EXPERIMENT STATION.

KANSAS STATE

AGRICULTURAL COLLEGE.

Bulletin No. 38—March, 1893.

BOTANICAL DEPARTMENT.

PRELIMINARY REPORT ON RUSTS OF GRAIN.

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MANHATTAN, KANSAS.

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EXPERIMENT STATION

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BULLETIN NO. 38—MARCH, 1893.

BOTANICAL DEPARTMENT.

A. S. HITCHCOCK, M. Sc., Professor of Botany.

M. A. CARLETON, B. Sc., Assistant in Botany.

PRELIMINARY REPORT ON RUSTS OF GRAIN.

FROM an economic stand-point, one of the most important of fungeus pests with which the farmers of Kansas come in contact is that which attacks grain causing the disease known as rust. The loss due to this disease in the United States in one year runs up into the millions of dollars. It is rare that a field of wheat is entirely free from it, and often a large portion of the crop is destroyed. In some parts of Kansas, especially the western portion, the disease causes little damage, for the reason that in such cases the conditions favorable for its spread do not occur; while in other parts, whole fields of wheat, in some seasons, are abandoned as not worth the harvesting, so abundant is the rust.

While many other important diseases of plants have been brought under control, such as oat smut and black rot of the grape, the various rusts have thus far proved impregnable. Wheat rust is found as widely distributed as the grain on which it grows, in every continent.

Within the last few years, especial attention has been given to this subject by botanists and agriculturists. In Australia a rust-in-wheat conference has held sessions in 1890, 1891, and 1892, for the sole purpose of discussing this question. In the United States, the Department of Agriculture and several of the Experiment Stations have devoted considerable time to its study. Although no specific remedy has been discovered, yet our knowledge concerning its life-history has been much extended.

This Station has devoted a considerable time during the past year to the investigation of this subject, and the present bulletin is in the nature of a report of progress, as the question will receive further attention in the future.

Before detailing the experiments carried on by the Station, it will be well to briefly review our knowledge of the life-history of the fungus.

The disease in wheat known as rust is due to the presence of a parasitic fungus — a lowly organized plant, resembling, in some respects, the moulds and mildews. The rusts, in general, comprise a group of parasitic fungi which grow in a variety of plants, producing on the stems or leaves red or black (rusty) spots. Two closely allied species are found on wheat in Kansas. These are known to botanists as *Puccinia rubigo-vera* and *Puccinia graminis*. The latter was the first rust whose history was worked out, and will be given briefly.

LIFE-HISTORY OF THE FUNGUS.

The vegetative portion of the fungus is in the form of microscopic threads permeating the tissue of the wheat plant, and absorbing its nourishment from the juices of its host. When the proper time arrives, it commences to form spores for dissemination. These spores are ovoid, one-celled, produced on short pedicels and aggregated in dense masses below the epidermis of the plant, through which they finally burst, and then form on the leaves and stalks the small red spots known as red rust. They are easily broken off and carried about by the wind, some alighting on the leaves of unaffected wheat plants. If the weather is favorable, being warm and damp, the spores germinate, that is, commence to grow by sending out a slender tube along the surface of the leaf. The epidermis, being compact, does not allow the tubes to pass through, except at the breathing pores, which are scattered quite regularly over the surface. These openings tend to close in dry weather, but are open during weather which is favorable for the growth of the rust spores. When the tube from the spore reaches one of these openings, it passes without hindrance into the interior of its victim. The tube continues to grow, forming its vegetative stage, or mycelium, which in turn produces more spores. During a period of damp, muggy weather the fungus may increase with astonishing rapidity.

But in time this mycelium which has been producing red rust commences to form another set of spores. These are formed in the same manner as those mentioned, but they are two-celled, dark brown in color, and more firmly fastened to their pedicels. The spots produced by these spores are known as black rust. The spores are usually capable of lying dormant for some time, and serve to carry the species through unfavorable conditions.

The following spring they germinate, sending out short tubes, bearing small branches, the ends of which produce spores known often as sporidia. These sporidia are blown about by the wind, and, if they alight on the proper host plant, commence to grow, sending a tube through the epidermis at any point, giving rise to a mycelium. The most curious fact in this connection is, that these sporidia are known to effect an entrance into the leaves of the barberry bush alone. Attempts to cause them to grow into the wheat plant have, thus far, entirely failed.

The fungus, having gained an entrance, continues to grow in the tissue of the barberry, and finally produces another set of spores. These are very unlike the previous kinds. A compact mass of short, upright branches of the mycelium is formed beneath the epidermis. These branches produce chains of roundish, red spores in parallel columns, the upward pressure of which finally bursts the epidermis above them. The whole mass is at first inclosed within a thin covering of tissue, but when it appears above the epidermis the top ruptures and the edges curve back, thus forming a miniature cup in which are the numerous spores. The upper spores break off easily and are carried away by the wind, their places being taken by the newly-formed ones from beneath. The spores, which germinate by sending out a tube, are unable to gain an entrance into the barberry, but only into some kind of a grass. They enter the tissue by the way of a breathing pore, and give rise to a mycelium similar to that with which we started.

