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STUDIES ON BUNT, OR STINKING SMUT, OF WHEAT AND ITS CONTROL
LEUKEL, R W   1 OF 1

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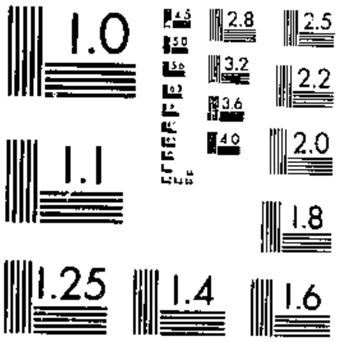

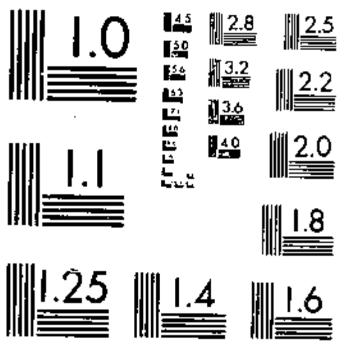

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STUDIES ON BUNT, OR STINKING SMUT, OF WHEAT AND ITS CONTROL

By

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Associate Pathologist
Division of Cereal Crops and Diseases
Bureau of Plant Industry

UNITED STATES DEPARTMENT OF AGRICULTURE, WASHINGTON, D. C.

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STUDIES ON BUNT, OR STINKING SMUT, OF WHEAT AND ITS CONTROL[1]

By R. W. LEUKEL,[2] *associate pathologist, Division of Cereal Crops and Diseases, Bureau of Plant Industry*

CONTENTS

INTRODUCTION

Experiments on bunt and its control have been conducted at the Arlington Experiment Farm, near Arlington, Va., for the last 12 years. Some of the early results have been published (*28*, *46*).[3] The purpose of this bulletin is to present the results of later experiments conducted at the Arlington Farm and at a number of State experiment stations on the influence of certain factors on the development of bunt and its control and the efficiency of a number of fungicides in controlling bunt. Data also are given showing the effects of certain seed treatments on germination and yield and the relation between the percentage of bunt and the resulting percentage reduction in yield.

MATERIAL AND METHODS

SEED AND INOCULUM

Purplestraw (C. I.[4] 1915) and Fulcaster (C. I. 1945) were the principal winter wheat varieties used in experiments on Arlington Farm. In experiments at southern experiment stations, Fultz (C. I. 1923) also was included. In experiments with spring wheat both on Arlington Farm and at a number of western stations the varieties used were: Ceres (C. I. 6900), Kota (C. I. 5878), Prelude (C. I. 4323),

[1] Received for publication Apr. 21, 1937.

[2] The writer is indebted to S. C. Salmon, A. G. Johnson, and V. F. Tapke, of the Division of Cereal Crops and Diseases, for their critical review of the manuscript.

[3] Italic numbers in parentheses refer to Literature Cited, p. 45.

[4] C. I. refers to accession number of the Division of Cereal Crops and Diseases.

153547°—37——1

Hard Federation (C. I. 4733), Supreme (C. I. 8026), Reliance (C. I. 7370), Reward (C. I. 8182), Bobs (C. I. 4990), White Federation (C. I. 4981), Little Club (C. I. 4066), and Mindum (C. I. 5296).

The bunt that was used to inoculate winter wheat was obtained from plots of Purplestraw wheat grown on Arlington Farm. That used on spring wheat was originally obtained from plots of Ceres wheat grown at Dickinson, N. Dak.

The inoculum was prepared by breaking up the bunt balls and then sifting the spores through an 80-mesh sieve. The seed was inoculated at spore dosages of 1 to 75, 1 to 100, 1 to 250, or 1 to 500; that is, 1 part by weight of spores was applied to 75, 100, 250, or 500 parts by weight of seed. The spores were thoroughly mixed with the seed in a mechanical mixer.

COMPOUNDS USED AS FUNGICIDES

The following copper, mercury, and other compounds were used either as such or in combination with other materials.

Copper carbonate (high grade), five commercial brands containing 50 to 55 percent of copper.

Copper carbonate (dilute), six commercial brands containing 18 to 25 percent of copper. Included in this lot were Coppercarb, Smut Bane, and Cuprojabonite.

Copper oxychloride, three brands.

Copper oxalate.

Copper beta-naphthol.

Copper chloride, cupric and cuprous.

Copper sulphate, basic, dehydrated, and monohydrate, full strength and diluted with talc.

Cupric hydroxynitrophenol.

Copper nitrate.

Copper stearate.

Copper phosphate.

Copper oxide, cupric and cuprous.

Höchst, a copper arsenic naphthol compound.

Cuprobol, containing 2 percent of metallic copper with ferric hydroxide, gypsum, bolus, and talc.

Vitrioline, containing about 16 percent of acid-soluble copper as copper sulphate and copper acetate.

Acco Dust, 10 percent of cuprous cyanide.

Mercuric chloride, 5 to 25 percent.

Mercuric cyanide, 10 to 65 percent.

Mercuric nitro-phenol, 10 percent.

Phenyl mercuric acetate, 2 percent.

Ethyl mercuric sulphate.

Para nitraniline orthomercuric chloride.

Abavit B, containing probably mercuric and potassium chloride and iodide.

S. F. A. 225, sodium cyanmercuricresol.

S. F. A. 225 V, sodium cyanmercurichlorphenol.

S. K. 413–a, a complex mercuric oxyphenol compound.

Wa Wa Dust, a copper mercuric chloride combination.

Mercury C, hydroxy-mercuri-cupric nitrophenol.

Semesan, mercuric chlorophenol sulphate.

Ceresan, 1.6- to 2-percent ethyl mercuric chloride.

New Improved Ceresan, 5-percent ethyl mercuric phosphate.

Sanoseed, ethanol mercuric chloride.

Scerocide, mercury furfuramid.

Paraformaldehyde, 2 to 5 percent, diluted with kaolin.

Iodine dusts of different compositions.

Resorcin combined with crystal violet.

Sulphur with and without various oxidizing agents.

Naphthalene compounds.

Formaldehyde dusts containing 4 to 8 percent of oxymethylene in talc or other inert material. This included Smuttox, Kantsmut, Ansul Dust, P. A. C. Dust, and others.

