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The Formalin Treatment for Controlling Oat Smut

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THE FORMALIN TREATMENT FOR CONTROLLING OAT SMUT.

JOHN A. KRALL.

INTRODUCTION.

Five million dollars is a conservative estimate of the annual loss incurred by the oat smut disease in Iowa. That this loss can be controlled is indicated by the following statements from farmers over the state of Iowa.

Reports from 5,300 farmers representing over 15,000 acres of farming land, showed that 7.5 per cent of their oat crop was destroyed by this disease. On the other hand, reports from 654 farmers who had treated their seed oats showed that their loss was only 1.4 per cent.

To insure more definite knowledge of the control methods for oat smut, and to determine if possible a practical and efficient method for the farmer has been the purpose of our work. In the results which have been secured the writer wishes to acknowledge the co-operation and assistance which was accorded from time to time by Dr. L. H. Pammel, Prof. H. D. Hughes and others interested in the work.[1]

EARLY HISTORY OF OAT SMUT CONTROL MEASURES.

Selby (47) from review of early literature makes mention of two articles which are interesting from a historical standpoint. In the September 29th issue of the American Farmer, Baltimore, 1820, page 215, a correspondent tells of oats so badly smutted that the craddlers were nearly as black as colliers. The crop was allowed to lie on the ground for curing, in the old manner, and was turned after showers some four or five times before binding and gathering. The same oats sowed the next season gave a crop free from smut. The value of washing the grain no doubt was early recognized. In a later publication of the Cultivator, May, 1856, page 139, the editor recommends to one of his correspondents that "he wash the grain thoroughly

[1]This work was done in the botanical and farm crop laboratories Iowa State College.

in water, or still better, in brine (or giving the last washing in brine), and then rolling it well in dry powdered, water-slacked, fresh lime, some hours before sowing."

An article published in the Cultivator, 1837, Vol. 11, page 107, mentions a method which no doubt was in vogue at that time. The grain was soaked in a brine solution for twelve hours after which it was rolled in fresh slacked lime before sowing.

After 1856 the records indicate that copper sulphate was used to some degree with varying success. In 1887 and 1888 Jensen (29) published the results of his experiments with hot water—a method which still bears his name. Following the introduction of the Jensen method, Kellerman and Swingle (33) in 1889, published a rather complete treatise of the history and methods of control. As a result of their experiments potassium sulphide proved an efficient preventive. The treatment consisted in soaking the oats in a ¾ per cent solution of potassium sulphide (1½ lbs. of salt in 25 gallons of water) for a period of 24 hours. From this time on there is a noticeable interest in the oat smut problem. As a result sundry methods of control have been tried in an effort to secure one that would be convenient, efficient, and cheap. Of the many materials experimented with for the control of the smut disease the following have come to the attention of the writer. Kellerman and Swingle (33) have tried various combinations of copper sulphate, copper nitrate, potassium sulphate, mercuric chloride, potassium bichromate, sodium hyposulphate, sodium hydrogen carbonate, corrosive sublimate, chloroform vapors, carbon bisulphide, ether vapor, ammonium hydrate vapors, verdigris, sulphur, salicylicid acid, castile soap, hot water. L. H. Pammel (17) experimented with ammonical carbonate, ferrous sulphate, bordeaux mixture. By others, ceres pulver or powder, soap, tar dips and various other products have been tried.

Since it is the purpose of the writer to follow the history and the use of formalin for the control of the oat smut, other treatments will not receive consideration in this paper only as they have a bearing on the subject at hand.

Early History of Formalin.

Goff (25[a]) in his treatise on the use of formalin mentions that formalin was first discovered by a German scientist who had produced the gas from wood alcohol. Its germicidal properties

seem first to have been discovered by Trillat in 1888. In 1895 Gruther published a paper stating that formalin was capable of destroying the germination of smut spores without injury to the grain.

The first use of formalin in the United States is credited to Professor Bolley of the North Dakota Station. After three years of investigational work the author made his first publication in March, 1897. During the same year Professor C. P. Close of the New York Station published the results of that season's experiments in Bulletin 131, 1897. During the next year Professor M. B. Thomas of the Indiana Station read a paper before the American Academy of Science regarding experiments with formalin. In this paper the author considers the effect of formalin on the germination of seed oats, and suggests that it might be well to try this substance upon the spores of smut as a possible prevention.

Arthur (1) in 1891 in his publication on loose smut of oats mentions the use of formalin. In this article the author states that various men have studied the action of this solution on seeds and spores but only in a subsidiary way. Its first application for the control of smut in a practical way is credited to Bolley. In the earlier publications of Bolley the writer failed to find any mention of the use of formalin. In his publication (6^b) on the treatment on wheat smut (1895) he mentions only the use of hot water, and copper sulphate, which had been in use for many years prior to that time. However, in a later publication (6^c), of 1897, he mentions the use of corrosive sublimate, sulphur dioxide, hot water, and formalin, and their effect upon the germination of wheat, oats, and barley. These experiments are quite extensive and are tabulated to show the effect of the treatment on the per cent of germination, the per cent of smut and the yield. The data are worthy of the attention of any investigator along similar lines of work. As a conclusion of his work Bolley sets forth the following treatment: "Thoroughly saturate a large pile of the grain with a solution made at the rate of one pound of formalin to 50 gallons of water. Shovel over rapidly so that the pile shall become evenly and thoroughly wet. In this treatment the grain should be left wet in the pile for two or more hours, or else dipped for two hours." The author also mentions the practical use of the solution and

its cheapness ($1.20 per pound) as compared with potassium sulphide which would cost approximately $3.60 to treat 50 bushels.

In a later publication (6°) 1910, the author reduces the water in the solution to 45 gallons. He also recommends that the grain should be soaked or covered for two hours after treatment. Two bushels of dry grain will equal approximately 2½ bushels after the treatment and due allowance should be made when seeding.