The cycle of development is now complete. The fungus, in its three stages, is so different that it was described as three species. From the fact that wheat was observed to be rusted worse in the vicinity of a barberry bush, it began to be suspected that there was a relation between them. The relation, however, was not certainly proved till 1864, when DeBary, a German botanist, showed, by actual experiment, that the spores of wheat rust would produce on the barberry the corresponding form.

A similar cycle has since been shown in many other species of rust. The three stages have received certain names. The first is known as the uredo stage; the second, as the teleuto stage; and the third, as the æcidium stage; and the spores have received the corresponding designations, uredo-spores, teleuto-spores, and æcidio-spores.

Puccinia graminis, the rust whose life-history has been given, is found, in Kansas, on wheat, oats, and barley, and on various grasses, viz.: *Bromus secalinus*, *Bromus pratensis*, *Hordeum jubatum*, and *Agrostis vulgaris*.

The other species of rust occurring on wheat, *Puccinia rubigo-vera*, has been found to have a similar life-history, but the æcidium stage occurs on various species of the Borage family. The teleuto stage has been found here on wheat and rye, and on *Elymus Canadensis*, *Elymus Virginicus*, *Elymus Sitanion*, and *Kœleria cristata*.

The æcidium stage of the oat rust (*Puccinia coronata*) is found on the buckthorn (*Rhamnus lanceolata*) and some other species of the order *Rhamnaceæ*.

THE RUST IN KANSAS.

In order to collect data concerning the rust of grain in Kansas, a circular containing the following outline was sent to several wheat-growers:

1. Date of first appearance.

2. Date of greatest abundance.

3. If there seems to be more than one kind of rust, how do they differ? We should be glad to have specimens sent to us for examination. The whole plant should be wrapped snugly in paper or packed in a light box, and sent by mail as soon after gathering as possible.

4. What varieties of wheat or other grains have suffered most? Which least?

5. What is the effect upon the whole plant and upon the grain?

6. What is the estimated damage to the crop? It would be desirable to have the estimate given in bushels of threshed grain, and to note if the grain is light in weight.

7. The direction of the wind, the temperature, the amount of rainfall, and the proportion of cloudy days, from about a week before the first appearance till the period of greatest abundance.

8. What crops have been raised for several years past on the ground under observation?

Twenty-eight replies were received, the substance of which is as follows:

J. W. ABBOTT, Saline county. No rust.

H. L. ALLEN, Logan county. No rust.

C. H. ANDERSON, Linn county. Fultz and Velvet Stem damaged about 50 per cent., while a field of Mediterranean was scarcely worth harvesting.

E. BARTHOLOMEW, Rooks county. First appearance of rust (*Puccinia rubigo-vera*), May 25; greatest abundance, June 20; *Puccinia graminis* also destructive; spring wheat, soft winter wheat and oats suffered considerably; hard wheats and the earliest sown of all varieties suffered least; from careful observation for a number of years, the damage is estimated to average 15 per cent.; the prevailing winds were southeast and southwest; average maximum temperature, 87° F.; rainfall, 2.80 inches, and cloudiness 22 per cent.; no difference noted between ground previously in wheat and that where corn had been grown.

N. CHRISTENSEN, Pottawatomie county. Poole wheat rusted.

S. B. DELANO, Bourbon county. No rust.

H. L. DELAPLAIN, Rush county. Rust appeared June 15; most abundant June 28; east wind, abundant rains, warm days, and cool nights; rust checked by the strong, dry winds.

S. B. FARWELL, Osborne county. All Turkish wheat struck by red rust, but no damage done; very little in Early May.

C. C. GARDINER, Wabaunsee county. Red Texas oats rusted.

W. S. GILE, Ellsworth county. No rust.

F. B. HARRIS, Morris county. No rust.

W. E. HIXSON, Brown county. May King suffered most severely from rust.

P. O. JEFFREY, Chase county. Rust first appeared after the wheat began to ripen; most abundant at harvest time.

J. H. JONES, Woodson county. Late wheat suffered most; first appearance, June

20; greatest abundance, June 27; damage, 75 per cent.; damp, warm, east winds are most favorable for rust.

H. B. MARSHALL, Elk county. Bald varieties of wheat affected most; bearded varieties least; first appearance, June 15; most abundant, June 20–23; causes the grain to shrink and ripen prematurely; wind, southwest and east; warm and very wet up to June 5.

J. W. MEANS, Marshall county. Turkish wheat raised; no rust.

H. MILLER, Chautauqua county. Observes that in previous years, rust, when present, was most abundant on rich ground, close to timber, and protected from free circulation of air.

