecks characteristic of resistance were observed on plants of this variety grown in the rust nursery. Two selections made in 1917 showed only 10 percent and 5 percent infection in 1918, giving further evidence of the resistance of this variety. A strain obtained from L C. Burnett of the Iowa Agricultural Experiment Station and grown in the 1918 rust nursery also had but 25 percent infection, as compared with many varieties running up to 90 percent.

C. I. No. 749, 5-year average, 15 percent; maximum infection 50 percent. Two selctions made in 1916 each had only a trace of stem rust in 1917, and in the severe epidemic of 1918 were graded 30 percent and 10 percent, both of which figures are significantly low.

Ruakura, C. I. No. 701, 5-year average, 3 percent; maximum 10 percent. Three selections made in 1916 and grown in 1917, were graded 25, 25 and 15 percent, respectively, and in 1918, 25, 35 and 35 percent, respectively. These 1918 figures are distinctly lower than the average for the group in the same year. This variety is really resistant to stem rust, in addition to showing a fair degree of resistance to crown rust. As has been stated, this variety and *Avena barbata* are the only sorts tested which seeem to possess resistance which is not limited to a single rust species.

Probably the most outstanding and at the same time most valuable occurrence of the character of resistance to stem rust is in the White Russian[1] variety of the side-oat group. One of these strains has a five-year average of only 3 percent and a maximum of only 10 percent. Because of the importance of these results, the figures for each year are given in some detail, as follows:

In 1914, the average stem-rust infection on the forty-three lots of the *Avena sativa* group was 11.2 percent, while of the twenty-six rows of White Russian grown in the rust nursery as checks, none had more than a trace of stem rust and most of them were graded 0. In 1915 the average percentage of stem-rust infection on the forty-three lots of common oats was 10.5 percent, while on the twenty-six rows of White Russian again grown as checks, one was graded 0, fourteen were recorded as "trace," six as having 5 percent infection, and one, 10 percent. In 1916, the percentage of stem-rust infection on the 47 lots in the experiment averaged only 5.5 percent; the epidemic was a very light one. The three rows of White Russian grown were almost entirely free of stem rust thruout the season, a significant fact even with so little stem rust present. In 1917 the average percentage for the 73 lots in the test was 6.7 percent, while all three of the rows of White Russian were free of stem-rust infection. In 1918, as mentioned above, the epidemic of stem rust was very severe, the average for the 71 lots

[1] Apparently identical with White Tartar, as described by Etheridge (7, p. 161).

being 61.1 percent. The White Russian variety showed but 5 percent of infection, a figure of especial significance, which confirms and emphasizes the less definite evidence of resistance obtained in previous years when the epidemics were not severe enough to afford a basis for final conclusions.

In 1917 several additional strains of the White Russian type were secured from seedsmen and experiment stations and were included in the rust nursery. The results are shown in table IX. Of the seven strains added, five were graded as 0 and two as trace, and in 1918, under the severe epidemic, six of these strains had less than 5 percent of stem-rust infection, the seventh having 20 percent. A number of individual plant selections made from these rows in 1917 showed extreme resistance when grown in the 1918 rust nursery.

Of thirty selections (see table IX) all but three showed 10 percent or less of stem-rust infection, in entire agreement with results already obtained and in sharp contrast to other varieties grown in near-by rows.

The resistance of the White Russian oat to stem rust has been proved to hold in other localities and in two different seasons. Pure lines of several oat varieties were grown in nursery rows at the Minnesota Agricultural Experiment Station in 1917, when the natural infection of stem rust was sufficient to afford an accurate comparison of the resistance of the varieties. The plants were frequently observed during the season, and no stem rust was present on any of the rows of the White Russian oat, in sharp contrast to those of other varieties. The percentage of stem rust infection on these varieties at time of maturity is shown in table XI.

The figures in table XI again show the distinct resistance of White Russian and the contrasted susceptibility of other varieties of the common oat group and of varieties of the red oat group, some of which are resistant to crown rust.

