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Bulletin No. 21 - The Grain Smuts and Potato Scab

University of Wyoming Agricultural Experiment Station

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UNIVERSITY OF WYOMING.
Agricultural College Department.

Wyoming Experiment Station,
LARAMIE, WYOMING.

BULLETIN NO. 21.
JANUARY, 1895.

THE GRAIN SMUTS AND POTATO SCAB.

BY THE BOTANIST.

Bulletins will be sent free upon request. Address: Director Experiment Station, Laramie, Wyo.
Wyoming Agricultural Experiment Station.

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SPECIMENS WANTED.

Specimens of cultivated plants of all kinds if found affected with fungi are particularly desired and all available information concerning the same will be furnished to the sender on request. We would also like to receive, from all parts of the State, information concerning and specimens of the bad weeds.

Plants of any kind will be cheerfully determined for the sender. All such specimens may be sent by mail.

If there are those in the State who would like to secure the determination of their local flora in whole or in part they will please write for directions for collecting.

Address all samples and correspondence to

THE Botanical Department,
Agricultural Experiment Station,
Laramie, Wyo.
The Grain Smuts and Potato Scab.

Aven Nelson.

General Observations.

It is only recently that Wyoming has come to be recognized as one of the agricultural States. Even after many fertile fields had been opened and bountiful crops of vegetables and grain had been harvested, after flouring mills had been established and were grinding the plump grain into the best of flour, we still continued to think of Wyoming simply as a State of boundless possibilities because of her mineral resources and as a fit place for the grazing of the great herds that roamed over her hills and plains. Slowly at first but recently more rapidly the valleys and plains have become dotted with the homes of those who, seeking for a place where their toil should have greater reward than the more crowded communities of the East could offer, found here on our sunny slopes and in our smiling valleys with their life-giving streams the conditions they had sought.

With them they brought the habits and methods of the older agricultural communities from which they had emigrated. The immense hay and stock ranches are still here, but besides these there are many small farms and small flocks and herds under the personal supervision of the owner which are doing more for Wyoming's material advancement than was possible under the former conditions.
Under the old conditions there was neither demand nor necessity for agricultural information. Success in the cattle business depended upon such natural causes as the rainfall, the snowfall, the severity of the winter, and upon the trustworthiness and faithfulness of the foreman and helpers of the ranch.

With the introduction of the farm, here as elsewhere, arises a demand for such information as will aid in controlling and guiding the forces of nature. One's power to do this makes the difference between success and failure, between prosperity and poverty.

But with the introduction of farming and the importation of seed into the State some at least of the evils with which the farmer of the East has to contend have found their way into our agricultural communities. Weeds are beginning to be a serious trouble and fungi are causing increasingly greater annual losses. This being the case no apology need be made for the dissemination of any information that will aid in securing to the husbandman the fullest return for his labor.

THE NATURE OF FUNGI.

As those whose reading has not been along botanical lines have very vague notions as to the nature of fungi and the relation of the same to plant diseases, it may be well to briefly recite their characteristics.

In the first place, then, fungi are plants of rather simple structure. They consist essentially of a plant body or vegetative part, the mycelium, which is made up of one to many very slender, usually microscopically small threads or filaments, and certain reproductive bodies known as spores.
These latter are produced either directly on modified branches of the filaments or in specially formed receptacles variously named according to the place and manner of formation. The spore is not a seed but is analogous to it in that it serves to perpetuate the plant. Spores are in most cases so exceedingly small and light that they may, unknown to us, be blown about by the wind in vast numbers. As a rule they have great vitality and will resist very unfavorable conditions of heat and moisture, but germinate promptly when favorable conditions are offered. Fungi differ from green plants in that by reason of the lack of leaf-green (chlorophyl) they cannot prepare (elaborate) their own food. Though preparing nothing they are vigorous feeders and help themselves freely to the products previously prepared by other plants or animals. If they live upon dead organic matter they are known as saprophytic fungi. Such are mushrooms, toadstools, etc. If they live upon other living plants they are called

PARASITIC FUNGI.

The parasitic fungi are the cause of a very large part of the diseases that lay waste our gardens, orchards and fields. In various ways the spores are distributed and find lodgment upon the tissues of other living plants which are then called the hosts. Here the spores begin to germinate, that is they begin to grow by sending out slender threads (hyphae) which penetrate into the tissue of the host or creep over the surface and in either case extract the nutritive fluids of the adjoining cells. This is done either directly or by means of special bodies, modified branches, which penetrate into the adjoining cells and are known as haustoria.