J. A. MOHR, Anderson county. Fultz wheat suffered most severely; damage, 40 per cent.; grain shriveled; first appearance, June 10; greatest abundance, July 1.

C. L. REED, Greeley county. Spring wheat, especially Sea Island, suffered most severely, white Turkish suffered least; damage, 50 to 75 per cent.; causes the grain to dry and ripen prematurely; wind south and southwest with light rainfall during the attack; first appearance, July 10, greatest abundance, July 16.

A. H. STILES, Wabaunsee county. Fultz wheat raised; winter-killed.

G. F. TASSELL, Edwards county. No rust.

R. A. VAN WINKLE, Reno county. Early May matured sufficiently early to escape the rust.

E. WALKER, Pottawatomie county. No rust.

R. M. WALLACE, Stafford county. No rust.

S. I. WILKIN, Rooks county. Turkish wheat raised, but not damaged up to June 20; first appearance, June 6.

J. W. WILLIAMS, Jackson county. No rust.

Anonymous, Crawford county. No rust.

Anonymous, Hodgeman county. No rust.

The term "no rust" must be understood to mean, not present in sufficient abundance to do noticeable damage. We have never yet failed to find, just before harvest time, in any of the wheat fields examined, at least a small quantity of rust present, although it was frequently reported to be absent.

It will be observed that the reports show no regularity in the distribution of the districts suffering damage. This depends upon local conditions. It will be noticed, however, that where the conditions are given, they are uniformly those most favorable for the propagation of the rust, combined warm and wet weather.

CONDITIONS AFFECTING THE RUST.

The favorable climatic conditions, previously alluded to, of combined hot and wet weather, under which the rust is propagated so extensively, usually do not occur till just before the harvest season. Hence some varieties may ripen early enough to escape the disease.

A large number of experiments were tried in New South Wales by Dr. Cobb,* bearing upon the power of varieties of wheat to resist rust. He found that no variety is rust-proof, but that in glaucous varieties the germinating spores could not easily enter the breathing pores, and that hairy varieties entangled the spores and tended to keep them so far from the breathing

* *Agricultural Gazette*, of New South Wales, vol. III, p. 190. Report of Rust-in-Wheat Conference, third session, 1892, p. 27.

pores that they could not reach them, thus making these two kinds less likely to be infected. He also found that in varieties with thick epidermis the rust, although having gained an entrance, was unable to rupture this, and so failed to produce spores.

SPRAYING TO PREVENT RUST.

Considerable has been done lately in endeavors to prevent rust by the use of fungicides. Since the fungus enters the plant by means of spores germinating upon its surface, it is quite evident that, could the spores be destroyed before they have time to grow into the tissue, the rust could be prevented.

Professor Kellerman sprayed wheat, barley and oats with flowers of sulphur, potassium sulphide, chloride of iron, and Bordeaux mixture, but without favorable result.*

Professor Pammel found the appplication of ammoniacal carbonate of copper and Bordeaux mixture to be entirely useless in preventing rust.†

A few experiments in spraying with fungicides were tried at this Station. As spring wheat was not obtainable, a number of plots were sown with barley and oats on April 30, as shown in the table. The barley plots were 10 feet square, and the oat plots 10 feet by 5. The cross rows of plots were separated from each other by a path one foot wide. The oats appeared May 5, and the barley May 7. The plots were on high ground, and the grain suffered considerably from the dry weather, especially the barley, which was nearly ruined.

	Four-rowed barley.	*Red winter oats.*	*Welcome.*	*Georgia.*	*Black Roman.*	*Rust-proof.*	
1							Bordeaux mixture.
2							Untreated.
3							Eau celeste.
4							Untreated.
5							Ammoniacal solution of copper carbonate.
6							Untreated.
7							Copper sulphate.
8							Potassium sulphide.
9							Copper acetate.
10							Alum and calcium chloride.
11							Untreated.
12							Iron sulphate.

* Bulletin No. 22, page 90, Kansas Experiment Station.
† Bulletin No. 16, page 329, Iowa Experiment Station.

The formulæ used in the preparation of the fungicides is as follows:

Bordeaux mixture. Copper sulphate, ¼ lb.; lime, ¼ lb.; water, 1 gal.

Eau celeste. Copper sulphate, ½ lb.; ammonia, ½ pt.; water, 4 gals.

Ammoniacal copper carbonate. Copper carbonate, ⅛ oz.; strong ammonia, 1 pt.; water, 1 gal. In the later sprayings the ammonia was reduced one-half.

Sulphate of iron (green vitriol), 1½ lbs.; water, 1 gal.

Copper acetate (verdigris), ½ lb.; water, 4 gals.

Alum, ⅜ lb.; calcium chloride ($CaCl_2$), 4⅜ lbs.; water, 2 gals.

Copper sulphate (blue vitriol), ⅙ lb.; water, 4 gals.