The Ruakura oat, tho not entirely rust free, showed a lower percentage of stem rust than any variety in the experiment except White Russian.

TABLE XI. PERCENTAGE OF STEM-RUST INFECTION ON OAT VARIETIES GROWN AT THE MINNESOTA AGRICULTURAL EXPERIMENT STATION IN 1917

Avena sterilis Varieties	Percentage of Stem-rust infection	*Avena sativa* Varieties	Percentage of Stem-rust infection
Appler	60	Black Tartarian	80
Burt	30	Ligowa	60
Do	40	Sixty-Day	40
Cook	40	Swedish Select	50
Fulghum	30	White Russian	0
Golden Rustproof sel.	50	Ruakura	20
Italian Rustproof sel.	40		
Red Rustproof sel.	60		
Turkish Rust proof	60		

In addition to these studies, field observations have been made in two states which further substantiate the fact that the White Russian oat is resistant to stem rust. In August, 1916, about ten fields of late side oats, probably White Russian, located between Brookings and Watertown, S. Dak., were examined for rust. Not a trace of stem rust was found on plants typical of the variety, while plants of other types, particularly the wild oat, *Avena fatua,* growing in the same fields, were heavily infected. Many fields sown to other varieties, as Swedish Select, Sixty-Day, and other open-panicled types in the same region were found to have a fairly abundant infection of stem rust.

In August, 1917, notes were taken on the percentage of stem-rust infection on the oat varieties grown in field plots at the Ashland (Wis.) Branch Experiment Station.[1] Of more than twenty plots carefully examined, all except White Russian showed some stem-rust infection, the amounts ranging from a trace to 80 percent. The four plots of White Russian, including one grown under the name of Giant Swedish, were entirely free from stem rust. Plate I is from a photograph of typical culms collected from these plots, and shows clearly the marked rust resistance of this variety.

These conclusions are in agreement with the observations of earlier workers in this and other countries, whose results were given in the reviews of literature. Greenhouse experiments conducted by the junior author (19) also gave indications of the resistance of the White Russian oat to stem rust.

There are other varieties of side oats, some of them grown under the name White Russian, which are not resistant to stem rust, and care should be taken to avoid confusion of names and varieties. From what has been said, it must not be concluded that the White Russian oat is suitable for general culture in the chief oat-growing districts. As has been stated, White Russian is a side oat, known botanically as *Avena sativa orientalis.* This variety has long and rather plump white kernels and is very late in maturing. Because of its late maturity, it is not a high yielder, particularly in localities subject to midsummer drought and hot winds. In such districts, early oats such as Sixty Day or Kherson are much more likely to succeed. In the central and north-central United States, also, such varieties as Swedish Select, Silvermine, Victory, and others will usually outyield the much later White Russian. However, it is grown to some extent in Canada and in Minnesota, Wisconsin, and North and South Dakota. At the Belle Fourche (S. Dak.) Experiment Farm, Aune (1) reports that in a five-year experiment on irrigated land, this variety produced the high-

1 Grateful acknowledgment is made to Supt. E. J. Delwiche for his courtesy in offering the use of facilities of the station and for specimens.

est average yield. Thus there may be certain areas in the northern part of the spring-oat district where late side oats will yield well. If stem rust is a serious limiting factor in such localities, losses from it can be greatly reduced or entirely avoided by growing the rust-resistant White Russian oat.

Probably the greatest potential value of this resistant variety lies in the use which plant breeders may make of it. The fact that it is a white oat in the *A. sativa* group simplifies the prob-