Arthur (1) in 1891 recommends, after reviewing the literature published by Bolley and after local experiments, that the formalin be used at the rate of one pound to 60 gallons of water. Immerse seed two hours or wet the pile thoroughly and let stand covered in a pile for two hours.

Goff (25) made first mention of the formalin treatment in 1901. After three years of experimenting on various treatments and methods of application the formalin treatment was considered efficient.

The following table shows the effect of the various formalin solutions on the growth of the plants under field conditions.

THE EFFECT OF VARIOUS FORMALIN SOLUTIONS ON THE GERMINATION, GROWTH AND YIELD OF OATS.

TABLE I. SHOWING AVERAGE HEIGHT OF PLANTS ON DIFFERENT DATES.

Treatment	Avg. Height in mm., May 14	Avg. Height in mm., May 22	Avg. Height in mm., July 30
Untreated	58.5	133.7	51.6
Formalin, 1 pint to 50 gal. of water.....	55.4	134.2	50.9
1 pint to 36 gal. water	63.8	138.7	52.6
1 pint to 25 gal. water	55.4	124.9	51.3
1 pint to 10 gal. water	26.2	80.7	54.7

TABLE II. WEIGHT OF PLANTS AT HARVEST.

Untreated	83.6 lbs.
Formalin, 1 pint to 50 gal. water.....	96.7 lbs.
Formalin, 1 pint to 36 gal. water.....	82.7 lbs.
Formalin, 1 pint to 25 gal. water.....	82.0 lbs.
Formalin, 1 pint to 10 gal. water.....	54.3 lbs.

The plots were seeded April 29th, a quantity of seed from each lot was planted on well prepared ground with a garden

seed drill. The seed was sown thickly in rows fourteen inches apart and with a uniform depth of two inches. As the plants appeared they were thinned out so as to stand two inches apart in the rows except in the 1—10 treatment where the plants averaged eight inches apart, owing to lack of germination. On May 11th, and again on May 22d, the height in millimeters was determined on 500 plants in each lot. At harvest time the height of the plants was determined in inches.

TABLE III. EFFECT OF FORMALIN TREATMENTS ON YIELD.

Treatment	Amt. of Seed per Acre	Wt. of Entire Plant	Cleaned Grain Bu. per Acre
	lbs.	lbs.	
Untreated	70	520.5	68¾
1 pt. to 50 gal....	70	575.0	68⅝
1 pt. to 36 gal....	70	399.0	53¾
1 pt. to 25 gal....	70	484.0	68⅛
1 pt. to 10 gal....	70	165.0	16⅞

Note: The above plots were 1/40 acre in size. The seed was thoroughly dried before seeding, being seeded at the rate of 70 lbs. per acre with a garden drill. The drill rows were four inches apart, and the grain seeded at a depth of two inches.

As a result of these field tests Goff concludes that under practical field culture the yield of grain is not appreciably affected by treating with a solution as strong as one pint of formalin to 36 gallons of water.

Clinton (12) 1895-1898, after comparing the relative value of hot water, formalin, copper sulphate, potassium sulphate, and ceres pulver, concludes that hot water and formalin proved most efficient.

TABLE IV. THE EFFECT OF FORMALIN ON THE PERCENTAGE OF SMUT.

Treatment	Smutted	Per cent Smutted
Formalin, 1 lb. to 25 gal. water...	Not a smutted panicle	0
Formalin, 1 lb. to 50 gal. water...	21 smutted on plot	0
Formalin, 1 lb. to 100 gal. water...	506 out of 4000	12.7
Untreated—check plot	440 out of 4000	11.0

For general use the author recommends the sprinkling method with formalin having a strength one pound to 40 to 50 gallons

water. Sprinkle the grain at the rate of 1 to 2 gallons per bushel, thoroughly stirring the oats. The treated grain is then left in sacks for a few hours and then planted.

W. Saunders (45) in 1899 recommended the following formalin method: Soak the grain for one hour in a formalin solution made up to a strength of one pint formalin to 36 gallons of water. This treatment has been found equal to the copper sulphate solution consisting of one pound of copper sulphate to five gallons of water.

Wilcox (61) of the Montana Station (1899) states that oats treated with a solution of formalin (1 lb. to 50 gallons of water) and soaked for two hours were free from smut. This method is to be preferred to the copper sulphate treatment, which is injurious to the vitality of the seed.

Moore (37), 1901, after careful investigation, recommends the use of one pound of formalin to 36 gallons of water. Formalin with a guaranteed strength of 40 per cent. The method suggested is to immerse the oats in sacks for ten minutes, then place on a floor in a thin layer to encourage drying. The seed may be sown in one to two days, setting the drill to seed one bushel more than normally required.

Henderson (27) in his work at the Idaho Station in 1906 experimented with various formalin solutions to determine their effect on germination of wheat and oats. His conclusions are as follows: (Idaho Bulletin 53, page 107). "1. Seed treated with solution at strength of one pint of formalin to 16 gallons of water and covered for nearly one day, was injured but little. 2. Seed treated as above, and covered nearly two days was decidedly injured. 3. When treated with solution of one part to 50 gallons, one to 40 gallons, or even one to 25 gallons, the seed was not injured, though covered for two days. 4. When wheat has been treated in piles on the floor, do not cover at all, since germination is delayed, even though the grain is not injured. 5. When farmers complain of seed being injured it is the result of too strong a solution—(below 1-50 or 1-40) or to covering for too long a period—two or more days."

Mackey (41) of the Canadian Experiment Station at Indian Head makes first mention of the formalin treatment in 1898. At this time experiments were conducted to compare the relative value of formalin, bordeaux mixture, and copper sulphate solu-

tion. The solutions used were 3 ounces and 4½ ounces of formalin to 10 gallons of water. The oats were soaked for two hours in the formalin solution, while in the bordeaux and copper sulphate solutions the grain was steeped for four hours.