These plants then are seen to be simply robbers, living
upon the products of others' toil, and were there only a few
they would probably but slightly affect the plant and might
escape our notice; but by reason of their rapid growth and
multiplication they often completely drain the host of its
prepared food or smother it, thus causing its fruitlessness or
death.

FORMER OPINIONS.

Very erroneous ideas formerly prevailed in regard to
the plant diseases designated as blights, mildews, rusts,
smuts, etc. They were variously attributed to "the wet
weather", "the hot weather", "the unfavorable weather",
and other like indefinite causes. The injuries inflicted were
considered as mere degeneration or decomposition of the
tissues of the plant due to a diseased condition caused by
unfavorable weather. It is now positively known, however,
that these diseases are caused directly by fungal plants, and
that these latter never arise spontaneously, but always from
similar plants or their reproductive bodies. Fungi like
other plants thrive best under certain climatic conditions to
which they have become adapted, and it does not necessarily
follow that these conditions are unfavorable to other
plants, except in so far as they become a prey to fungi de-
veloping under like conditions. Now it happens that the
rusts and mildews are propagated and distributed most rap-
idly during wet and hot seasons or during that part of the
season when those conditions prevail. On that account,
Wyoming may hope to escape all serious invasions of the
above fungi which live upon the host plant, rather than
within its tissues. As the whole of the State lies within the
arid belt, very few sections, if any, being entirely indepen-
dent of irrigation, and as the altitude of even the lowest
of the State is considerable, it is not likely that any season will offer those optimum conditions for the development of fungi, viz: wet and hot weather at the same time. But this applies only to those fungi that attack growing plants; those whose spores are distributed by the wind and are capable of successively infecting new plants and new fields. The spores of such must not only have heat and moisture before they will germinate freely, but must be able to force their hyphae through the cutinized epidermis of the leaf or stem and thus place themselves in contact with the nutritive tissues of the host. And here I think we find an additional safeguard, for it is probable that plants growing in this dry atmosphere produce a more heavily cutinized epidermis than do similar plants growing in a moister climate. This adaptation enables them to more fully protect themselves against loss of water from their tissues. But this applies only in part, for many fungi penetrate into the interior of the host by way of the leaf pores (stomata.)

Experience has shown, however, that we are no more exempt than other states from such plant diseases as result from infected or spore covered seed. This includes our two most serious plant diseases, the grain smuts and potato scab.

**THE GRAIN SMUTS.**

**THE EXTENT OF INJURY.**

There is a general lack of appreciation of the injury caused, except in cases where almost or quite a total failure results. Then the victim bewails his loss and looks about him for a remedy. The loss of one, five or even fifteen per cent. of the crop remains unremarked although it may make the difference between profitable and non-profitable farming.
From correspondence with men in different parts of the State, I am convinced that there were very few fields, if any, that last season entirely escaped some loss by reason of smut in wheat and oats, although in nearly every instance this disease was reported less destructive than during former years. Notwithstanding that the loss was smaller than usual, different localities reported losses amounting in some instances to one-third of the crop. From this maximum the per cent. of loss ranged down to one. In the minds of some of my correspondents this latter loss, apparently, was considered very trivial, too small in fact to be worthy of attention. It may be noted here, however, that especially if the loss is small the tendency is to underestimate it, for the smutted heads maturing a little earlier than the healthy grain are by harvest-time stripped of their contents by the wind and only the inconspicuous stalks remain.

It may enable us to form an idea of the unnecessary losses we each year sustain to know that a careful estimate of the loss through smut in wheat and oats in Michigan* in 1892 was placed at $1,000,000. This was considered a low estimate and that too with a percentage of loss no greater than is the case in this State.

SUCCESSFUL PREVENTIVE TREATMENT.

There is no longer any doubt about the successful prevention of these diseases by proper treatment. The remedies suggested are not founded on theories but on the facts of repeated experiments, and on several years of successful application in different parts of the world. The character and nature of these fungi are known and the treatment necessary for their extermination fully established.