TREATING AND SOWING THE SEED

The dust fungicides were applied to the seed usually at the rate of 2 or 3 ounces per bushel. In some preliminary experiments the dusts were applied by the "excess" method; that is, the seed was mixed with an excess amount of the fungicidal dust until every kernel was thoroughly coated, after which the excess dust was removed by sieving. The seed invariably was dusted 1 or more days before it was sown. The contrivance used for applying the dusts has been described in a previous article (*29*).

In applying the formaldehyde treatment the seed was soaked for 30 minutes in the ordinary 1:320 solution of commercial formaldehyde, drained, covered 2 hours, and then dried sufficiently to be sown. When formaldehyde-treated seed was to be sent to different stations for sowing, the following modification of Braun's method (*2*) was used: The inoculated seed was soaked in water for 15 minutes, drained and covered with a damp cloth for 6 hours, soaked 10 minutes in a 1:320 formaldehyde solution, drained and covered as before for 4 hours, rinsed in fresh water, and then thoroughly dried. Subsequent periodic germination tests showed that no apparent injury to the seed resulted from this treatment, even if sowing was delayed for several weeks.

The inoculated treated and untreated seed was sown usually by hand in rod rows at the rate of 12 to 14 g per row. Several replications were devoted to each treatment. When yield data were to be obtained, the sowing was done with a hand row planter to insure greater uniformity in the rate of sowing.

The effect of the different treatments on germination was studied by sowing 300 seeds of each treated and untreated lot in the greenhouse bench. As far as possible, the sowings in the field and in the greenhouse were made on the same day. In some experiments the treated seed was stored for different periods or under different conditions before being sown. Data on emergence were taken just before the appearance of the second leaf.

Percentage of bunt was determined by counting the bunted heads in all the rows and also the total number of heads in those rows in which more than a trace of bunt appeared. Partially bunted heads were counted as bunted. The term "trace" in these experiments means less than 0.1 percent of bunted heads.

CORROSION STUDIES

One of the chief requirements for a suitable dust fungicide is that it be relatively noncorrosive to the metal parts of treaters and drills. Therefore, most of the materials tested for fungicidal effectiveness also were tested as to their corrosive effects upon metal. These studies were carried out by exposing strips of metal in a humid atmosphere to the action of the different dusts. This also served to determine to what extent the dusts were hygroscopic. Many dusts were discarded without further tests because of their corrosive or hygroscopic properties displayed in these tests.

Similar tests are described by Friedrichs (*12*), who found that several commercial fungicidal dusts were corrosive to the iron parts of treaters and drills and that others were sufficiently hygroscopic to clog the drill unless the seed was sown immediately after treatment.

EXPERIMENTAL RESULTS

FACTORS INFLUENCING INFECTION

The control of bunt is contingent largely on factors or conditions that favor or inhibit its development and the consequent severity of infection. Among these factors may be the temperature, moisture, composition, reaction, and possibly the fertility of the soil, the degree of soil infestation, the spore load on the seed, and the relative resistance or susceptibility of the variety.

SOIL TEMPERATURE BEFORE EMERGENCE

The temperature of the soil after sowing the seed and before emergence of the seedlings is generally conceded to be the principal environmental factor influencing infection. In general, investigators (*8*, *23*, *37*, *52*) agree that infection may occur at temperatures from about 5° to 20° C. In order to secure more exact information as to this relation, four varieties of spring wheat were grown in controlled soil-temperature tanks (*27*) from seed inoculated with spores of *Tilletia levis* Kuehn and in parallel experiments with spores of *T. tritici* (Bjerk.) Wint. Pertinent data are given in table 1.

TABLE 1.—*Influence of soil temperature on bunt infection in 4 varieties of wheat*

Variety	Soil temperature	Total and infected plants from seed inoculated with—					
		Tilletia levis			*Tilletia tritici*		
		Total	Infected		Total	Infected	
	°C.	*Number*	*Number*	*Percent*	*Number*	*Number*	*Percent*
White Federation	6	123	35	28.5	93	32	34.4
	10	57	30	52.6	49	24	49.0
	15	55	17	30.9	60	5	8.3
	20	35	0	.0	57	0	.0
	24	38	0	.0	46	0	.0
Purplestraw	6	148	66	44.0	106	66	62.3
	10	61	53	86.9	53	47	88.7
	15	58	49	84.5	61	47	77.0
	20	60	8	13.3	61	0	.0
	24	50	0	.0	52	0	.0
Bobs	6	116	41	35.3	90	39	43.3
	10	61	36	59.0	46	33	71.7
	15	49	32	65.3	56	25	44.6
	20	55	2	3.6	55	0	.0
	24	46	0	.0	48	0	.0
Little Club	6	109	58	53.2	89	59	66.3
	10	56	53	94.6	37	34	91.9
	15	56	40	71.4	49	14	28.6
	20	57	1	1.8	53	0	.0
	24	51	0	.0	45	0	.0
Totals for all varieties	6	496	200	40.3	378	196	51.9
	10	235	172	73.2	185	138	74.6
	15	218	138	63.3	226	91	40.3
	20	207	11	5.3	226	0	.0
	24	185	0	.0	191	0	.0

In every case except one the highest percentage of infection occurred at 10° C., and in the single exception the difference is not great. There was a marked drop in infection at the higher temperature. With *Tilletia tritici* no infection occurred at temperatures above 15° C. and with *T. levis* none above 20° C. It seems possible that the optimum temperature for infection may be slightly different for the two species of bunt.

SOIL TEMPERATURE AFTER EMERGENCE

Faris (*8*) concluded from his experiments that growth conditions after emergence of the host plants had no marked effect upon the development of bunt in Dawson and O. A. C. No. 104 wheats. Smith (*42*), on the other hand, working with Hope wheat, obtained 100-percent infection when the plants were kept until maturity at an average temperature of 9° C., and only 2.4 percent when they were grown to emergence at 9° and then kept at an average temperature of 21° until maturity. In Jenkin wheat, similarly environed, a high percentage of infection was secured in both cases, indicating that different varieties may react differently under a given set of environmental conditions. An experiment was designed to determine the effect of soil temperature after emergence on bunt infection in Purplestraw wheat. Seed of this variety was inoculated with spores of *Tilletia levis*, and the seedlings were grown to emergence at 6°, 13°, and 26°. At the time of emergence, one-third of the seedlings in each lot was retained at the initial soil temperature while an equal number was transferred to each of the other two soil temperatures. All seedlings were transferred to the greenhouse bench when in the fourth-leaf stage. The infection data taken later are shown in table 2. Of the six transfers, only two, 6° to 26° and 26° to 6°, seem to have affected the percentage of infection. This may have been because some plants had not yet passed the susceptible stage when they were transferred.