The result indicated that the formalin solutions were both efficacious—no disease being found in the resulting crop from the treated seed.

R. S. Shaw after three years' work at the Montana Station in 1903 (48) recommends a formalin solution consisting of one pint formalin to 40 gallons of water. Treat the grain either by dipping or sprinkling. In either case the grain should remain covered for two hours, after which it should be dried.

Shutt (49) in his report of 1906 remarks that the use of formalin for treating smut in cereals is increasing rapidly, due to its ease of application and effectiveness. Two strengths then in use were three and four ounces of formalin to 10 gallons of water. The grain was immersed for five minutes or sprinkled. In the majority of cases the weaker solution has proven as effective, and thorough sprinkling equal to immersion.

Stevens (52) in 1906 and 1907 conducted some extensive experiments to determine the influence of various formalin solutions on the germination of oats, especially when covered for different periods of time. Other experimenters have suggested strong solutions of formalin, but the effect on the vitality of the grain was often quite marked. The following table gives the results of the first series of experiments in which solutions of one ounce of formalin were used with one-half, one, two and three gallons of water.

EFFECT OF FORMALIN UPON GERMINATION.

TABLE V. SOLUTION OF DIFFERENT CONCENTRATIONS.

Strength, Amt. formalin Solution, Amt. of water	1 oz. 2½ gal.	1 oz. 1 gal.	1 oz. 2 gal.	1 oz. 3 gal.
	Per cent	Per cent	Per cent	Per cent
Covered 12 hrs. after treatment then seeded immediately	25	95	97	93
Seeded immediately after treating	47	99	88	89
Dried 48 hours before seeding	43	96	98	94
Covered 12 hours, dried with lime before seeding	35	94	94	96
Average	37	96	94	93

The author concludes that the strongest solution is decidedly injurious, either when seeded immediately or after covering 12 hours, as in either case the formalin was kept in contact with the seed much longer as compared with the other treatments. While it is apparent that the solution (one ounce to one gallon) had no apparent affect field tests have demonstrated that at times even this solution may cause a decreased stand.

The variability in results might be attributed to other causes, which raised the following questions:

Do different varieties of oats offer different degrees of resistance to formalin? What percentage of the seed is killed by formalin of the strengths usually employed? Does formalin have any stimulating affect upon germination? Are the seeds of inferior quality more susceptible than those of medium or excellent quality? Does the fatality increase with the increase of the time of application? While many tests have been made bearing upon these points, they have usually been made with only one or two factors in mind, and the results are neither concordant nor conclusive. In order to determine some of these factors a series of crucial experiments were planned with the hope of gaining conclusive answers.

In all cases 1,000 seeds of average quality were taken and treated for twelve hours. They were treated with formalin of the strength indicated and one cc. of the solution was employed to 9.3 cc. of seeds, this being equivalent to the usual practice of using one gallon of liquid to one bushel of seed. The seeds, after being thoroughly wetted by the solution, were placed in glass capsules, of suitable size, to prevent loss of formalin by evaporation. Great care was taken to have the lots exactly alike, except as regards the factor under observation. After treatment the seeds were planted in flats in clean sifted sand in rows one-half inch apart, with the seeds evenly distributed in the rows. In this manner, it was possible to account for every seed. The final record of germination was taken two weeks after planting, since experience showed that all available seeds germinated in that time.

All seeds designated as average quality were secured by discarding from a clean commercial sample of considerable size, all foreign seeds and empty chaff, but retaining all actual oat seeds, each of which, in case of any possible doubt, was inspected

as to its integrity. This sample was thoroughly mixed and the 1,000 seeds for the test were taken absolutely without selection by always taking the seed lying nearest at hand, be it large or small. The strengths most used in practice, .26 per cent, .39 per cent, and .78 per cent of formalin, or as more commonly designated, one ounce to three gallons, one ounce to two gallons, and one ounce to one gallon, were employed; also a weaker solution, one ounce to four gallons (2 per cent formalin). The first of these is mostly used, the second often, the third rarely.

Several varieties were used in this experiment to determine whether there was any noticeable difference in their ability to withstand certain treatments. These results are indicated in the following tables.

INFLUENCE OF DIFFERENT STRENGTHS UPON WHITE SPRING, RED RUST PROOF, VIRGINIA WINTER GRAY, APPLER, BURT, BLACK SPRING OATS OF AVERAGE QUALITY TREATED TWELVE HOURS.

TABLE VI. TEST OF THE WHITE SPRING OAT, 1,000 SEEDS.

Flat No.	Strength of Solution	Number Germinated	Per cent Germinated	Per cent due to Treatment
11	Control	998	99.8	..
14	1 ounce to 4 gal.[1]	996	99.6	.2
15	1 ounce to 3 gal.[2]	993	99.3	.5
13	1 ounce to 2 gal.[3]	985	98.5	1.3
12	1 ounce to 1 gal.[4]	941	94.1	5.7

[1].2 per cent formalin, .08 per cent formaldehyde.
[2].26 per cent formalin, .104 per cent formaldehyde.
[3].39 per cent formalin, .156 per cent formaldehyde.
[4].78 per cent formalin, .312 per cent formaldehyde.

TABLE VII. TEST OF RED RUST PROOF OAT, 1,000 SEEDS.

Flat No.	Strength of Solution	Number Germinated	Per cent Germinated	Per cent due to Treatment
16	Control	989	98.9	..
17	1 ounce to 4 gal.	984	98.4	.5
20	1 ounce to 3 gal.	984	98.4	.5
19	1 ounce to 2 gal.	973	97.3	1.6
18	1 ounce to 1 gal.	925	92.5	6.4

TABLE VIII. TEST OF VIRGINIA GRAY OAT, 1,000 SEEDS.