*Experiment Station, Bulletin No. 87.
The manner of infection and growth is essentially the same in all the smuts. Rarely if ever does the smut fungus find entrance into the grain except during the germination of the grain seed. No danger need be apprehended from any source except from spores introduced into the soil with the seed or from already infected soil, straw and fresh manure brought into contact with it. If the field of grain from which the seed was obtained was infected the threshing of the same would distribute the spores throughout the threshed grain. When any of this grain is used as seed and is covered with moist soil the germination of the adherent spores follows closely upon the germination of the grain itself. Only those spores that lie very near the germ end of the grain are likely to effect an entrance into the growing plant, but once they penetrate they continue to grow as the host grows, passing up through the tissues of the stem, more or less filling them, but not fruiting until the host begins to fruit. When the host plant begins to form its reproductive bodies, the ovules, the fungus occupies these or the protecting husks of the same, or both, with its hyphae, on the branches of which are produced large masses of the brown or black spores.

Loose Smut of Oats. [Ustilago avenae (Pers.) Jensen.]

In this smut not only the grains but the husks are occupied by the black powdery masses of spores. In this form as in the other kinds of smuts there is no indication of its presence until the grain begins to head unless it be that the diseased stalks are slightly smaller and less thrifty. The general appearance of this form of smut is indicated in Fig. 1. It is unlike the following kind in this, that it does
Loose Smut of Oats: a, The smut spores; b, A completely smutted head; c, A similar head as it appears at harvest-time; d, A head only partially smutted. [a, greatly enlarged, b, c and d about natural size.]
not persist in the head and may all be blown away by harvest time.

THE STINKING SMUT OF WHEAT. [Tilletia faetens (B. & C.) Shroet.]

In this smut only the interior of the kernels of the grain are occupied by the spores. The heads except on close examination appear nearly normal, and not till the kernels are crushed in the hand does one realize that they are filled only with a mass of dark brown greasy spores. These if fresh or slightly wet give forth a very disagreeable odor. This answers for a test of the presence of this smut, whose general appearance is shown in Fig. 2.

Wheat is subject to yet one other kind of smut, which in general appearance closely resembles the loose or black smut of oats and is known as the loose smut of wheat. [Ustilago tritici (Pers.) J. Jensen.] Like the loose smut of oats this is

FIG. 2. Stinking Smut of Wheat: a, The smut spores; b, Sound wheat grains; c, Smutted wheat grains of different shapes; d, A badly smutted head as it appears when harvested. [a, very greatly magnified, b, c and d about natural size. The grains as represented in d, are too dark.]
odorless and occupies the husks as well as the grains and may all be blown away before harvest. For this smut no very effective remedy is known, but as it is far less common and destructive here than the other a remedy for it is not so important as an effective one for the prevention of the stinking smut of wheat and the loose smut of oats.

MEANS OF PREVENTION.

All means proposed for the prevention of smuts have for their object the killing of the smut spores adherent to the seed grain. If this is accomplished without injury to the germ contained in the seed you may expect a crop free from smut unless the soil contains smut spores from the previous crop or they are introduced with freshly applied manures. Several methods have been practiced with some degree of success, but only two have proven completely effective. Probably the better of these two methods is the one known as

THE JENSEN, OR HOT WATER TREATMENT.

This method is applicable to both oats and wheat smut and has the advantage of being cheap, easily applied, safe and effective.

It originated with J. L. Jensen of Denmark in 1887. He discovered that water of sufficient heat to kill the spores of the smut did not injure the seed grain but rather improved its germinating power and increased the yield. This method has been repeatedly tested in all parts of the world and has always proven effective where the proper precautions have been observed. It consists simply in immersing the seed, which is to be freed from smut, in water of such a temperature and for such a time as will be fatal to the smut
It has been found that water whose temperature is 130 deg. F, or above will kill the spores if they are subjected to it for some minutes. On the other hand the temperature of the water must not rise above 135 deg. F, nor must the treatment be continued much beyond fifteen minutes, otherwise the germinating power of the seed will be injured or destroyed. Various contrivances for carrying out this method have been suggested, but the procedure briefly outlined below indicates the usual practice.

METHOD OF PROEDURE.