TABLE 2.—*Effect of soil temperature before and after emergence on the percentage of infected plants and heads in Purplestraw wheat grown from seed inoculated with spores of Tilletia levis*

Soil temperature		Plants			Heads		
Before emergence	After emergence	Total	Infected		Total	Infected	
°C.	*°C.*	*Number*	*Number*	*Percent*	*Number*	*Number*	*Percent*
6	6	114	109	96	350	347	97
6	13	105	99	94	398	378	95
6	26	96	80	83	401	328	82
13	6	127	119	94	608	588	97
13	13	111	103	93	501	486	97
13	26	112	107	96	564	548	97
26	6	132	16	12	313	18	6
26	13	119	0	0	304	0	0
26	26	100	0	0	333	0	0

PERIOD REQUIRED FOR EMERGENCE

Since relatively low temperatures favor infection, it has been suggested that this fact might be related to the longer period required for emergence at the lower temperatures. Accordingly, each day as the seedlings in the soil-temperature studies referred to in table 1 emerged they were marked with metal tags indicating the number of days required for emergence. At 20° C. the variation in the emergence period was from 5 to 7 days; at 15°, from 8 to 10 days; at 10°, from 12 to 16 days; and at 6°, from 17 to 29 days. After all the plants had emerged they were transferred to the greenhouse where a temperature of about 15° was maintained. Later the percentage of bunt was tabulated according to the period of emergence.

The combined data from the four varieties are shown in table 3. Since no infection took place at 24°, and very little at 20°, results obtained at these temperatures are not included. There seems to be a definite negative correlation between length of the emergence period and percentage of plants smutted at each temperature. This is especially apparent for the seedlings that emerged at 6°. The belief (*19*) that rapidly emerging seedlings "grow away" from the bunt fungus is therefore not borne out by these results. Faris (*8*) arrived at similar conclusions.

TABLE 3.—*Relation of length of emergence period to infection by bunt in 4 wheat varieties grown to emergence at 1 of 3 soil temperatures*

Emergence period (days)	Soil temperature	Total and infected plants—								
		From seed inoculated with—						In both series		
		Tilletia levis			*Tilletia tritici*			Total	Infected	
		Total	Infected		Total	Infected				
	° C.	*Number*	*Number*	*Percent*	*Number*	*Number*	*Percent*	*Number*	*Number*	*Percent*
8		151	101	66.9	129	55	42.6	250	156	55.7
9	15	54	27	50.0	77	21	27.3	131	48	36.6
10		4	3	75.0	10	2	20.0	14	5	35.7
12		82	69	84.1	48	44	91.7	130	113	86.9
13		41	32	78.0	40	39	97.5	81	71	87.7
14	10	64	42	65.6	35	25	71.4	99	67	67.7
15		9	5	55.6	16	4	25.0	25	9	36.0
16		27	15	55.6	33	21	63.6	60	36	60.0
17		37	25	67.6	8	8	100.0	45	33	73.3
18		---	---	---	11	8	72.7	11	8	72.7
19		30	18	60.0	14	6	42.9	44	24	54.5
20		46	25	54.3	27	22	81.5	73	47	64.4
21		94	49	52.1	53	40	75.5	147	89	60.5
22		42	22	52.4	20	9	45.0	62	31	50.0
23	6	106	37	34.9	90	55	61.1	196	92	46.9
24		36	9	25.0	31	16	51.6	67	25	37.3
25		20	3	15.0	20	6	30.0	40	9	22.5
26		18	3	16.7	24	8	33.3	42	11	26.2
27		11	4	36.4	19	7	36.8	30	11	36.7
28		8	4	50.0	20	4	20.0	28	8	28.6
29		14	1	7.1	19	3	15.8	33	4	12.1

SOIL MOISTURE AND OTHER SOIL FACTORS

Soil moisture also may affect bunt development. Caspar (*5*) and Rabien (*37*) found that bunt development was inhibited in extremely wet or dry soils. Woolman and Humphrey (*52*) and Hungerford (*23*) secured little or no infection in extremely wet soil. In experiments designed to determine the relation of various soil factors to the effectiveness of fungicides, the detailed results of which are discussed later, the percentage of infection in the controls was reduced from 31.4 to 6.5 by saturating clean soil and from 54 to 28 by saturating bunt-infested soil in which in both cases bunt-inoculated seed had been sown. In another case wetting the soil reduced the percentages of bunt from 7 to 1.2 in one sowing and from 10 to 4.5 in another. These reductions in infection may be explained by the fact that in wet soils the oxygen supply is insufficient for abundant spore germination.

Soil type is mentioned by Faris (*8*), Volk (*50*), Rabien (*37*), and others as a factor influencing infection by bunt. These investigators agree in general that soils rich in organic matter are more conducive to bunt infection than are light sandy soils. In agreement with this, the writer has observed over a period of years that in wheat grown from the same lot of seed sown the same day, infection was consistently higher in that grown on clay loam or on rich black soil than in that on sandy soil. In one case inoculated seed sown the same day in clay loam and sandy soil produced 27 and 7 percent bunted heads, respectively, and in another experiment 22.3 and 4.8 percent, respectively.

Rabien (*37*) states that pH 5.0 represents the acid limit for the germination of bunt spores in the soil. Soil reaction, therefore, is one of the factors largely responsible for the lower percentages of infection usually observed in wheat grown on sandy soil. In field experiments on bunt control, which will be discussed later, the addition of lime to a sandy soil increased the percentage of bunt from 4.7 to 10.3. In another experiment in which two lots of soil were adjusted to pH 5.6 and pH 7.9, respectively, and sown to Purplestraw wheat inoculated with bunt the percentages of infection were 5.8 and 42.3, respectively.

The effect of fertilizers on the development of bunt has been investigated by Caspar (*5*), Feucht (*9*), Heuser (*19*), Rabien (*37*), and others, but without any outstanding or consistent results. In general, heavy applications of potassium and phosphate fertilizers seemed conducive to bunt development, whereas nitrogenous fertilizers seemed to inhibit it. However, the use of commercial fertilizers solely for the control of bunt can hardly be recommended.