Flat No.	Strength of Solution	Number Germinated	Per cent Germinated	Per cent due to Treatment
30	Control	895	89.5	..
29	1 ounce to 4 gal.	883	88.3	.2
28	1 ounce to 3 gal.	855	88.5	.4
27	1 ounce to 2 gal.	821	82.1	7.4
26	1 ounce to 1 gal.	790	79.0	10.5

TABLE IX. TEST OF APPLER OAT, 1,000 SEEDS.

Flat No.	Strength of Solution	Number Germinated	Per cent Germinated	Per cent due to Treatment
10	Control	966	96.6	..
8	1 ounce to 4 gal.	977	97.7	1.1
9	1 ounce to 3 gal.	958	95.8	.8
7	1 ounce to 2 gal.	933	93.3	3.3
6	1 ounce to 1 gal.	912	91.2	5.4

TABLE X. TEST OF BURT OAT, 1,000 SEEDS.

Flat No.	Strength of Solution	Number Germinated	Per cent Germinated	Per cent due to Treatment
1	Control	903	90.3	..
2	1 ounce to 4 gal.	922	92.2	1.9
3	1 ounce to 3 gal.	930	93.0	2.7
4	1 ounce to 2 gal.	901	90.1	.2
5	1 ounce to 1 gal.	730	73.0	17.5

TABLE XI. TEST OF BLACK SPRING OAT, 1,000 SEEDS.

Flat No.	Strength of Solution	Number Germinated	Per cent Germinated	Per cent due to Treatment
25	Control	934	93.4	..
24	1 ounce to 4 gal.	959	95.9	2.5
23	1 ounce to 3 gal.	949	94.9	1.5
22	1 ounce to 2 gal.	903	90.3	3.1
21	1 ounce to 1 gal.	911	91.	2.3

In the foregoing test the White Spring, Red Rust Proof and Virginia Gray oats gave perfectly consistent results, showing decreased germination with an increase in the strength of the solution employed, the loss ranging from .2 to 5.7 per cent with the White Spring Oat and from .2 to 10.5 per cent with the Virginia Gray oat. The Burt oat and the Black Spring oat (Tables X and XI) show some inconsistencies in the test. However, it seems evident that the Burt oat is more susceptible to the strongest solution.

The conclusion may be drawn that solutions stronger than one ounce of formalin to three gallons of water are questionable, due to their appreciable effect upon the vitality of the oat. The added stimulus is offset by the loss of stand.

Stevens also worked on the effect of formalin solution on seed oats which varied in quality. In these experiments four kinds of seed were used. The grain was examined individually and divided into three classes: the largest and plumpest were designated as "good"; the next grade as lower or "medium"; and the smaller shrunken ones as "poor"; the average was the sample as found. In each instance 1,000 grains were used for each grade. All grades were treated with the same solution, namely one ounce of formalin to one gallon of water.

EFFECT OF QUALITY OF SEED ON RESISTANCE TO FORMALIN.

TABLE XII. APPLER OAT, 1,000 SEEDS.

Flat No.	Strength of Solution	Quality of Seed	Number Germinated	Per cent Germinated	Per cent Loss due to Treatment
10	Control	Average	966	96.6	5.4
6	1 ounce to 1 gal.	Average	912	91.2	
45	Control	Good	991	99.1	3.7
46	1 ounce to 1 gal.	Good	954	95.4	
43	Control	Medium	976	97.6	
47	1 ounce to 1 gal.	Medium	920	92.0	4.6
44	Control	Poor	937	93.7	
48	1 ounce to 1 gal.	Poor	780	78.0	15.7

TABLE XIII. VIRGINIA GRAY OAT, 1,000 SEEDS.

Flat No.	Strength of Solution	Quality of Seed	Number Germinated	Per cent Germinated	Per cent Loss due to Treatment
30	Control	Average	895	89.5	10.5
26	1 ounce to 1 gal.	Average	790	79.0	
36	Control	Good	924	92.4	
32	1 ounce to 1 gal.	Good	826	82.6	9.8
37	Control	Medium	909	90.9	
33	1 ounce to 1 gal.	Medium	801	80.1	10.8
38	Control	Poor	859	85.9	
34	1 ounce to 1 gal.	Poor	659	65.9	20.0

From tables XII and XIII it is evident that the poorer the grade of seed, the greater is the loss due to treating. Stevens suggests that the beneficial results often seen after certain treatments when the grain is seeded in the field is due to the destruction of the inferior seed. The averaged run of oats in the test indicates the presence of the inferior seed. If such results occur under all conditions it would seem advisable to grade and fan the seed oats prior to the treatment for smut.

For general use the solution of one pint to 48 gallons of water is recommended. The grain is either immersed for 20 minutes or sprinkled. Cover the grain for 6 to 12 hours. The oats may be readily dried by mixing with air slacked lime. The lime may be removed by a fanning mill. The seed may be stored after being thoroughly dried without affecting its vitality. In general one gallon of solution will treat one bushel of oats.

Willis (63), 1908, recommended in his treatments for oat smut a formalin solution with the strength of one pint to 25 gallons of water. The grain was to be submerged for 5 to 10 minutes and sown at once. This formula would treat 20 bushels of oats. The above mentioned solution is stronger than those recommended for general use by any experiment station today, yet it coincides with the results of our recent investigations. However, the author makes no mention of covering the oats for a period of time. Since the "time covered" element is regarded essential by many investigators the effectiveness of this treatment might be questioned.

Wilcox (62) suggests that the oats be immersed for 10 minutes in a formalin solution made up of one pint formalin to 30 to 40 gallons of water. After draining, cover the treated grain for two hours, after which spread the grain out to dry. when the sprinkling method is used the grain should be covered after treatment for several hours or over night. Dry the grain before seeding.

Bowman (7) recommended the sprinkling method using a solution "one pint formalin to 40 gallons of water," and one gallon of solution for each bushel of oats. Shovel the oats thoroughly, after which they should be covered for several hours. Spread out in a thin layer to dry.