Potassium sulphide (liver of sulphur), ⅓ oz; water, 1 gal.

The plots were sprayed several times, the dates being as follows:

Plot No. 1. Bordeaux mixture: May 16, 25; June 2, 15, 29.
Plot No. 3. Eau celeste: May 18, 26; June 4, 20; July 1.
Plot No. 5. Ammoniacal copper carbonate: May 18, 26; June 4, 20; July 1.
Plot No. 7. Copper sulphate: May 16, 25; June 2, 16, 30.
Plot No. 8. Potassium sulphide: May 18, 26; June 4, 20; July 2.
Plot No. 9. Copper acetate: May 18, 26; June 4, 20; July 2.
Plot No. 10. Alum and calcium chloride: May 23; June 2, 16, 30.
Plot No. 12. Sulphate of iron: May 23; June 2, 15, 30.

The uredo-spores of *Puccinia graminis* appeared on oat plot No. 6 (untreated), June 28, and on barley plot No. 3 (eau celeste), July 4. A careful examination July 8 showed the presence of the same on oat plots Nos. 2, 3, 4, 5, 6, 8, and *Puccinia coronata* on plot 6.

The rust appeared on the treated and untreated plots in about equal abundance, though nowhere in but very small quantity, not noticeable except by careful examination. A field of winter wheat a few rods distant was badly rusted, as were other fields in the vicinity. It will be observed that the rust appeared on the plots after the sprayings had ceased, and after it had appeared in abundance on neighboring wheat fields. The results were not satisfactory, as the untreated plots were not badly attacked, yet, since the rust was abundant elsewhere, they cannot be looked upon as indicating a failure. Further experiments, using winter wheat, are under way.

GERMINATION OF RUST SPORES IN FUNGICIDES.

In order to ascertain the probable value of fungicides for preventing rust, the uredo-spores were placed in dilute solutions of various chemicals, under otherwise favorable conditions for germination, and the fact noted whether or not this process took place, and if so, it was compared with checks germinated in water. *Puccinia coronata* was the only one of the three rusts available in the uredo stage during July. The apparatus used for this purpose was a germinating cell mounted on a glass slide and covered with a thin cover glass, from which depended a drop of the liquid under trial. In this drop were placed some fresh uredo-spores. The slides were placed in a moist chamber and set in a warm room, together with the checks containing spores in water.

The following tables give the results in detail. Unless otherwise stated, the solutions are $\frac{1}{10}$ per cent. (1 part in 1,000). The proportion is calculated on the basis of the crystallized salt in cases such as copper sulphate.

Puccinia graminis. June 17; 7 hours.

Water; successful.

Hydrogen peroxide (1 part of the strong solution in 1,000 of water); better than in water.

Copper sulphate; not freely.

Potassium sulphide; better than in water.

Puccinia rubigo-vera. June 22; 17 to 18 hours.

Water; successful.

Potassium sulphide; very few spores germinated.

Hydrogen peroxide; better than in water.

Calcium hydrate (1 part saturated solution in 100 of water); a few spores germinated.

Copper sulphate; failure.

Copper nitrate; four or five spores germinated.

Manganese sulphate; three spores germinated.

Potassium chromate; failure.

Puccinia coronata. July 1; 21 to 24 hours.

Water; successful.

Potassium chromate; a few spores germinated.

Copper sulphate; a few spores germinated.

Copper nitrate; a very few spores germinated.

Copper acetate; failure.

Lead acetate; failure.

Ferric chloride; failure.

Potassium permanganate; successful.

Mercuric chloride (1 to 10,000); a few spores germinated.

Potassium bichromate; a very few spores germinated.

Hydrogen peroxide (8 parts of strong solution in 100 of water); spores germinated quite freely.

Potassium sulpho-cyanide; four or five spores germinated.

Potassium sulphide; better than in water.

Puccinia coronata. July 6; 27 hours.

Water; successful.

Ammonium sulpho-cyanide; successful.

Chrome alum; successful.

Potassium chromate; two or three spores germinated.

Magnesium chloride; a few spores germinated.

Nickel sulphate; not very freely.

Puccinia coronata. July 8; 24 hours.

Water; successful.

Copper chloride; failure.

Zinc chloride; a few spores germinated.

Potassium sulphide; successful.

Potassium sulphide (1 to 100); failure.

Lead acetate; not freely; germ tubes stunted.

Copper acetate; failure.

Puccinia coronata. July 11; 45 to 48 hours.

Water; not very freely.
Sodium arsenite; successful.
Potassium chromate; a few spores germinated.
Copper nitrate; a few spores germinated.
Eau celeste (1 part of the solution used in spraying to 100 of water, or one part of copper sulphate in 22,500 parts of water); successful; germination peculiar. Figs. 27, 28.)
Ammonium carbonate; very freely.
Ferric chloride; very few spores germinated.