In certain sections of the United States the degree to which the soil is infested with viable spores when the seed is sown largely governs the amount of bunt infection in the crop. These spores usually are blown from neighboring fields where harvesting or threshing operations are in progress. They are deposited on the dry fallow land on which wheat is to be sown and germinate along with the wheat after the late fall rains. Seed treatment under such conditions is not fully effective. Fortunately, soil infestation with bunt spores is common in only a small part of the country.

Deep sowing, thick sowing, and excessive shade also have been reported to be conducive to infection, while old seed, excessive stooling, and a very loose seedbed tend to inhibit infection (*5, 19, 47*).

SPORE LOAD

It has been shown repeatedly both by formal investigations (*17, 31*) and by general observations for those areas where soil infestation does not occur that the degree of infection in the crop is influenced greatly by the number of spores per kernel. Assuming favorable conditions for infection, seed visibly dark with spores may be expected to produce a heavily infected crop; if only the brush of the seed is darkened with spores 10 to 25 percent infection may follow; and if the smut on the seed is not visible to the naked eye bunt infection may range from a trace to about 5 percent. Much, of course, depends upon the viability of the spores, the environmental conditions during emergence, and the relative susceptibility of the variety.

Seed of Purplestraw and Fulcaster wheats inoculated at different spore dosages and sown on different dates yielded the results summarized in table 4. There is obviously a relation between spore load and infection. However, infection in Purplestraw was consistently higher than in Fulcaster, and there is a wide range of infection in both varieties, as governed by the date of sowing. These results indicate that the degree of infection cannot safely be predicted from a knowledge of the spore load alone.

TABLE 4.—*Effect of spore load, date of sowing, and variety on bunt infection in wheat*

Variety and spore load [1]	Bunted heads from seed sown—				Variety and spore load [1]	Bunted heads from seed sown—			
	Sept. 20	Oct. 2	Oct. 16	Nov. 2		Sept. 20	Oct. 2	Oct. 16	Nov. 2
Purplestraw:	*Pct.*	*Pct.*	*Pct.*	*Pct.*	Fulcaster:	*Pct.*	*Pct.*	*Pct.*	*Pct.*
1 to 50	3.0	15.7	34.0	81.1	1 to 50	1.8	5.3	11.2	48.9
1 to 100	1.4	14.0	30.0	77.0	1 to 100	1.1	7.2	13.5	37.2
1 to 250	.5	10.0	23.6	63.9	1 to 250	.4	5.4	9.0	31.2
1 to 500	.2	7.6	16.4	54.8	1 to 500	.5	5.2	8.1	22.0
1 to 1,000	[2] T	4.8	8.0	27.2	1 to 1,000	[2] T	3.1	6.0	18.0

[1] Expressed as relative weights of spores and seed. [2] Represents trace, or less than 0.1 percent.

VARIETAL SUSCEPTIBILITY

As suggested above, the severity of bunt infection is greatly influenced by the relative susceptibility of the variety of wheat to the strain or strains of bunt fungi infecting it. Much work has been done in recent years in developing varieties of wheat resistant to bunt. Some of these varieties which seemed to be highly resistant to bunt (*3*) later proved to be more susceptible to certain other strains of the bunt fungus (*21*). The existence of these different strains greatly complicates the work of developing resistant varieties. However, in regions where soil infestation occurs, resistant varieties necessarily will continue to be the chief means of combating bunt.

EXPERIMENTS WITH BUNT FUNGICIDES

RELATIVE EFFECTIVENESS OF VARIOUS FUNGICIDES

Seed treatment for the control of bunt has been practiced to some extent for nearly three centuries and as a standard agricultural practice for more than 60 years. Copper sulphate and later formaldehyde were the first fungicides to come into general use. The literature on the early use of these and other liquid treatments, such as mercuric chloride, hot water, and Uspulun, has been reviewed by Woolman and Humphrey (*51*).

The first dust fungicide to be widely used was copper carbonate, owing largely to the work of Darnell-Smith (*6*) in Australia and that of Mackie and Briggs (*31*) in the United States. The apparent advantages of a dust treatment greatly stimulated a search for other and better dust fungicides for the control of bunt and other cereal diseases.

Space will not permit a complete review of the innumerable publications on bunt control, but a brief general summary of the results obtained and the recommendations made will be attempted.

Until recently most investigators in the United States have recommended copper carbonate as the most practicable dust fungicide for bunt control. The usually recommended rate of application is 2 to 3 ounces per bushel for the high-grade copper carbonate and 3 to 4 ounces for the so-called "extended" or diluted brands. Some contend that the latter brands are as effective as the high-grade brands when used at the same rate of application, but others maintain that this obtains only when there is a light spore load on the seed. The majority recommend the high-grade material at least for moderately severe infestation, and many favor the wet formaldehyde treatment instead of dust fungicides for very badly infested seed. Copper carbonate and the better dust fungicides in general are, on the whole, credited with improving the stand, while the opposite effect is frequently observed to follow the use of formaldehyde and copper sulphate solutions.

Many other copper salts have been tried as bunt fungicides with varying degrees of success by a number of workers in the United States. The following compounds of copper have at times been recommended: Oxalate, oxychloride, chloride, acetate, stearate, phosphate, fluosilicate, oxide, nitrate, arsenate, bromide, iodide sulphate, silicate, sulphide, and combinations of these with each other or with other materials. The following have at times been found unsuitable as bunt fungicides: Acetate, chlorate, dichloracetate chromate, phosphide, sulphide, stearate, sulphocyanide, sulphophenate, tartrate, sulphate, and others.

Among other chemicals that have been found inferior to copper carbonate are the carbonates of lead, nickel, barium, calcium, and sodium, the sulphates of ammonia, potassium, magnesium, and iron, calcium arsenate, furfurol, paris green, and the acetate, chloride, and silicate of nickel. A number of American investigators (*4, 13, 18, 25, 32, 33, 48*) have included in their experiments such proprietary products as Wa Wa Dust, Abavit B, Vitrioline, Seed-O-San, Semesan, Corona 620, Bayer Dust, Jabonite, and others. Although some of these dusts at times were reported as satisfactory bunt fungicides, the fact that at present they are not on the American market as such seems to indicate that, on the whole, they were not able to compete with copper carbonate and other popular bunt fungicides.