Provide the following necessities, viz: a loosely woven gunny sack or, much better, a bushel basket lined or covered with fine meshed wire netting or a basket made wholly of such netting. This is for holding the grain while it is being dipped. Next two large kettles, boilers or barrels to contain the water into which the seed is to be dipped. Keep the water in the first between 110 and 130 degrees. That in the second as near 132½ as possible. Finally provide two other vessels, one for cold, the other for boiling water, so that either may be at hand for regulating the temperature of the water in the vessels into which the grain is to be dipped. The object of dipping the grain into the first vessel is to warm it so that when plunged into the second the temperature of the water in the second may not be greatly lowered. When everything is at hand proceed as follows: Place a bushel, more or less, of the grain to be treated into the basket or sack. Plunge it into the first vessel, raising and lowering and shaking it by alternate right and left movements till all the grain is uniformly warmed. This should require less than a minute. Now raise and drain for a moment, then plunge into the second vessel, repeating the above move-
ments six to a dozen times in the course of twelve to fifteen minutes. Then raise, drain for a moment, and immediately cool by dashing cold water over it or by dipping it into the same, after which spread it out to dry.

The temperature of the water in the two vessels must be kept within the indicated limits, which can best be done in the case of kettles over a fire or boilers on a stove by the addition of cold water from time to time. If barrels are used a large kettle over a fire near by will furnish the hot water with which to keep up the temperature of the water in the barrels. Proceed in this manner till all the required seed is treated.

The process just given is particularly applicable to wheat but applies also to oats. However on account of the hulls which enclose the seeds of the latter, the following modifications have been found to be of advantage. Either have the water in the second vessel 140 to 143 degrees and immerse for only five minutes, cooling afterwards with cold water, or have the water at the usual temperature of 132½ and immerse for ten minutes, after which spread out to dry without first cooling with water.

If the seed is to be used at once it will soon be dry enough for sowing broadcast or from a force feed drill, but the drill must be set to feed more freely to compensate for the increased size of the grain. Wheat may be completely dried and stored again, but oats on account of its hulls is dried with difficulty.

PRECAUTIONS AND SUGGESTIONS.

1. Keep the water in the second vessel within the limits of 130 to 135 degrees.
2. See that every grain is subjected to water of this temperature.
3. Secure a reliable thermometer suitable for this use.
4. Let the quantity of water be ample.
5. Do not fill the basket so full that it cannot be deftly and easily handled.
6. Do not return the treated seed into the same sacks nor into other infected sacks without first scalding them.
7. Remember that infected bins, vessels, seeders and other tools will again infect the seed if brought into contact.
8. Remember that the threshing machine, if just previously used elsewhere on smutty grain, will infect your grain and make treatment necessary.
9. Remember that you shall reap what you sow; if you sow smut you will reap more smut.

The second best treatment, and judging from my correspondence the only method known or ever used in the State, is

**THE COPPER SULPHATE (BLUE STONE) TREATMENT.**

This consists in treating the seed with a solution of copper sulphate. Two methods have been followed, viz: first, that of using a strong solution of copper sulphate, say 1 pound to 5 gallons of water, immersing the seed in this for a few hours and then drying preparatory to use as seed. The second method consists in using a dilute solution, say 1 pound to 20 or 25 gallons of water, in which the seed is immersed 12 to 24 hours. It is then transferred into lime-water (1 pound good lime to 10 gallons of water) for only 5 to 10 minutes and is then dried preparatory to sowing. The latter of these two ways is recommended as not likely to injure the seed, while it is as effective as the former, but
neither is as safe nor productive of as great gain as the Jensen method.

ADVANTAGE OF TREATING THE SEED.

Experiments at different stations and by many practical farmers have proven that the gain arising from treating the seed according to the Jensen method is not simply the saving of the grain that otherwise would have been smutted, but there is a gain over and beyond this due to the increased germinating power of the seed and increased thriftiness of the resulting crop. This latter gain is in itself sufficient to much more than pay for the time and trouble of treating the seed.

SUGGESTIVE AND PRACTICAL QUOTATIONS.*

†1. "Stinking smut is one of the most destructive diseases to which the wheat crop is subjected."

"Do not follow smutted wheat with wheat again for one or better for two years."

†2. "It is a fair estimate based on counts in many parts of the Union to estimate the net gain to be obtained by treating seed oats, at 8 per cent. of the crop obtained. Since the aggregate value of the oat crop of the United States from 1880 to 1890 was $2,030,712,605, the net gain from a universal system of seed treatment would have been $162,457,008.40 for those years."

*In the preparation of this Bulletin I have drawn freely upon the facts as given by other botanists and station workers, but as the facts have now become public property and as the language and arrangement is my own I find it impracticable to give more than this general acknowledgment.