Puccinia coronata. July 11; 51 to 53 hours.

Water; very few germinated.
Copper chloride; three or four spores germinated.
Lead acetate; very few spores germinated.
Potassium bichromate; failure.
Sodium thiosulphate ($Na_2S_2O_3$); successful.
Potassium permanganate; not very freely.
Mercuric chloride (1 to 10,000); failure.
Copper acetate; failure.
Potassium cyanide; failure.

Puccinia coronata. July 12; 16 to 17 hours.

Water; successful.
Lead acetate; very few spores germinated.
Ammonium carbonate (1 to 100); not very freely.
Magnesium chloride; successful.
Ammonium sulpho-cyanide; successful.
Chrome alum; fairly good.
Zinc chloride; a few spores germinated.
Sodium thiosulphate (1 to 100); successful.

Puccinia coronata. July 13; 24 to 26 hours.

Water; successful.
Potassium bichromate; failure.
Sodium thiosulphate (1 to 100); not very freely.
Nitric acid (68 to 10,000); failure.
Nitric acid (68 to 100,000); successful.
Mercuric chloride (1 to 10,000); failure.
Potassium sulphide; successful.
Acetic acid (108 to 100,000); failure.

Puccinia coronata. July 14; 17½ to 19 hour

Water; fairly good.
Potassium cyanide (1 to 10,000); very freely.
Sulphuric acid; failure.
Potassium bichromate (1 to 10,000); fairly good.

Puccinia coronata. July 15; 24 to 26 hours.

Water; not very freely.
Copper acetate (1 to 10,000); a few spores germinated.
Copper sulphate (1 to 10,000); a very few spores germinated.
Mercuric chloride (1 to 100,000); a few spores germinated.

Potassium bichromate (1 to 10,000); not good, but several spores germinated.
Copper nitrate (1 to 10,000); failure.
Lead acetate (1 to 10,000); six spores germinated.
Acetic acid (54 to 1,000,000); rather freely.

Puccinia coronata. July 16; 21 hours.

Water; successful.
Copper sulphate (1 to 10,000); successful.
Potassium permanganate (1 to 10,000); successful.

From the above it will be seen that the uredo-spores germinate successfully in the following solutions, having a strength of 1 to 1,000: Potassium sulphide, potassium permanganate, ammonium sulpho-cyanide, chrome alum, nickel sulphate, sodium arsenite, ammonium carbonate, sodium thiosulphate, magnesium chloride.

Germination is not prevented by solutions, 1 to 100, of ammonium carbonate and sodium thiosulphate.

Germination may take place but is considerably hindered by solutions of the following, having a strength of 1 to 1,000: Copper sulphate, copper nitrate, copper chloride, potassium chromate, zinc chloride, lead acetate, and ferric chloride.

Germination is prevented by a solution having a strength of 1 part to 1,000 of mercuric chloride, copper acetate, potassium bichromate, potassium cyanide, acetic acid, and sulphuric acid. Of these three, potassium cyanide, potassium bichromate and copper acetate do not prevent germination if diluted 10 times (1 to 10,000).

Mercuric chloride prevents germination in a solution of 1 to 10,000, but does not do so in a solution of 1 to 100,000.

Dr. E. Wüthrich* records a series of experiments in which he investigated the effect of various solutions upon the germination of the uredo-spores of *Puccinia graminis.* He found that the spores germinated normally in ferric chloride (1 to 10,000), zinc chloride (1 to 100,000), copper sulphate (1 to 100,000), and mercuric chloride (1 to 100,000). Germination was entirely prevented by ferric chloride (1 to 10), zinc chloride (1 to 100), copper sulphate (1 to 100), and mercuric chloride (1 to 1,000).

The fungicides used in spraying the plots were of the usual strength. The eau celeste contained 1 part of crystallized copper sulphate to 225 parts of water; the ammoniacal carbonate of copper, 1 part of copper carbonate to 1,144 parts of water; Bordeaux mixture, 1 part copper sulphate and 1 part of lime to 35 parts of water; iron sulphate, 1 to 9; copper acetate, 1 to 74; alum solution, 1 part of alum and 8 parts of calcium chloride to 33 parts of water; copper sulphate, 1 to 112; potassium sulphide, 1 to 300.

* Zeitschrift für Pflanzenkrankheiten, vol. II, p. 84.

WINTERING OF THE RUST.

While all three of the grain rusts are abundant in the first two stages, the æcidium stage is quite rare in Kansas.

It seems highly probable that the cycle of development may be completed without the intervention of the æcidium stage, or else that the latter may occur on other host plants than are at present known.

There seems to be good evidence that the mycelium of *Puccinia rubigo-vera* is able to pass the winter in the tissue of the wheat plant. Sorauer* finds this to be true in Germany. Bolley makes a similar statement for the rust in Indiana.†

Observations made at this Station during the present winter show that, up to date, the same statement will hold good here.