Ceresan, containing 1.6 and later 2 percent of ethyl mercuric chloride, was found by some to be equal to copper carbonate in bunt control, but much higher in price. In 1933 Ceresan was succeeded by New Improved Ceresan, containing 5 percent of ethyl mercuric phosphate. In experiments by a number of investigators (*15, 25*), it has been found equal or superior to copper carbonate with respect to bunt control, ease of application, effect upon drills, and cost per bushel of seed treated.

Investigators in the British Empire, in general, have found copper carbonate the most acceptable dust bunt fungicide (*30, 43, 44, 47, 48*), although in some cases anhydrous and basic copper sulphates and some proprietary copper dusts have been found superior to copper carbonate.

In France and her colonies different workers (*1, 11, 14, 34, 35, 36, 40*) have recommended the use of such salts of copper as carbonate, acetate, chloride, oxychloride, sulphate, and arsenite for effective bunt control. The use of mercury in dust fungicides does not seem to have been encouraged in France.

In the countries of central Europe copper carbonate (*41*) is not generally recommended for bunt control, although in Germany (*39*) American brands of this fungicide have been found effective. It is possible that the frequent failure of copper carbonate as a bunt fungicide in these countries is due to the use of material not especially made

153547°—37——2

for this work (*31*). The dusts most frequently used in bunt-control experiments, especially in Germany (*20, 26, 49, 50*), are such proprietary preparations as Tillantin, Höchst, Agfa, Kusperit, Segetan, Porzol, Tutan, Urania, Abavit, Abavit B, Fusariol, and others. These are not commercially available in the United States and their relative merits therefore need not be discussed.

Although copper carbonate was recognized as a fairly good bunt fungicide as early as 1913 (*6*) and has been widely used as such since that time, it has certain objectionable features that have stimulated a search by State and Federal investigators for something better. Commercial concerns also have been trying to develop more acceptable dust fungicides and usually have submitted their products to Government experimental agencies for testing. In such experiments carried on by the writer, copper carbonate has been used as a standard of comparison. Any dust found inferior to copper carbonate in bunt control, or equal to it but more objectionable in one or more other respects, can hardly be expected to replace it as a bunt fungicide.

In the spring of 1929, experiments relating to the control of bunt in spring wheat were carried out at 13 experiment stations through the cooperation of the workers at those stations.[5]

Seed of four varieties of spring wheat was inoculated with bunt spores at a 1 to 250 spore dosage, and separate portions were treated with the different fungicides at Arlington Farm on March 8, 1929. Prelude was sent to seven of the stations and Reliance to six, while Kota and Supreme were sent to all of them. The treated and untreated seed was sown by hand at the rate of 12 g per rod row in four replications at each of the stations.

Data on bunt control were taken by the writer at 9 of the 13 stations. At Moscow, Aberdeen, Moro, and Pullman they were taken by the respective cooperators at those stations. These data are presented in table 5.

TABLE 5.—*Bunt control in Prelude, Kota, Supreme, and Reliance wheats grown from inoculated treated seed, sown in rod rows, and replicated 4 times for each treatment applied to each variety at a number of stations in 1929*

Variety and seed-treatment compound [a]	Smutted heads at—														
	Manhattan	North Platte	Madison	St. Paul	Brookings	Fargo	Dickinson	Moccasin	Bozeman	Aberdeen	Moscow	Moro	Pullman	All stations	
	Pct.	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*No.*	*Pct.*
Prelude:															
Control	49.00	39.00	25.00	52.00	21.00	29.00	34.00	-----	-----	-----	-----	-----	-----	5,857	38.00
Ceresan	.04	.48	1.30	.56	.87	2.40	2.60	-----	-----	-----	-----	-----	-----	170	1.00
Copper carbonate	.08	1.00	.06	.00	.53	.40	.19	-----	-----	-----	-----	-----	-----	56	.34
Coppercarb	.08	2.10	.12	.25	.53	.28	.80	-----	-----	-----	-----	-----	-----	107	.67
Control	44.00	30.00	18.00	51.00	15.00	29.00	31.00	-----	-----	-----	-----	-----	-----	5,723	34.00
Copper chloride	.00	.50	.00	.00	.00	.04	.00	-----	-----	-----	-----	-----	-----	17	.11
Copperoxychloride	.16	.70	.06	.15	.07	.44	.17	-----	-----	-----	-----	-----	-----	47	.29

[a] Coppercarb was applied at 3 ounces and the other dusts at 2 ounces per bushel. The formaldehyde was applied by a modification of the Braun (*8*) method.

[5] The writer gratefully acknowledges the assistance of the following cooperators in carrying out experiments in the western United States: C. O. Johnston, Manhattan, Kans.; G. F. Sprague, North Platte, Nebr.; J. G. Dickson and R. G. Shands, Madison, Wis.; C. S. Holton and E. R. Ausemus, St. Paul, Minn.; K. H. Klages, Brookings, and E. S. McFadden, Redfield, S. Dak.; W. E. Brentzel, Fargo, R. W. Smith, Dickinson, and G. S. Smith, Langdon, N. Dak.; B. B. Bayles and Joe E. Sutherland, Moccasin, LeRoy Powers and J. E. Norton, Bozeman, and M. A. Bell, Havre, Mont.; Loren Davis, Aberdeen, and C. W. Hungerford, Moscow, Idaho; E. F. Gaines and H. H. Flor, Pullman, Wash.; J. F. Martin, Moro, Oreg.; and B. L. Richards, Logan, Utah.