†Dr. J. C. Arthur, Bulletin No. 28, Indiana.
"It has been demonstrated over and over again that perfectly clean seed and clean ground will produce a clean crop. It is with smut as with weeds of all sorts, if we have seeds we shall have weeds growing up as a result, but if we have no seeds there will be no weeds. So with smut. Clean seed upon a clean field will result in a clean crop."

**ANOTHER METHOD.**

In the *Journal of Mycology*, Vol. VII., No. 4, recently issued, I find given by B. T. Galloway, Chief of the Division of Vegetable Pathology, U. S. Department of Agriculture, a new method for the application of the Jensen treatment. By it one can treat large quantities of seed grain in less time and with less labor than by the old method. As there may be those in the State to whom it may be of service I take the liberty of quoting it in full.

"During the past year Mr. Elam Bartholomew, of Rockport, Kans., a special agent of the Division, made some interesting experiments in the treatment of oat smut by the Jensen or hot-water process. Among other things, Mr. Bartholomew devised a method for treating large quantities of grain without resorting to the tedious basket-dipping process. The latter, he says, will answer fairly well for a few bushels of grain, but where a large acreage is to be planted the labor involved and the general inconvenience of the work will prevent many farmers from adopting the method. Mr. Bartholomew's method of treating five bushels of grain at a time was essentially as follows:

A common kerosene barrel was procured, and after removing the head a 1½-inch hole was bored in the bottom close to the rim. The hole was then covered with a piece of wire window screen, the latter being tacked to the bottom of the barrel on the inside. A pine plug was then fitted
to the hole from the outside in such a way that the end barely reached the fine wire screening. After making these preparations the barrel was placed on a box high enough to allow a pail or tub to be slipped under the bung. An old well bucket, such as are used in bored wells, was then obtained, and after removing the bottom, four rows of half-inch holes, running the entire length of the bucket, were punched, as nearly as possible the same distance apart, six being placed in a row, making twenty-four in all. After punching the holes the bucket was placed in the center of the barrel, bottom end up, and resting on its bail, thereby raising it four or five inches from the bottom of the barrel and causing it to project a little above the top of the latter.

Holding the bucket in position, five bushels of badly smutted oats were emptied into the barrel. There were already on hand a common wash boiler and an iron pot filled with water which had been heated to boiling point on the cook stove. The contents of the two vessels were cooled to 130 degrees F. by the addition of cold water, thereby increasing the quantity of the liquid to fifteen gallons. This was then poured into the bucket in the center of the barrel until all the grain was covered. The floating grain was pushed under with the hand and the barrel covered with a cloth to hold in the heat. After standing ten minutes the water was drawn off through the hole at the bottom of the barrel, the temperature in the meantime having fallen to 100 degrees F. More boiling water was added to the water drawn off, until the temperature reached 133 degrees F., when the liquid was again poured into the barrel and allowed to stand ten minutes, as before. Again the drawing off and heating process was repeated, the water being poured back into the barrel and allowed to stand ten minutes. It was then drawn off for the last time and a new lot of grain put in and treated as in the first case.

Mr. Bartholomew says that seed treated in this way yielded less than one-tenth of one per cent. of smutted oats, while in fields where no treatments were made twenty per
Stinking Smut of Wheat: 1 and 2, smutted heads of beardless and bearded wheat respectively; 3, sound grain of wheat; 4, same in cross-section; 5 and 6, smutted grains; 7 and 8, same in cross-section. [1 and 2 natural size; the others somewhat enlarged.]

Note—We are permitted to present the above excellent plate through the courtesy of the officers of the Kansas Experiment Station.
cent. is often affected with the fungus. A piece of 6-inch stovepipe, it is thought, will answer the same purpose as the bucket. The pipe should be arranged so that it will stand at least four inches above the bottom of the barrel.

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**POTATO SCAB.**

There is no one crop in Wyoming of so much promise and importance as the potato crop. It can be grown with almost absolute certainty and experience shows with great profit, and that too in all parts of the State. The enormous yield and fine quality have won for Wyoming potatoes during 1894 and previous years several prizes against all competitors. The experiments on the different Experiment Farms of the State show that the crop can be produced with a minimum of expense and labor. It is therefore important that steps be taken to preserve these conditions by keeping out of the State, as far as possible, the diseases to
which the potato is subject. The one most to be feared by us is the

POTATO SCAB. (*Oospora scabies* Thaxter.)