Uredo-spores of *Puccinia rubigo-vera*, gathered from volunteer wheat on November 5, germinated in water fairly well. Another sample was gathered January 9, and germinated well in water, and also, but not quite as well, in beef broth. A specimen of wheat containing rust was transferred in the fall to the greenhouse. Material from this, on January 17, germinated well in wheat decoction after 29 hours, but entirely failed in water. The same material germinated well in milk, while in neutralized urine only a few spores germinated, but these produced very long tubes. Another sample, taken January 24, germinated in four hours.

On January 23, spores from the field, from both green and decayed leaves, germinated nicely in water and wheat decoction. Another sample, taken January 25, germinated in water, and within two hours produced tubes of considerable length. In 24 hours these tubes had grown to an extreme length and had a very vigorous appearance. Spores from dead leaves of the same, taken February 25, germinated in water in 16 hours. On March 1, various patches of volunteer wheat showed plenty of red-rust spots on the dead leaves, as did much of the drilled winter wheat. Some of *the latter showed fresher spots on the green leaves. Several samples of this* material were taken, and all showed some germination in water, but best from the spores from the green leaves. It was noticeable that the spots on the dead leaves were still covered by the epidermis, except a crack at one side. The spores beneath were, therefore, considerably protected. The spores from the midst of the spot were redder than those near the opening at the side.

It would seem that the uredo-spores were not formed during the winter, but had retained their vitality since the preceding fall.

From the weather reports by Prof. E. R. Nichols we extract the follow-

*Sorauer; Handbuch der Pflanzenkrankheiten, ed. 2, vol. II, p. 216: "Das Mycel des Rostes (wenigstens das von *Pucc. straminis* [= *P. rubigo-vera*]) überwintert schadlos im Parenchym der Getreideblätter."

†Bolley; Bull. Agr. Exp. Sta., Indiana, No. 26, pp. 13 and 19: "One species (*P. rubigo-vera*), in its uredo stage, is able to pass the winter in the tissues of the young wheat plant." Cf. Bolley; Agr. Sci., vol. III, p. 105.

ing notes on the temperature for the winter months: December, maximum, 67° (F.), on the 5th; minimum, —9°, on the 26th; mean, 24.02°. January, maximum, 53°, on the 24th; minimum, —1°, on the 15th; mean, 22.99°. February, maximum, 61°, on the 19th; minimum, —6°, on the 7th; mean, 26.69°. There was considerable snow on the ground for several weeks during the winter.

SUMMARY.

The rust of grain is due to three species of parasitic fungi, two of which, *Puccinia graminis* and *Puccinia rubigo-vera*, are found chiefly on wheat, and the third, *Puccinia coronata*, is apparently in Kansas confined to oats.

The answers to questions sent to wheat-growers show that the rust is distributed throughout the State, but that its severity is governed by local conditions. All varieties of wheat may suffer, but hard wheats suffer least, and early varieties are likely to mature before seriously injured. The most favorable conditions are warm, wet weather, such as are generally afforded by frequent showers, hot sun, and moist east winds. Under these conditions the fungus is able to produce spores with great rapidity. The rust became noticeable about the middle of June, and was most abundant from June 20 to July 1.

Those varieties of wheat which have stiff, upright leaves are affected less than those with flaccid foliage. Varieties whose leaves have a thick epidermis, or whose surface is glaucous or hairy, are less likely to rust.

Experiments in preventing rust, by spraying oats with various fungicides, were unsatisfactory, from the fact that the disease did not appear in the untreated plots. Further experiments are to be tried with winter wheat.

Observations were made on the germination of the uredo-spores in various fungicides. In some cases, germination would take place in solutions of 1 to 100, while in one chemical, mercuric chloride, this process was prevented by a solution of 1 to 10,000.

Puccinia rubigo-vera lives during winter in the tissue of the wheat plant, and uredo-spores gathered at various times during the winter were capable of germination. In consequence of this fact, it is advisable to destroy all volunteer wheat.

EXPLANATION OF PLATES.

For several reasons it was not found practicable to draw all the figures with the same magnification. Most of the germination figures have a linear magnification of 250. The drawings of germinations have been purposely varied to show their appearance from different points of view; *e. g.*, Fig. 17 shows clearly the outflow of the spore contents in the formation of germ tubes, while Fig. 20 shows one spore in perspective. But most of them show, as far as possible, the exact appearance with the most distinct focus of the microscope.

PLATE I.

Fig 1. Section through a fresh pustule of the uredo stage (red rust) of *Puccinia rubigo-vera* (D. C.) Wint., showing uredo-spores, and mycelium ramifying through the tissue. × 385.

Fig. 2. Section through a series of teleuto-spores (black rust) of *Puccinia rubigo-vera* (D. C.) Wint., showing the spores still enclosed by the epidermis, and the spore-producing mycelium below. Both this and the above sections were made through leaves of wheat. × 185.