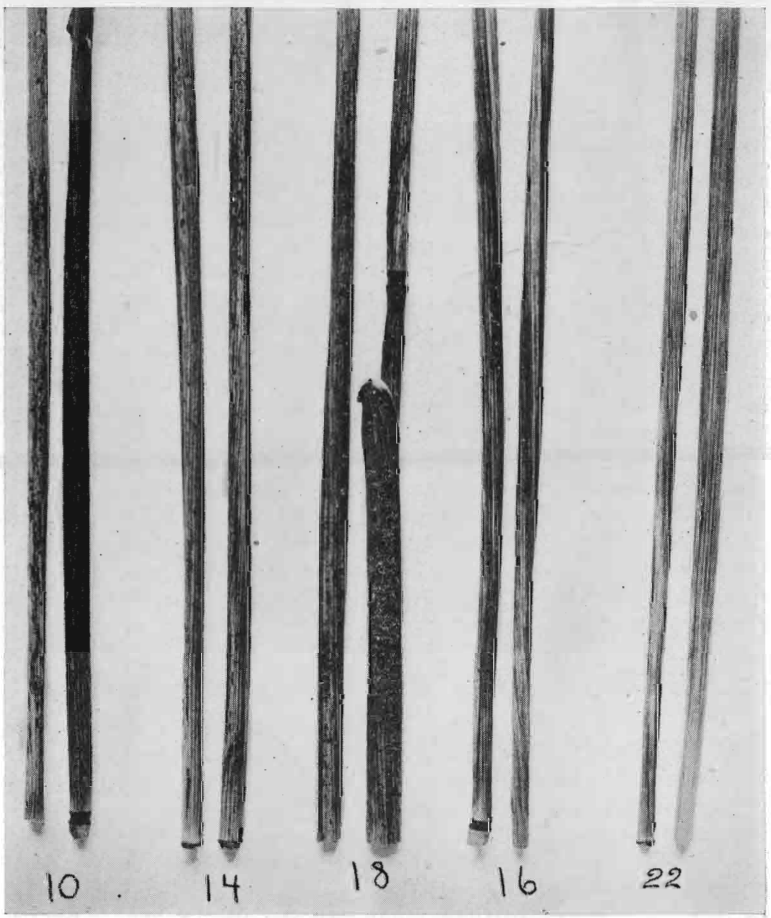

Plate I. Culms of oats from Ashland, Wis., in 1917, showing different degrees of resistance to stem rust.
10 and 18. White Jewel (side oats), susceptible.
14. Early Gothland, susceptible.
16. White Russian, resistant.
22. Giant Swedish (similar to White Russian), resistant.

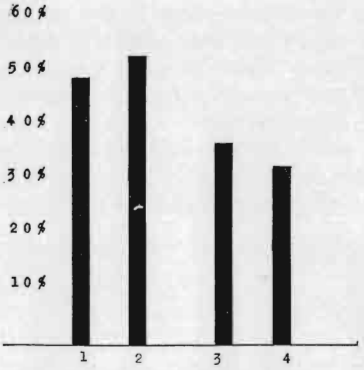

Fig. 7. The relation of the time of planting to the degree of rust infection.
P. graminis. Stem Rust:
1. Average percentage of rust on early-sown varieties.
2. Averae percentage of rust on late-sown varieties.
P. coronata. Crown Rust:
3. Average percentage of rust on early-sown varieties.
4. Average percentage of rust on late-sown varieties.

lem of producing thru hybridization a resistant variety for northern conditions which is earlier and higher in yield than White Russan.

EFFECT OF DATE OF SOWING ON AMOUNT OF INFECTION

The effect of early or late sowing on the amount of rust infection is shown by a survey of the data from the 1918 rust nursery. Duplicate plots were sown at intervals of two weeks. Early in the season the difference in the growth of the two sets of plants was quite noticeable, but toward the end of the season there was little difference in size, general appearance, or date of ripening. The plots were side by side and were equally exposed to infection. A close inspection, however, revealed a difference in the total degree of rust infection on the early- and late-sown plots.

This relation is shown graphically in fig. 7, which indicates that in the case of stem rust, the later plots were more heavily infected. Some of this difference is, no doubt, due to an increased effort to infect the later plot, but it is to no less an extent due to the nature of the rust and its relation to the host. On the other hand, the earlier sowings were more heavily infected with crown rust.