E. M. Freeman and E. C. Stakman (20) used a formalin solution one pint to 40 to 50 gallons of water. The treated grain may be either immersed or sprinkled, after which it should be covered for 12 to 24 hours. The grain should be dried so that it can be run through a seeder.

Güssow (22) prefers the formalin treatment to that of copper sulphate since it does not affect the vitality to the same degree. The solution used consists of one pound or one pint of formalin to 40 imperial gallons of water. Either immerse or sprinkle the grain, then cover for two to three hours, after which it should be spread out to dry.

Various other statements in regard to the formalin treatment could be cited, but the foregoing are representative of all and give the history and range of variation occurring in the methods of treatment.

From the above citations it is evident that no standard method even with formalin has yet been secured. The solutions used ranged from one pint of formalin to 25 to 50 gallons of water. Various times for covering also are suggested, and this last factor is of considerable importance to the farmer. The advisability of seeding directly after covering and the amount of grain which should be used following such treatment are still open questions.

The Use of Vapor for Oat Smut.

Various experimenters have worked with different vapors in an effort to find some treatment which would eliminate the objections so apparent in the use of solutions.

Kellerman and Swingle (33) in their report of 1890 show that vapors of chloroform, carbon bisulphide, ether, ammonium hydrate, and sulphurous oxide were all ineffective. At that time formalin vapor was not used in their experiments.

Prior to 1899 Bolley had secured satisfctory results with the formalin solution (1 to 50). However, he recognized the objections that would be raised against any treatment which necessitated wetting the grain. In 1897 and 1898, Bolley ascertained that the gas treatment was effective, but was not positive of its use on a large scale. Following later experiments the author (6-87) concludes that for the gas to be effective it is necessary to have it accompanied by a vapor dense enough to form a film over the surface of every grain. The dry gas has no effect on the smut spores. The vapor factor again brings in the objection raised against solutions; however, the gas treatment is to be preferred for extensive work.

Clinton (1898) found that carbon bisulphide fumes were not effective, but work with stronger solutions of formalin applied in smaller amounts was very promising. In cases of too strong a solution the vitality of the grain was injured.

Wheeler (60) of the South Dakota Station (1904) conducted some preliminary experiments with various vapor treatments for stinking smut of wheat. These experiments included formaldehyde, ammonia and chloroform. The apparatus used for the gas treatment is described as follows:

It consists of a hand blower (a), a cylinder containing the grain (c), a test tube to contain the fungicide (b) and tubes for connection. The air is forced by means of the blower through the liquid fungicide in the test tube. From there it is conducted by a tube to the lower part of the cylinder containing the grain and up through the seed grain. The air permeated with the fungicide vapor is taken up from the cylinder by the blower and forced through the liquid fungicide. By repeatedly passing the same air through the fungicide, it was thought that a saturated atmosphere would be secured and greater uniformity of results obtained than if the air were passed only once through the fungicide.

The following treatments were considered in this preliminary work: The grain was exposed to the formaldehyde vapor (40 per cent solution) for the following periods of time ¼, ¾, 1½, 2, 2½, 3 hours, both with and without return current. (See tables XV and XVI.)

TABLE XV. FORMALDEHYDE VAPOR APPLIED WITHOUT RETURN CURRENT.

	Length of Treatment	Length of Row	Date of Seeding	Total No. of Heads	No. of Heads Smutted	Per cent of Heads Smutted
a	Untreated	20 ft.	Apr. 16	1,136	36	2.37
b	¼ hour	40 ft.	Apr. 16	2,303	31	1.35
c	½ hour	40 ft.	Apr. 16	2,245	26	1.16
d	¾ hour	40 ft.	Apr. 16	2,509	18	.72
e	1½ hours	40 ft.	Apr. 16	2,501	4	.16
f	2 hours	40 ft.	Apr. 16	2,570	17	.66
g	2½ hours	40 ft.	Apr. 16	2,791	19	.68
h	3 hours	40 ft.	Apr. 16	2,727	16	.59

TABLE XVI. FORMALDEHYDE VAPOR APPLIED WITH RETURN CURRENT.

	Length of Treatment	Length of Row	Date of Seeding	Total No. of Heads	No. of Heads Smutted	Per cent of Heads Smutted
a	¼ hour	40 ft.	Apr. 16	2,397	17	.7
b	½ hour	40 ft.	Apr. 16	2,397	6	.29
c	¾ hour	40 ft.	Apr. 16	2,638	5	.19
d	1 hour	40 ft.	Apr. 16	2,640	0	.00
e	1½ hours	40 ft.	Apr. 16	2,571	2	.08
f	2 hours	40 ft.	Apr. 16	2,407	1	.04
g	Untreated	40 ft.	Apr. 16	2,606	25	.96

Results of these trials indicate that the grain exposed to formaldehyde vapor without the return current was only slightly disinfected when compared with the check. The return vapor current at room temperature proved much more efficient as indicated by the declining percentage of smut in the treated plots.

It has been observed that temperature has more or less influence on the efficiency of formalin fumes. Some investigators recommend the use of warm water in the ordinary solution treatments.

Wheeler also conducted a series of experiments to determine this factor and its relation to the gas treatment. (See Table XVII.) Rossnau states that temperature is an important factor in disinfecting with formaldehyde. The gas condenses at 20 degrees C. to the solid polymeric paraform and disinfection should never be attempted if the temperature is under 10 degrees C. The action of the gas seems to be about the same between the temperature of 10 degrees C. and 27 degrees C.

TABLE XVII. FORMALDEHYDE VAPOR—EFFECT OF TEMPERATURE.