Fig. 3. Two uredo-spores of *Puccinia graminis* Pers., showing their attachment to the mycelial threads (hyphæ). × 185.

Fig. 4. Two teleuto-spores of *Puccinia graminis* Pers. × 185.

Fig. 5. Two teleuto-spores of *Puccinia coronata* Corda. × 185.

All the figures following these show the germination of uredo-spores in various media.

Fig. 6. Germination of four uredo-spores of *Puccinia rubigo vera* (D. C.) Wint., in water-drop culture; after 29 hours (in summer). × 250.

Fig. 7. As above, except that spores were taken from material that had passed the winter to date (January 21) on volunteer wheat, and kept in culture 44 hours. Four spores. × 150.

Fig. 8. Same as in Fig. 7, except that spores were taken from *dead* leaves. Four spores. × 150.

Fig. 9. Germination of three spores of the same, in 44 hours, from greenhouse material, on volunteer wheat, transplanted to greenhouse November 8. Date of germination, January 21. Uredo-spores were meanwhile being produced all the time on the greenhouse plants between these two dates. × 150.

Fig. 10. Five spores, showing well the successive stages in germination; in 4 hours, in water-drop culture, from greenhouse material. × 150.

Fig. 11. One spore of the same species; after 48 hours in water, from greenhouse material, January 9. × 250.

Fig. 12. Four uredo-spores of *Puccinia coronata* Cda.; after 28 hours in water. Germination carried on in summer. × 250.

Fig. 13. One spore of the same species; after 21 hours in water (in summer). × 250.

Fig. 14. Ditto; showing a fusion of germ tubes (in summer). × 250.

Fig. 15. Two spores of the same; after 25 hours in water (in summer). × 250.

PLATE II.

Fig. 16. Two spores of the same; after 17 hours in a solution of sodium thiosulphate, with a strength of one part of the salt to 100 hundred of water (in summer.) Germ tubes are undulate. × 250.

Fig. 17. Two spores of the same, in same solution; one part to 1,000, after 52 hours (in summer). × 250.

Fig. 18. One spore; all conditions same as above. Shows the extreme length of germ tube attained in a favorable medium. × 250.

Fig. 19. One spore of *Puccinia rubigo-vera* (D. C.) Wint. in solution of common salt, 1—1,000, after 21 hours; from greenhouse material, in January. Shows nicely the branching of germ tubes, and the peculiar distribution of endochrome within the tubes. × 185.

Fig. 20. Three spores of *Puccinia coronata* Corda, after 27 hours in solution of ammonium sulpho-cyanide, 1—1,000. One spore is shown in perspective; summer. × 250. (All the following figures, except Fig. 32, represent spores of *Puccinia coronata* germinated in summer.)

Fig. 21. Three spores; after 19 hours in potassic bichromate, 1—1,000. × 250.

Fig. 22. Four spores in same medium, but 1—1,000 in strength; after 23 hours. No germination, but spores are much contracted and shriveled. × 250.

Fig. 23. Two spores; after 48 hours in ammonium carbonate, 1—1,000. The germ tubes represent simply the average length for this medium. × 185.

Fig. 24. Four spores; after 22 hours in lead acetate, 1—1,000. No germination. × 250. (The number for this figure is omitted by mistake of the engraver. It is the only figure without a number.)

Fig. 25. Two spores; after 16 hours in magnesium chloride, 1—1,000. × 250.

PLATE III.

Fig. 26. Three spores; after 47 hours in sodium arsenite, 1—1,000. Tubes very much undulated, as a rule. × 185.

Fig. 27. Seven spores, in eau celeste (ordinary spraying mixture), 1—1,000. Germination was very good in this medium; after 48 hours. In many cases there was a fusion of germ tubes, as shown in figure. × 250.

Fig. 28. Seven more spores in eau celeste; same proportions. Four of these have united their germ tubes; after 48 hours. × 250.

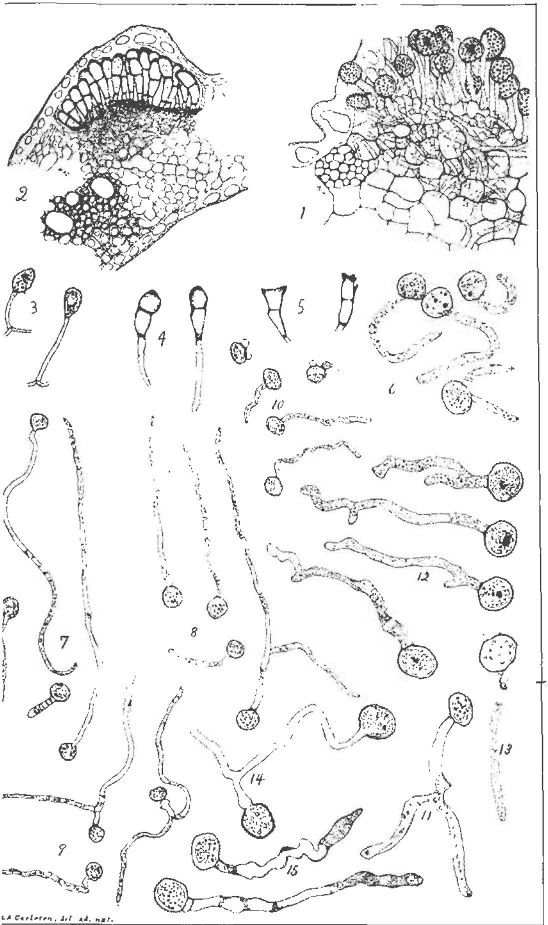
Fig. 29. Two spores; after 45 hours in magnesium chloride, 1—1,000. × 250.