GREENHOUSE STUDIES OF RUST RESISTANCE OF OAT VARIETIES

In addition to maintaining cultures of rust in the greenhouse with which to start field infection in the spring, a study of the varietal resistance of oats in the seedling and heading stages was made under greenhouse conditions during the winter of 1917-1918. The results of these comparative greenhouse tests are given in tables XII to XV, inclusive. The varieties used in this work were the same as those used in the rust nursery. The seedlings were grown to the height of 4 to 6 inches and inoculated only with crown rust. Four plants of each variety were grown in 8-inch pots and inoculated with stem and crown rusts when beginning to head.

With such large numbers of plants as were used in these experiments it was impossible to give all equal opportunity for infection. Therefore, the results in rust percentages for each variety are not tabulated. The figures given for each variety were determined on the basis of the amount of infection shown

TABLE XII. RUST RESISTANCE OF OAT VARIETIES AS TESTED IN GREENHOUSE IN 1917, COMPARED WITH RESISTANCE OF SAME VARIETIES TESTED IN RUST NURSERY IN 1918
AVENA STERILIS

Variety	Source or Number	Percent crown rust		Percent stem rust	
		Greenhouse 1917	Rust nursery 1918	Greenhouse 1917	Rust nursery 1918
Appler	C. I. 695	44	37	14	95
Burt	C. I. 710	52	100	17	107
Culberson	C. I. 651	111	115	114	82
Early Ripe	Cornell	64	65	86	63
Fulghum	C. I. 694	41	112	78	114
Golden Rustproof	Class. 1796	55	87	182	82
Italian Rustproof	C. I. 409	54	95	48	107
Red Rustproof	C. I. 261	65	95	159	101
Do	C. I. 518	13	27	100	51
Turkish Rustproof		64	115	68	107
Do	C. I. 627	45	80	77	82
Average		55	84	85	90

TABLE XIII. RUST RESISTANCE OF HYBRIDS AS TESTED IN THE GREENHOUSE, 1917, COMPARED WITH THE SAME HYBRIDS TESTED IN THE RUST NURSERY, 1918
A. SATIVA x A. STERILIS HYBRIDS

Hybrid	Percent of crown rust		Percent of stem rust	
	Greenhouse 1917	Rust nursery 1918	Greenhouse 1917	Rust nursery 1918
Early Ripe x Black Mesdag	144	60	100	82
Do	54	70	14	89
Do	70	65	86	89
Do	92	67	57	107
Do	59	40	186	
Do	52	137	35	101
Do	42	75	43	101
Do	111	65	28	95
Do	150	42	73	101
Do	103	122	71	51
Do	105	88	21	101
Early Champion x Early Ripe	66	92	27	89
Do	83	15	43	89
Do	73	62	10	76
Do	7	62	10	107
Early Ripe x Sixty-Day	109	77	40	19
Do	82	75	55	19
Do	46	70	82	63
Do	79	32	38	38
Do	63	60	123	63
Swedish Select x Early Ripe	76	67	79	31
Do	87	52		
Do	69	77	146	63
Do	50	80	107	51
Do	30	75		
Do	83	90	53	69
Do	102	155		
Do	66	95	121	82
Average	76.8	73.8	65.9	74.0

TABLE XIV. RUST RESISTANCE OF OAT VARIETIES AS TESTED IN THE GREENHOUSE, 1917, COMPARED WITH SAME VARIETIES TESTED IN RUST NURSERY, 1918