TABLE 5.—*Bunt control in Prelude, Kota, Supreme, and Reliance wheats grown from inoculated treated seed, sown in rod rows, and replicated 4 times for each treatment applied to each variety at a number of stations in 1929*—Continued

Variety and seed-treatment compound	Smutted heads at—														
	Manhattan	North Platte	Madison	St. Paul	Brookings	Fargo	Dickinson	Moccasin	Bozeman	Aberdeen	Moscow	Moro	Pullman	All stations	
Prelude—Continued.	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*No.*	*Pct.*
Copper oxalate	0.96	02.00	0.06	0.70	0.40	0.70	0.37	----	----	----	----	----	----	171	1.07
Control	52.00	31.00	14.00	40.00	17.00	28.00	35.00	----	----	----	----	----	----	5,361	32.00
Höchst	.00	.10	.00	.06	.07	.00	.00	----	----	----	----	----	----	6	.04
Copper-beta-naphthol	10.00	13.10	4.20	9.00	4.60	1.20	6.50	----	----	----	----	----	----	1,488	9.30
Formaldehyde 1:320	.00	.10	.06	.08	.13	.00	.00	----	----	----	----	----	----	9	.06
Kota:															
Control	31.00	14.00	6.00	27.00	9.00	24.00	20.00	20.70	24.80	28.10	23.60	19.30	36.00	5,622	23.30
Ceresan	.15	.40	.12	.32	.27	1.60	1.35	2.00	.54	.90	3.50	7.10	1.00	232	1.20
Copper carbonate	.08	.05	.06	.13	.00	1.20	.24	2.00	.40	3.10	.04	2.20	.92	172	.74
Coppercarb	.08	.85	.00	.03	.27	.50	.02	2.90	1.60	2.70	1.20	2.00	.80	221	.90
Control	26.00	15.00	7.00	24.00	7.00	26.00	20.00	24.80	24.30	25.60	31.20	30.20	39.30	5,562	23.90
Copper chloride	.00	.00	.00	.10	.00	.00	.07	.50	.16	.15	2.20	1.50	.00	78	.33
Copperoxychloride	.45	.60	.00	.32	.40	.75	.27	2.09	1.03	1.15	.40	2.80	.75	164	.70
Copper oxalate	.15	.30	.00	1.10	.07	1.30	.42	2.09	.40	.85	2.30	4.80	.80	224	.90
Control	29.00	13.00	8.00	26.00	11.00	23.00	24.00	30.80	18.90	26.50	33.20	63.10	41.00	6,196	22.60
Höchst	.00	.10	.00	.00	.13	.13	.16	.40	.17	.20	2.30	.00	.70	98	.41
Copper-beta-naphthol	3.00	3.50	1.70	3.10	3.00	4.90	7.70	11.20	4.20	5.70	1.50	11.80	6.30	1,082	4.50
Formaldehyde 1:320	.00	.00	.00	.13	.00	.00	.00	.30	.13	.10	.50	1.50	.00	32	.13
Supreme:															
Control	3.50	2.50	2.00	1.00	1.40	2.00	2.90	.69	3.00	4.90	1.70	21.90	18.00	1,225	4.80
Ceresan	.00	.00	.07	.00	.00	.00	.05	.00	.03	.00	.36	5.40	.10	39	.15
Copper carbonate	.00	.00	.00	.00	.00	.00	.00	.00	.00	.27	.60	.00	.10	24	.09
Coppercarb	.00	.04	.00	.00	.00	.00	.00	.00	.10	.30	.16	1.70	.06	21	.08
Control	2.70	3.50	1.50	1.60	1.50	2.60	3.50	.60	3.20	7.20	6.50	18.70	14.00	1,229	4.70
Copper chloride	.00	.07	.07	.00	.00	.00	.00	.00	.00	.00	.00	.00	.10	7	.02
Copperoxychloride	.00	.32	.00	.00	.00	.00	.00	.00	.25	.50	.04	1.60	.06	32	.12
Copper oxalate	.00	.04	.00	.00	.00	.00	.05	.00	.07	.50	1.30	.00	.20	53	.21
Control	3.10	3.40	1.30	.70	1.20	2.90	2.50	.80	3.40	5.70	4.40	19.40	15.50	1,127	4.40
Höchst	.00	.04	.00	.00	.00	.00	.00	.00	.07	.00	.32	.00	.20	17	.06
Copper-beta-naphthol	.80	.61	.20	.07	.36	1.20	1.10	.20	1.00	1.00	.16	10.20	3.90	317	1.20
Formaldehyde 1:320	.00	.04	.00	.00	.00	.00	.00	.00	.03	.10	.00	.00	.00	4	.01
Reliance:															
Control	----	----	----	----	----	----	----	.70	2.50	4.20	2.03	14.29	11.40	343	4.70
Ceresan	----	----	----	----	----	----	----	.00	.10	.05	.32	2.77	1.10	53	.46
Copper carbonate	----	----	----	----	----	----	----	.00	.00	.00	.46	.00	.00	11	.10
Coppercarb	----	----	----	----	----	----	----	.00	.06	.30	.00	.37	.00	9	.07
Control	----	----	----	----	----	----	----	.20	2.03	1.60	2.70	5.50	8.70	456	3.90
Copper chloride	----	----	----	----	----	----	----	.00	.00	.00	.00	.00	.00	0	.00
Copperoxychloride	----	----	----	----	----	----	----	.00	.00	.05	.00	.96	.00	5	.04
Copper oxalate	----	----	----	----	----	----	----	.00	.06	.25	.05	.00	.00	8	.06
Control	----	----	----	----	----	----	----	.10	2.50	5.50	2.75	11.80	9.60	575	5.30
Höchst	----	----	----	----	----	----	----	.00	.06	.00	.04	5.33	.09	32	.26
Copper-beta-naphthol	----	----	----	----	----	----	----	.00	.20	1.30	.15	2.14	2.84	132	1.11
Formaldehyde 1:320	----	----	----	----	----	----	----	.00	.00	.00	.00	.00	.01	1	.01

The pronounced range in infection and in the apparent effectiveness of the different dusts at various stations is difficult to explain, in view of the fact that the seed had been uniformly inoculated and treated. The results from some of the stations suggest the possibility of soil infestation or recontamination of the seed after treatment. It is possible that differences in the nature of the soil at the different stations also may have contributed somewhat to the disparity in results. None of the treatments reduced the number of bunted heads to less than 1 percent in all of the varieties at all of the stations. On the basis of the lowest average percentage of bunted heads for all stations, formaldehyde effected the most nearly perfect control and next in order were copper chloride, Höchst, copper oxychloride, copper carbonate, Coppercarb, copper oxalate, Ceresan, and copper-beta-naphthol, the last named compound being generally ineffective.

In the fall of 1929, cooperative experiments with winter wheat were carried out at a number of experiment stations in the southeastern United States.[6] Seed of three winter-wheat varieties was inoculated with bunt spores at a 1 to 500 spore dosage, treated with fungicides at the rate of 2½ ounces per bushel, and sown in rod rows replicated four times at each of six stations.