Temperature of Formaldehyde Solution	Strength of Solution	Length of Treatment	Date of Seeding	Length of Row	Total No. of Heads	Number of Heads Smutted.	Per Cent Heads Smutted.
a. 19° C.	40 p. c.	½ hr.	4/19	20 ft.	1,210	0	0.0
b. 20° C.	20 p. c.	½ hr.	4/19	20 ft.	1,263	0	0.0
c. 30° C.	40 p. c.	½ hr.	4/19	20 ft.	1,208	0	0.0
d. 60° C.	40 p. c.	½ hr.	4/19	20 ft.	1,280	0	0.0
e. 75° C.	40 p. c.	½ hr.	4/19	20 ft.	1,084	0	0.0
f. 19° C.	20 p. c.	3 hrs.	4/19	20 ft.	1,193	12	1.0
g.	5 p. c.	24 hrs.	4/19	20 ft.	1,319	3	.22
h. Untreated	.....	.....	4/19	20 ft.	1,074	13	1.24

In the above table (d) was raised to 60 degrees C. at the start and a second time after the treatment had been under way for five minutes. Treatment (e) was maintained at 75 degrees for five minutes. All others were simply started at the temperature designated. Some condensation took place on the grain under treatment (a) which may have injured the germination.

When the formaldehyde solution was heated the gas was much more effective. However, at the higher temperature 75 degrees C. for one-half hour a lowering of the germination was noticeable, due probably to condensing of the vapor on the grain. (See Table XVII.)

Further work with formalin vapor and formalin solution showed both to be ineffective in killing the spores within infected wheat grains. Other factors which may influence the results are mentioned, e. g., it was found that a 30 per cent solution of formaldehyde after air had passed through for two hours analyzed 38 per cent of formaldehyde. New chemicals should be used for each treatment to eliminate error.

TABLE XVIII. LENGTH OF GAS TREATMENT AND ITS EFFECT UPON GERMINATION.

Chemical Used	Length of Treatment	Per cent Germination 6 days after Sowing	Per cent Germination 7 days after Sowing	Per cent Germination 10 days after Sowing	Vigor of Growth, 10 equals Normal
Formaldehyde	1/3 hr.	79	85	90	10
Formaldehyde	2/3 hr.	72	76	81	10
Formaldehyde	1 hr.	65	75	80	10
Formaldehyde	1½ hr.	29	39	55	9
Formaldehyde	2 hr.	27	37	45	7
Formaldehyde	2½ hr.	21	23	24	7
Formaldehyde	3 hr.	26	31	33	7
Formaldehyde	4 hr.	18	22	24	7
Formaldehyde	5 hr.	15	20	23	7
None	.....	75	83	84	10

The germination tests show that formaldehyde vapor from practically standard formalin solution can be applied to wheat for one hour without injury and is efficient in controlling the smut. (See Table XVIII.) Whether the above conclusions can be applied to the oat crops is still a question. The main problem is the feasibility of applying the treatment on a large scale for treating oats, which are of different structure and more bulky.

At present there is no satisfactory way of treating the grain with formaldehyde gas either on a large scale or on the farm. And since it is necessary to have the vapor at the point of saturation for efficient results, the solutions may as well be used for practical purposes.

EXPERIMENTS WITH VARIOUS FORMALIN SOLUTIONS AND THEIR RELATION TO THE GERMINATION AND CONTROL OF THE OAT SMUT.

AMES, IOWA, 1915.

At the present writing the formalin treatment seems to be the most efficient remedy for oat smut. However, it embodies one or more objectionable features from the standpoint of the practical farmer. These are, first, the time involved in treating; and second, the need of saturating the oat grain. While its efficiency is not questioned the still present objections may bear investigation.

Numerous experiments have been conducted with formalin, but as yet there is no uniformity in the results or recommendations. The solutions recommended vary from one pint of formalin to 25 to 50 gallons of water, the most common formula being one pint to 40 gallons. In addition recommendations include dipping and sprinkling of the solution, the grain to be either seeded directly or covered for various periods of time—from two to ten hours or more. To arrive at some definite and satisfactory method has been the purpose of this investigation. While one year's data are not conclusive it will indicate the possibilities of certain methods and act as a guide for further experimentation.

In these experiments twenty-two bushels of Kherson oats were used for the tests. Practically a half gallon of smut spores were thoroughly mixed with the oats to insure infection. However, it later developed that the spores were not as virile as was expected—the checks only showed an average of 1.83 per cent smut. One-half bushel, by measure, of the infected oats were used for each test. The container used in treating the oats was a large galvanized iron pan five inches deep and four by five and one-half feet in area. This was large enough to permit spreading and shovelling the oats. The container was cleaned out after each treatment.

After treating the oats were removed and piled on a muslin sheet about six feet square, the ends of which were pulled over the pile and tucked in around the base thus providing a good cover. Each pile was tagged stating the nature of the treatment, the time, and the various periods at which samples should be secured for a germination test.

About one pound of oats from each treatment were used for the germination test. In each instance the sample was secured from the center of the pile. These were taken at stated periods —time of treatment; end of first and second hours; and thereafter in two-hour periods, up to twelve hours. The sample was placed upon a clean table until dry, then sacked in a paper bag, after which it was stored for a period of one and one-half weeks, when germination tests were made.

In the germination tests duplicates were run in every case and the average of the two was recorded. Should the duplicate vary to any marked degree a new test was made of the sample.

Each test was on the basis of 200 kernels. The rag doll method was used, since a large number of tests could be taken care of in a rather small space. When the rag doll method is used it is advisable to place the oats on folds of the cloth arranged in successive tiers. It is essential that aeration is not retarded. In most cases the tests were ready to read within six days. Some of the readings indicate a marked variation even in the same series. Inconsistent tests were checked over again, but in some cases the results did not improve the average of the readings. The cause could not be determined in every case, which was illustrated by good and poor readings alternating in the same tester under identical conditions. The rag doll method is not as accurate as a good commercial tester, unless it is given careful observation.