AVENA SATIVA

Variety	Source or Number	Percent crown rust		Percent stem rust	
		Greenhouse 1917	Rust nursery 1918	Greenhouse 1917	Rust nursery 1918
Abundance	Minn. 272	122	135	82	101
Do	C. I. 796	57	115	69	95
Alberta	Class. 1797	46	100	64	95
Albion	Iowa 103	88	78	48	51
Do	Do	100	27	72	76
American Banner	Minn. 275	13	100	50	89
Archangel	Minn. 280	56	75	93	101
Archangel x Early Gothl'd	Minn. 305	105	120	150	107
Banner	Minn. 348	111	120	157	89
Big Four	Minn. 354	49	142	78	82
Bumper Crop	Class. 1791	55	120		
Challenge	Minn. 273	71	87	69	107
Clydesdale	Class. 1729	51	125	78	101
Do	Class. 1793	45	75	35	120
Colorado No. 9	Minn. 386	62	136	98	101
Conqueror	Class. 1798	103	162	146	114
Danish	C. I. 798	53	127	62	101
Danish Giant	C. I. 672	58	150	55	107
Early Gothland	Minn. 26	88	125	131	114
English Wonder	Class. 1807	20	136	62	82
Garton No. 5	C. I. 730	116	117	86	89
Garton No. 396	Minn. 405	42	125	20	120
Garton Record	C. I. 108			189	107
Goldmine	Class. 1805	100	70	85	95
Green Mountain	Class. 1799	73	110	69	107
Green Russian	Brookings	48	27	62	82
Do	Minn. 350	53	150		
Do	Do	87	120	18	12
Do	Do	50	160	11	6
Johnson	Class. 1808	123	162	51	89
Junghans	Class. 1800	42	120	45	114
King Oscar	Minn. 341	58	95	55	114
Ligowa	Minn. 6	40	82	31	114
Pickett	Class. 1728	60	125	112	114
Richland	Iowa 105	35	35		
Roosevelt	Class. 391	48	62	52	114
Ruakura Rustproof	C. I. 701	25	117	17	12
Do	Do	66	98	17	31
Do	Do	16	52	17	44
Do	Do	61	87	71	44
Shadeland Challenge	C. I. 680	53	92	65	114
Shadeland Climax	C. I. 681	68	80	76	95
Shireff	Minn. 285	106	42		
Silvermine		82	67	104	76
Sparrowbill	C. I. 804	67	80	55	107
Stormking		52	106	82	95
Swedish Select	Minn. 271	52	90	70	82
Do	Do	64	90	74	76
White Russian		59	130	59	101
Do		55	80	52	1
Do		162	82		
Do		39	80	21	6
Do		65	95	23	6
Do		88	87	20	2
White Tartarian		59	137	76	6
Do		66	75		
Do		100	55	139	6
Do		105	52	57	6
White Wonder	Minn. 299	71	100	107	101
Yielder	C. I. 799	84	122	103	114
(Unnamed)	C. I. 601	101	60	161	95
Do	C. I. 603	96	98	153	95
Do	C. I. 609	89	156	65	76
Do	C. I. 749	48	87	114	76
Do	Do	90	105	202	63
Do	Do	97	107		
Do	Minn. 343	81	130	75	12
Vilmorin's Black Hybrid	C. I. 830	60	110	62	51
Average		70	101	75	75

TABLE XV. RUST RESISTANCE OF MISCELLANEOUS SPECIES OF OATS AS TESTED IN THE GREENHOUSE, 1917, COMPARED WITH THE SAME SPECIES TESTED IN THE RUST NURSERY, 1918

Miscellaneous Species

Variety	Source or Number	Percent crown rust		Percent stem rust	
		Greenhouse 1917	Rust nursery 1918	Greenhouse 1917	Rust nursery 1918
A. barbata	S.P.I. 25354	30	17	24	12
A. fatua		101	155	119	195
A. orientalis flava		46	80	26	63
A. orientalis mutica		9	97	9	6
A. orientalis obtusa		78	20	143	101
A. orientalis tristis		57	195	92	63
A. purpurea	S.P.I. 25357	40	150	11	57
A. sativa	S.P.I. 25356	56	130	14	51
A. sativa aristata		96	115	88	51
A. sativa aurea		82	110	52	82
A. sativa brunnea		93	117	57	107
A. sativa grisea		63	95	25	0
A. sativa krausei		84	82		
A. sativa montana		66	150	100	89
A. sativa mutica		87	98	82	90
A. sativa nigra				10	95
A. sativa praegravis		73	114	62	104
Average		66.3	107.8	57.1	72.9

by the check, arbitrarily fixed at 100 percent. Thus twenty or thirty varieties and several checks (Swedish Select) might be exposed to infection in moist chambers one day and another lot exposed to a different amount of infection another day, while the varieties in the rust nursery received still another amount of infection. As the checks in each case were all of the same variety, the most satisfactory method of estimating relative degrees of infection was that just stated.