The data on bunt infection at each of the stations are shown in table 6. In Fulcaster wheat the infection in the controls ranged from 8.7 percent at Knoxville to 45.7 percent at Athens, and each of the treatments reduced the occurrence of bunt to less than 1 percent at every station. In Purplestraw infection in the controls ranged from 14.4 to 54.9 percent and every treatment except Ceresan reduced bunt infection to less than 1 percent at each station. In Fultz, which showed the highest infection in the controls, 20.9 to 64.6 percent, only formaldehyde and basic copper sulphate reduced infection to less than 1 percent at every station. However, none of the treatments for any variety at any station permitted an infection of more than 1.7 percent. It would appear, therefore, that all the treatments gave fairly satisfactory commercial control.

TABLE 6.—*Bunt control in Purplestraw, Fulcaster, and Fultz wheats grown from treated inoculated seed sown in rod rows replicated 4 times for each treatment applied to each variety at each of 6 stations, 1929–30*

Variety and seed-treatment compound [1]	Bunted heads at—							
	Arlington	Raleigh	Athens	Knoxville	Lexington	Morgantown	All stations	
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Number*	*Percent*
Purplestraw:								
Control	23.0	45.3	54.9	16.0	21.3	30.0	3,851	35.0
Ceresan	.0	1.7	.6	.0	.3	.0	48	.6
Copper carbonate	.0	.2	.2	.0	.0	.3	12	.1
Basic copper sulphate	.0	.2	.2	.0	.0	.0	9	.1
Control	27.2	47.2	54.4	14.4	17.4	32.2	3,862	35.4
Coppercarb	.1	.5	.3	.0	.0	.0	18	.2
Copper oxalate	.1	.4	.6	.0	.2	.8	33	.3
Formaldehyde	.0	[2] T	.1	.0	.1	.0	5	T
Fulcaster:								
Control	15.1	35.0	43.0	10.2	13.2	16.7	1,882	24.7
Ceresan	.0	.3	.4	.0	.2	.1	12	.2
Copper carbonate	.0	.0	.2	.0	.0	.0	3	T
Basic copper sulphate	.0	.1	.0	.0	.0	.0	1	T
Control	15.0	36.1	45.7	8.7	12.3	16.1	1,860	25.7
Coppercarb	.0	.1	.0	.0	.2	.0	3	T
Copper oxalate	.0	.2	.1	.0	.2	.0	5	.1
Formaldehyde	.0	.0	.3	.0	.0	.0	4	T
Fultz:								
Control	36.6	61.0	64.6	26.2	31.4	36.5	4,618	46.2
Ceresan	.0	1.7	1.3	.0	.2	.0	57	.6
Copper carbonate	.0	1.2	.8	.0	.3	.5	44	.5
Basic copper sulphate	.1	.6	.4	.0	.0	.1	20	.2
Control	43.5	50.2	63.9	20.9	31.8	33.6	4,374	46.7
Coppercarb	.0	1.0	.6	.0	.2	1.0	35	.4
Copper oxalate	.5	1.7	.8	.0	.1	1.0	50	.6
Formaldehyde	.0	.2	.2	.0	.6	.0	13	.1

[1] The dusts were applied at 2½ ounces per bushel; the formaldehyde treatment was applied according to a modification of the Braun (*2*) method.
[2] T represents trace, or less than 0.1 percent.

A series of cooperative field experiments similar to those of the previous year were carried out in 1930 at 15 western experiment stations. Seed of Reward, Ceres, and Kota was inoculated at a spore

[6] The writer gratefully acknowledges the helpful cooperation and assistance of the following persons in carrying out these experiments: S. G. Lehman, Raleigh, N. C.; R. R. Childs, Athens, Ga.; C. D. Sherbakoff, Knoxville, Tenn.; W. D. Valleau, Lexington, Ky.; and C. R. Orton, Morgantown, W. Va.

dosage of 1 to 250, and separate portions were treated with different fungicides. Coppercarb was applied at 2, 3, and 4 ounces per bushel, in order to determine whether the extended brands of copper carbonate should be used at a heavier rate than is usually recommended for pure copper carbonate. The inoculated, treated, and untreated seed was sown in rod rows in two replications at each of the 15 stations.

Each cooperator sent in a thermograph record of the daily temperature range and rainfall, from the date of sowing to the date of emergence, and samples of soil (in sealed containers) taken at each of these dates. These soil samples were tested for moisture content, water-holding capacity, and reaction. These data are presented in table 7. The data relating to infection are shown in table 8.

TABLE 7.—*Data relating to environmental conditions between the dates of sowing and emergence in experiments on bunt control in spring wheat at a number of stations, 1930*

Station	Mean air temperature	Water-holding capacity of soil	Soil saturation at time of—		Total rainfall	Hydrogen-ion concentration of soil	Period of emergence	Average infection in controls
			Sowing	Emergence				
	°C.	*Percent*	*Percent*	*Percent*	*Inches*	*pH*	*Days*	*Percent*
Arlington	5.5	35.0	67.0	56.5	1.01	5.87	19	8.2
Madison	11.9	30.0	41.7	64.1	2.19	5.67	9	1.1
Brookings	12.5	41.8	35.7	61.5	.74	6.67	10	4.9
St. Paul	6.1	49.3	44.6	47.6	----------	5.10	14	6.1
Redfield	----------	47.0	34.6	67.2	1.05	6.30	12	(¹)
Fargo	6.1	61.9	10.3	87.0	1.12	6.72	17	24.6
Dickinson	6.8	46.0	51.0	44.5	1.33	5.83	10	5.0
Langdon	9.2	64.6	31.7	63.3	2.45	6.57	11	²T
Moccasin	10.5	45.1	39.6	39.0	.06	7.93	9	13.8
Havre	11.0	40.4	33.8	40.3	.39	6.07	7	²T
Bozeman	10.6	45.5	51.5	32.7	.34	5.80	9	2.1
Aberdeen	11.1	35.1	50.3	35.2	²T	6.12	8	7.1
Moscow	10.5	48.1	44.5	41.5	.25	5.85	8	8.8
Logan	12.8	37.9	29.3	66.0	1.05	8.02	13	2.8
Moro	11.1	36.5	30.4	27.1	.0	6.15	11	25.3
Pullman	11.2	37.9	50.2	50.9	.4	5.94	12	22.8

¹ Plots ruined by wind-blown dust. ² T represents trace, or less than 0.1 percent.