Fig. 30. Two spores; after 24 hours in nitric acid, 68—100,000. × 250.

Fig. 31. Eight spores; after 24 hours in lead acetate, 1—1,000. Germ tubes are much stunted, and usually branched. × 125.

Fig. 32. Five uredo-spores of *Puccinia rubigo-vera* (D. C.) Wint.; after 48 hours in beef broth (prepared in the ordinary way); from greenhouse material, January 7. × 250.

Fig. 33. Four uredo-spores of *Puccinia coronata* Corda; after 17 hours in chrome alum, 1—1,000. Germ tubes are much knotted or undulated. × 250.



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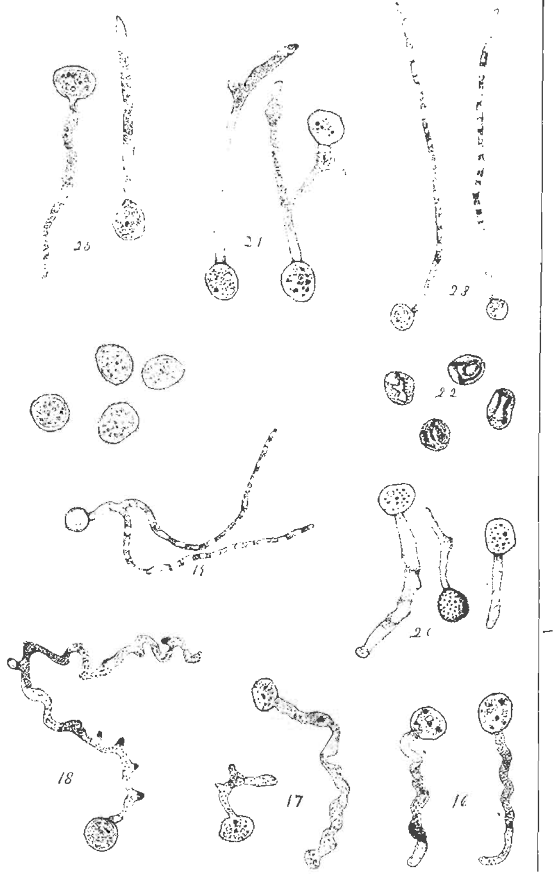
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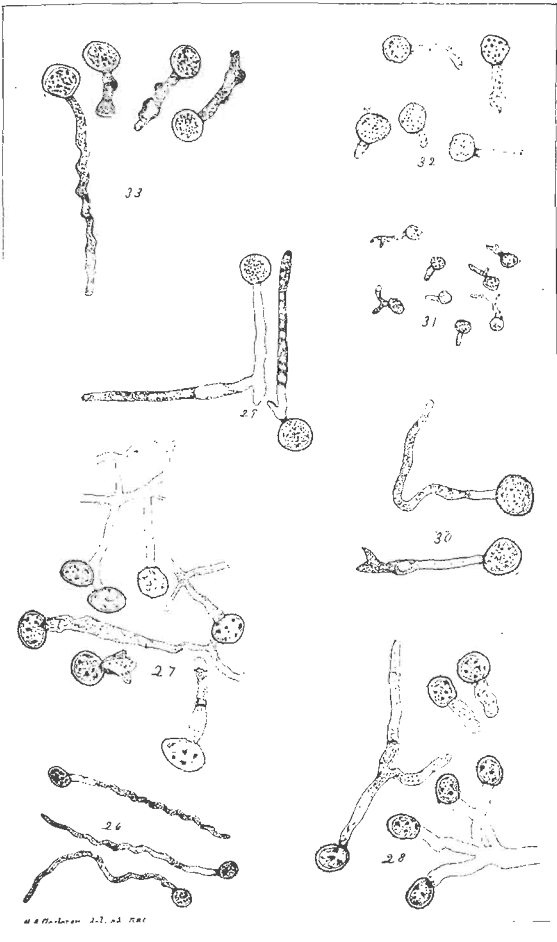
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