This is a wholly preventable fungous disease and never occurs in clean soil unless the germs are introduced with the seed. The cause, means of infection and distribution of the disease have been worked out by others,* and it is my intention to merely state briefly the means for its prevention.

It needs no description for it is becoming entirely too well known. It is identical with the beet scab, the treatment for which is the same. The importance of treating the seed cannot be put too strongly, for not only does the scab injure the sale of the crop but it greatly reduces the yield. More than that, the fungus once introduced into the soil persists in the soil for a number of years. The writer has strong evidence that even five years will not eliminate it from the soil if once introduced. Seed apparently clean was planted in 1894 on ground that had been fallow for five years, but that previous to that time had for several years produced scabby potatoes. The crop of 1894 was almost uniformly scabby. As the seed used was not treated this experiment is not conclusive, but it is not likely that seed apparently clean would have infected the whole crop. It is known, at least, that it is not safe to follow a crop of scabby potatoes with potatoes again. How many years the ground


Dr. Thaxter, Conn. Station, New Haven, Conn., Report 1890.


must be used for other crops before potatoes may again be safely grown in it, is not yet settled. In this State where the soils are mostly yet new and free from the fungus, it will pay to keep them so by careful treatment of all scabby or even suspected seed. It is well to remember that even perfectly smooth tubers may be infected, if they have been in contact with scabby potatoes in the bin or elsewhere. In the selection of seed, if possible, secure seed known to be free from scab.

TREATMENT.

In about fifteen gallons of water dissolve two ounces of corrosive sublimate, (bichloride of mercury). In this solution immerse the seed potatoes for one and a half hours, after which spread them out to dry, then cut and plant as usual.

CAUTION. If taken internally corrosive sublimate is a violent poison, hence all animals must be kept away from the solution and the treated seed. On account of its action on metals the solution must be prepared in wooden vessels, a barrel, for instance. See that the potatoes are clean. Put them into a coarse gunny-sack and place it in the solution. The vessels and all objects in contact with this poisonous solution must be destroyed or thoroughly cleaned.
List of Bulletins and Annual Reports by the Agricultural Experiment Station. May 1, 1891, to March 1, 1895. Laramie, Wyo.

BULLETIN No. 1—May, 1891. The Organization and the Proposed Work of the Station. D. McLaren, Director.

* " No. 4—December, 1891. Meteorology for 1891. B. C. Buffum, Meteorologist.

FIRST ANNUAL REPORT, 1891.
General Statement regarding Station Work with Bulletins Nos. 1 to 4 included. D. McLaren, Director.

† " No. 6—May, 1892. Soils of the Agricultural Experiment Farms. Relation of Geology and the Chemistry of Soils to Agriculture. J. D. Conley, Geologist; Analysis of the Soils of Wyoming Station Farms, E. E. Slosson, Chemist.
† " No. 7—July, 1892. Insecticides F. J. Niswander, Entomologist.
† " No. 8—October, 1892. Irrigation and Duty of Water. B. C. Buffum, Horticulturist.
† " No. 9—December, 1892. Sugar Beets in Wyoming in 1892. E. E. Slosson, Chemist.
† " No. 10—December, 1892. Meteorology of Wyoming in 1892. B. C. Buffum, Meteorologist.

SECOND ANNUAL REPORT, 1892.
General Statements, with Bulletins Nos. 5 to 10. A. A. Johnson, Director.


† " No. 12—April, 1893. Ground Squirrels (Gophers). F. J. Niswander, Entomologist.
† " No. 13—July, 1893. The Feeding and Management of Cattle. W. A. Henry, Ph. D., University of Wisconsin. (Reprint by permission.)
† " No. 16—December, 1893. Grasses and Forage Plants. B. C. Buffum, Horticulturist.

THIRD ANNUAL REPORT, 1893.
Progress of Station Work, with Bulletins Nos. 11 to 16. A. A. Johnson, Director.


" No. 18—June, 1894. I. Reclamation of Arid Lands. II. The Harvey Water Motor. A. A. Johnson, Director.
" No. 20—October, 1894. The Artesian Wells of Southern Wyoming. J. D. Conley, Physicist.

FOURTH ANNUAL REPORT, 1894.
Reports from the Departments and Bulletins Nos. 17 to 20. A. A. Johnson, Director.


* Supply limited. † Out of print.