Notwithstanding the fact that the greenhouse studies were conducted under conditions differing from those in the field and that the results represent but one season's work, the similarity between the results and those obtained in the field is noticeable. Particularly is this true in the group averages for crown rust shown in table XVI.

The red-oat group, as in the five year nursery averages, maintains a comparatively greater resistance to crown rust in the greenhouse.

It is interesting also to compare the degree of rust on certain outstanding varieties that showed resistance in the field and to note that resistance is exhibited in the greenhouse in these

TABLE XVI. AVERAGE PERCENTAGE OF CROWN RUST ON VARIETIES OF *AVENA STERILIS* AND *A. SATIVA* IN GREENHOUSE AND FIELD

Groups	In greenhouse 1917	Rust nursery 1918
Avena sterilis	55	84
A. sativa	70	101

varieties. Thus *Avena barbata* shows its usual resistance to both crown and stem rust. *Avena sativa grisea* and *Avena orientalis mutica* in greenhouse cultures showed a similar degree of resistance to stem rust to that exhibited under field conditions. Of the other varieties, Appler, one strain of Red Rustproof and Ruakura show comparatively the same degree of resistance to crown rust whether grown in the field or in the greenhouse; and Green Russian and White Russian manifest the same resistance to stem rust in the greenhouse as in the field.

On the whole, the results in the greenhouse are quite com-

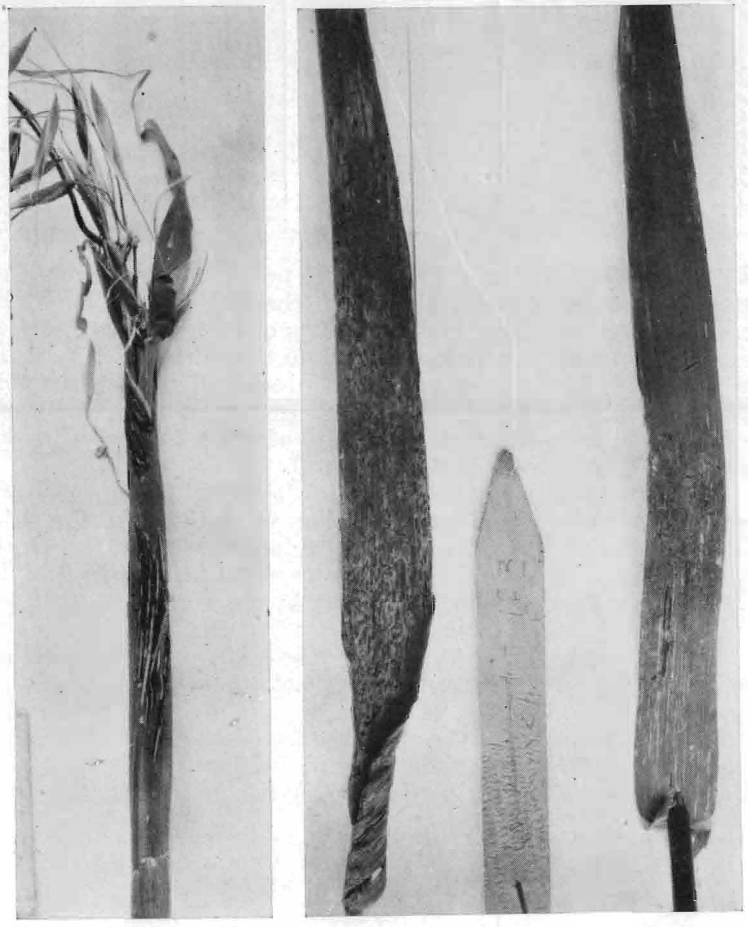

Plate II. Figs. 1 and 2. Infection in Greenhouse.
Fig. 1. (on left) **Puccinia graminis** on **Avena fatua.**
Fig. 2. (on right) **Puccinia coronato** on **Avena fatua.**

parable to those in the rust nursery and may be considered as a confirmation of that work. In Plates II, III, IV, and V are shown representative infections obtained on different varieties and the checks in the greenhouse studies.