The field plots used were 1-5 of an acre in size. With the exception of 45 plots in the series of 290, they were all the same shape, being 3x33½ feet. The soil was not as uniform as would be desirable; neither was the seed bed in as fine shape as it should have been owing to variable climatic conditions and lack of horse power. The resulting yields were, no doubt, influenced and will have to be discounted to a slight degree, since variations occur which can not be attributed to the treatments.

The plots were seeded April 10th and 11th, the grain being planted by hand in furrows one inch deep made with a hand marker. The rate of seeding was three bushels per acre, the grain having been previously weighed out for each row, placed in an envelope, and labelled. As the season progressed weed growth was kept down by frequent hoeings.

Harvesting was done by hand. The crop from each plot was shocked and labeled. At threshing time each plot was threshed separately in a small nursery thresher and the weight of the grain secured.

Results of the germination tests, based upon tables XIX and XX.

Conclusions to be drawn from Table XX—showing the effect of various formalin solutions and time of covering on the germination of oats. For each grade of solution the amount used per bushel of oats ranged from 1, 2, 4, 6 and 8 pints and the treated oats were then covered up for 0, 1, 2, 4, 6, 8, 10 and 12 hours respectively.

A. Solution—one pint formalin to three gallons of water.

1. While the germination tests do not seem to be consistent there is a gradual decrease in vitality as the amount used is increased from one pint to eight pints, and as the time of covering increases from none to twelve hours.
2. One pint per bushel may be used with comparative safety.
3. Two pints apparently affects the vitality. Larger amounts seem to have a decided affect upon the germination and should not be used.
4. Field tests showed that all the oats receiving 4, 6, and 8 pints per bushel were killed, except the first two of the 4-pint treatment. The zero and 1-hour covered seed evidently recovered from the effect of the treatment.

GERMINATION TEST OF OATS.

TABLE XIX. FOLLOWING TREATMENT WITH VARIOUS KINDS OF FORMALIN SOLUTIONS.

Solution	Pints per Bu.	Hours Covered							
		0	1	2	4	6	8	10	12
		Per Cent	Per Cent	Per Cent	Per Cent	Per Cent	Per Cent	Per Cent	Per Cent
1 pint formalin to 3 gal. of water A	1	100	96	99	96	91	87	91	89
	2	85	92	93	91	82	83	87	86
	4	89	66	30	9	23	7	8	4
	6	6	23	1	0	0	0	0	0
	8	1	4	0	0	0	0	0	0
1 pint to 5 gal. B	1	96	97	91	96	96	98	98	96
	2	91	98	96	96	94	96	85	91
	4	96	98	61	79	38	54	32	31
	6	76	76	63	8	0	0	0	0
	8	19	11	1	0	0	0	0	0
1 pint to 10 gal. C	1	98	98	98	98	98	98	100	99
	2	94	90	94	95	97	94	96	96
	4	93	96	89	93	94	91	88	89
	6	99	81	91	83	83	94	94	95
	8	86	87	84	86	66	57	47	53
1 pint to 20 gal. D	1	96	96	95	94	90	94	95	92
	2	96	98	95	94	92	93	91	93
	4	96	94	95	93	91	91	90	92
	6	95	95	91	95	94	92	94	96
	8	98	96	94	98	91	96	95	95

Solution	Pints Per Bu.	Hours Covered							
		0	1	2	4	6	8	10	12
		Per Cent	Per Cent	Per Cent	Per Cent	Per Cent	Per Cent	Per Cent	Per Cent
1 pint to 30 gal. E	1	94	99	97	94	94	97	98	98
	2	77	97	92	97	97	97	95	97
	4	98	98	92	89	95	90	93	93
	6	98	93	92	91	93	96	96	93
	8	98	96	94	97	92	97	97	98
1 pint to 40 gal. F	1	93	90	97	94	98	99	96	97
	2	95	98	95	97	97	95	94	98
	4	97	99	97	98	98	96	92	..
	6	96	98	97	98	96	95	94	96
	8	98	97	98	97	95	95	93	95

Average of checks 95 per cent.

B. Solution—One pint formalin to five gallons of water.

1. One pint per bushel is safe for any of the hours covered.
2. When two pints are used there is a slight decrease in the vitality when covered for six or more hours.
3. Four pints may be used with safety when covered not to exceed one hour.
4. Larger applications and continuous covering lower the percentage of germination to zero, especially after the second or fourth hour of covering.
5. Field tests showed that all plots were below the average of the checks.

The plots seeded with the grain treated with six pints and covered zero and one hour germinated a little slowly, showing a decrease in stand of 50 to 60 per cent. However, at harvest time the yield was practically normal. Those plots seeded with the other treatments of the six and eight pints failed to germinate except occasionally could be seen a stray plant that had survived.

C. Solution—One pint formalin to ten gallons of water.

1. Germination tests indicate that one pint per bushel may be covered for a period of twelve hours without any apparent injury.

2. Two pints per bushel did not affect the vitality unless it be at the end of ten to twelve hours.

3. An application of four pints was followed by a slight decrease in germination when covered eight or more hours.

4. When six pints per bushel were used, there was an apparent decline in the germination from one to six hours, after which the germination seemed to improve. This may be due to the drying out of the oats and consequently the lessening effect of the formalin. Apparently there is some experimental error incurred when dealing in quantities smaller than several bushels.

5. Eight pints caused a gradual decrease in the germination for each hour covered. Covering for more than one hour is questionable.

6. Field tests showed that as the treatments per bushel increased there was a slight irregularity in germination, especially for those covered for several hours. No apparent accelerated germination was noted due to stronger treatments, as has been observed with the hot water treatment.

D. Solution—One pint formalin to twenty gallons of water.

1. The results of the germination tests indicate that a solution of this strength has no decided effect upon the vitality, even when covered for twelve hours.