Plate III. **Puccinia coronata** infection in the greenhouse on variety White Russian. Note that stems are clean of **P. graminis,** tho exposed to spores resulting in 25 percent infection on checks.

SUMMARY

1. Little work has been done, either in Europe or America, on the comparative resistance of varieties of oats to crown and stem rusts. During the five years from 1914 to 1918, inclusive, such a comparison has been made on some 200 lots of oats at the Iowa Agricultural Experiment Station and, tho the results were obtained only under Iowa conditions, it is believed they are indicative of the general reaction of these varieties to rust.

Plate IV. Type of **Puccinia graminis** infection on checks of the greenhouse varietal experiments. Variety Silvermine.

2. In obtaining artificial infection in rust nursery and greenhouse, different methods are applicable, tho the use of a spore blower was found most satisfactory. By this method a uniform distribution of the spores may be obtained and possible injury to the spores applied in water suspension is avoided.

3. The degree of rust infection was estimated according to the scale used by the Office of Cereal Investigations of the U. S. Department of Agriculture. Additional estimates were also made by counting the number of sori per square centimeter of leaf surface on each variety. In the majority of cases one sorus appears on each fleck, at first. The number of sori may in-

Plate III. Type of infection secured in greenhouse. **Puccinia graminis** on the variety Conqueror.

crease as much as 56 percent eight days after the appearance of the first sorus. To obtain uniform results, therefore, the percentage of rust on different plants should be estimated at equal periods of time after infection.

4. The ratio between amount of infection and the number of viable spores applied to susceptible host tissue is direct when a small number of spores is applied, but with larger numbers this ratio is not maintained.

5. The greater susceptibility of seedlings is suggested not only by an average of 18 percent more rust obtained on them, but by the shorter incubation period of the rust. The incubation period on seedlings is two days shorter than on half grown or older plants.

6. Altho the manifestations of resistance to rust in field and greenhouse were comparable, yet they were more marked in the field. In the case of crown rust only a few varieties showed a high degree of resistance, the great majority averaging between 25 and 70 percent of infection. *Avena barbata* was the most resistant oat. Other outstanding varieties manifesting resistance to crown rust were the varieties Appler, Burt, Early Ripe, Golden Rustproof, Green Russian, and Ruakura, and the species *A. sativa trisperma* and *A. brevis.*

7. The results of the varietal experiments conducted in the greenhouse indicate that the varietis of the red-oat group, *Avena sterilis,* show more resistance to crown rust than those of the common-oat group, *A. sativa.* The most resistant varieties in the species *A. sterilis* were found to be Appler and Red Rustproof. The varieties White Russian and Green Russian of the *A. sativa* group and the strains grown under the names *A. sativa grisea* and *A. orientalis mutica* were resistant to stem rust, while the variety Ruakura and *A. barbata* were resistant to both rusts.

8. There are apparently more varieties of oats which show resistance to crown rust than to stem rust, tho few are extremely resistant to crown rust when subjected to a severe epidemic. White Russian, Green Russian, Ruakura and the species *A. barbata, A. orientalis mutica,* and *A. sativa grisea* show a high degree of resistance to stem rust under rust nursery conditions.

9. The variety White Russian is the most resistant to stem rust under Iowa conditions, showing an average of only 3 percent and a maximum of 10 percent of infection. Similar resistance of this oat to stem rust has also been noted in other localities in the North Central States.

10. Under the conditions of the experiment, the species *A. barbata* and the varieties Green Russian and Ruakura are the only oats evidencing marked resistance to both rusts.

11. The effect of time of seeding on the degree of rust infection, as shown by a survey of the 1918 rust nursery data, indicates that crown-rust infection is greater on the earlier sown oats, while stem rust infection is slightly greater on the later seedings.

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