2. In the field work there were no apparent differences in the plots seeded with the treatments of one and two pints per bushel.

3. When four pints were used and covered for eight hours, there was delayed heading of one day. When covered ten to twelve hours the heading was delayed at least two days.

4. The same effect was observed with the six pint treatment; however, the variation was more pronounced.

5. When eight pints were used, those treatments covering eight to twelve hours showed a lack of uniformity and also a decrease in the yield. How-

ever, as was previously mentioned, the yields are not a reliable criterion in such short term experiments.

E. Solution—One pint formalin to thirty gallons of water.

1. From the germination tests all treatments are safe.
2. In the field work the low yield assigned to a part of the plots was due largely to lodging prior to ripening. Otherwise, no particular difference was observed between these plots and the checks.

F. Solution—One pint formalin to forty gallons of water.

1. The vitality of the oats was not injured by any of the treatments.
2. The field records show that the crop yielded somewhat better than the checks. This is partly accounted for in that the soil in a portion of the series had received a heavier dressing of manure two years previous. No increased yields should be ascribed to the treatments.

Notes on Amount of Solution per Bushel.

1. When one pint per bushel was used, considerable handling made the oats damp but not wet. They were ready to plant after the treatment. Oats were practically dry at the end of twelve hours.

2. Two pints per bushel moistened the oats, but did not wet them to any marked degree. The oats were ready to seed after the treatment and were dry at the end of twelve hours.

3. With four pints per bushel the oats seemed to be covered with a film of solution, but there was no excess solution left after a thorough shovelling. The oats swelled considerably. At the end of twelve hours the pile was only slightly damp.

4. Six pints made the oats very wet, only a comparatively small amount of solution was left over after a thorough mixing.

5. Eight pints caused the oats to drip, a small amount of solution remaining after the oats were well mixed; evidently being more than could be taken up by the oats.

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RESULTS OF GERMINATION TESTS OF GRAIN IMMERSED FROM ONE TO FOURTEEN MINUTES IN THE VARIOUS FORMALIN SOLUTIONS.

TABLE XX. GERMINATION OF IMMERSED GRAIN.

Solution		Time Immersed in Minutes			
Formalin Pints	Water Gallons	1 S. W. D.	2 S. W. D.	3 S. W. D.	4 S. W. D.
1	5	4— 6— 90	2— 2— 96	0— 0—100	0— 0—100
1	10	25—25— 50	23—21— 56	16—22— 62	2— 6— 92
1	15	55—13— 32	58—14— 28	39—22— 39	46—11— 43
1	20	70—14— 16	70—12— 18	66—12— 22	69—14— 17
1	30	93— 4— 3	93— 5— 2	94— 4— 2	95— 3— 2
1	40	93— 4— 3	95— 3— 2	92— 4— 4	93— 3— 4

TABLE XX.—CONTINUED.

Solution		Time Immersed in Minutes			
Formalin Pints	Water Gallons	8 S. W. D.	10 S. W. D.	12 S. W. D.	14 S. W. D.
1	5	0— 0—100	0— 0—100	0— 0—100	0— 0—100
1	10	1— 5— 98	0— 2— 98	0— 0—100	0— 0—100
1	15	32— 9— 59	9—12— 79	10—11— 79	10—12— 78
1	20	69—11— 20	68—12— 22	38—45— 17	53—15— 32
1	30	90— 6— 4	91— 6— 3	89— 6— 5	85—10— 5
1	40	93— 3— 4	93— 3— 4	89— 7— 4	92— 3— 5

Note: The symbols S. W. D. stand for strong, weak and dead.

It will be noted from the above table that the stronger solutions have a marked influence on the vitality of the oats. For all solutions below one to thirty the danger resulting from immersing is apparent. Even immersing for one minute in those solutions caused more injury than the use of eight pints per bushel of the one to ten solution and covering for two hours. Dipping grain in the solution of one to thirty and one to forty caused no apparent injury, and for practical purposes these may be recommended.

Effects of Various Treatments upon the Smut.

In the field tests the grain was seeded on April 10th and 11th. Heading was completed between the dates of June 22d and 26th, and the grain was all ripe July 16th to 18th. Harvest was finished by July 20th. Notes on the percentage of smut were taken at full heading. A two-foot division board was used for spacing the plants while counting. Six counts were made on each plot. The division stick was inserted at given intervals on a number of check plots. In this manner thirty-one checks were counted and the resulting average used for the compilations. There was an average of 105 panicle-bearing stems in the two-foot space. Only an average of 1.83 per cent of smut was noted on the checks, some ranging higher than others. This percentage was much below the expected, yet it served to indicate the value of the treatments.

In counting the percentage of smut on the treated plots every row was observed. In no instance did the formalin treated plots show any smut. This was contrary to expectations, expecially in the case of one to forty solution when applied in small amounts. Such results can hardly be accounted for since there was not a check that was not infected.

The plots treated with hydrogen peroxide showed as much smut as the check plots. It is no doubt safe to say that such peroxide treatments as were used can not be relied upon to control the oat smut.

It has been recognized for some time that climatic conditions have more or less influence on the intensity of the oat smut disease. When the seeding period is followed by warm weather a greater percentage of smut has been observed under similar conditions than when followed by cool weather. This is due in part to the maximum temperature of the smut spore being comparatively high. This, together with the adaptability of the oat plant to a cool moist climate, may account for the comparatively small percentage of smut in the test plots. The reverse conditions would result with wheat owing to the fact that wheat does best in a warm seed bed.

While some satisfactory results have been secured in regard to various formalin solutions and their methods of application it is desirable that the experiments be conducted one or more

seasons under more favorable conditions. However, it may be safe to conclude that solutions as strong as one pint of formalin to twenty gallons of water when applied at the rate of six pints per bushel and covered for a period of six to twelve hours will control the oat smut without materially decreasing the vitality of the seed.

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