Conditions during the spring of 1930 apparently were not so conducive to infection as in the previous year. At three of the stations, Madison, Langdon, and Havre, so little infection occurred in the controls that no data of value on bunt control were obtained. At Redfield the plots were ruined by wind-drifted soil. At the remaining stations the average percentages of total heads infected in the three varieties ranged from 2.1 to 25.3. As in the previous year, the fungicides varied somewhat in their effectivness at the different stations, despite the fact that the seed sown had been uniformly inoculated and treated. None of the fungicides reduced the amount of infection to less than 1 percent at every station. Taking the average percentage of bunted heads in all varieties at 12 stations as a basis for comparison the different treatments in the order of their effectiveness were formaldehyde, Coppercarb (3 ounces), Coppercarb (4 ounces), copper carbonate, basic copper sulphate, Coppercarb (2 ounces), Cuprojabonite, and Ceresan (table 8). Better results were obtained with Coppercarb when used at 3 ounces per bushel than at 2 ounces, but no advantage from a still heavier rate of application was apparent.

The only stations at which formaldehyde did not effect complete control were Moscow, Moro, and Pullman, suggesting either some recontamination or the possibility of some soil infestation at these places.

TABLE 8.—*Bunt control in Reward, Ceres, and Kota wheats grown from treated inoculated seed sown in paired rod rows at 12 stations, 1930*

Variety and seed-treatment compound	Rate per bushel	Bunted heads at— Arlington	Brookings	St. Paul	Fargo	Dickinson	Moccasin	Bozeman	Aberdeen	Moscow	Logan	Moro	Pullman	All stations	
	Oz.	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*No.*	*Pct.*
Reward:															
Control	----	5.58	5.62	2.18	21.00	2.93	6.08	1.59	5.50	6.59	2.02	20.09	18.28	1,331	7.80
Ceresan	2	.0	.0	.0	3.71	.0	.71	.0	.0	.74	.0	1.75	1.26	113	.66
Copper carbonate	2	.0	.0	.0	.43	.0	.0	.0	.0	.31	.0	.38	.11	19	.11
Coppercarb	2	.0	.31	.05	.50	.0	.43	.0	.17	.90	.0	.80	.60	48	.29
Do	3	.0	.0	.05	.0	.0	.29	.0	.0	.48	.07	1.29	.0	26	.15
Control	----	5.24	5.12	3.44	20.50	1.80	7.77	3.21	6.41	5.60	.81	19.11	16.01	1,230	7.40
Coppercarb	4	.0	.0	.0	.57	.0	.0	.0	.0	.63	.0	1.14	.0	31	.19
Cuprojabonite	3	.0	.0	.0	.64	.0	1.14	.0	.22	.85	.0	.0	.34	40	.30
Basic copper sulphate	2	.0	.0	.0	.71	.0	.43	.0	.06	.42	.0	.43	.0	27	.16
Formaldehyde 1:320	(1)	.0	.0	.0	.0	.0	.0	.0	.0	.30	.0	.0	.17	13	.08
Ceres:															
Control	----	8.73	5.63	8.96	36.59	8.86	16.60	3.39	9.70	12.33	1.96	37.36	24.00	2,071	14.24
Ceresan	2	.0	.28	.0	5.31	.45	.92	.25	.33	.71	.7	4.31	2.47	177	1.27
Copper carbonate	2	.0	.0	.0	.54	.0	1.08	.08	.50	.10	.0	.29	.0	25	.18
Coppercarb	2	.0	.0	.21	1.92	.0	1.08	.17	.25	.28	.1	.53	.0	50	.35
Do	3	.0	.0	.0	.42	.0	.46	.0	.09	.10	.0	.0	.0	11	.08
Control	----	11.33	7.65	7.55	35.06	6.64	15.54	2.10	7.15	10.67	5.02	33.25	27.13	2,105	14.37
Coppercarb	4	.0	.0	.0	.25	.0	.46	.0	.0	.15	.1	.0	.20	14	.10
Cuprojabonite	3	.0	.0	.0	.67	.0	1.54	.25	.42	.15	.2	.38	.20	38	.27
Basic copper sulphate	2	.0	.0	.14	.50	.0	.31	.0	.60	.35	.0	.63	.25	36	.25
Formaldehyde 1:320	(1)	.0	.0	.0	.0	.0	.0	.0	.0	.13	.0	.63	.0	18	.05
Kota:															
Control	----	8.81	2.70	7.46	17.94	4.68	19.59	1.43	8.43	10.22	5.40	23.95	25.94	1,492	11.34
Ceresan	2	.0	.0	.15	1.64	.44	2.44	.0	.58	1.91	.10	2.17	.47	99	.79
Copper carbonate	2	.0	.0	.08	.36	.0	1.11	.0	.25	2.38	.0	1.17	.24	66	.53
Coppercarb	2	.0	.0	.0	.73	.0	1.11	.0	.58	1.64	.0	.33	.0	61	.41
Do	3	.0	.0	.29	.09	.0	1.11	.0	.17	1.41	.0	.67	.0	40	.32
Control	----	9.52	2.37	7.26	16.64	4.90	17.05	.84	6.30	7.39	1.28	16.99	24.50	1,235	9.55
Coppercarb	4	.0	.0	.0	.80	.0	.0	.0	.33	1.98	.0	.33	.0	51	.41
Cuprojabonite	3	.0	.0	.21	1.40	.0	1.78	.0	.83	1.70	.0	.67	.35	75	.64
Basic copper sulphate	2	.0	.0	.21	.50	.0	1.33	.0	.0	2.11	.0	.50	.0	56	.45
Formaldehyde 1:320	(1)	.0	.0	.0	.0	.0	0	.0	.0	2.15	.0	1.60	.06	52	.41

[1] Applied according to a modification of the Braun (2) method.

The data on environmental conditions during the period of emergence, as presented in table 7, fail to reveal any consistent relation between any of these conditions and the occurrence or control of bunt. Too many factors beyond the control of the investigator entered into the field experiments to make it possible to draw definite conclusions regarding the influence of any one of them. Experiments dealing with the influence of certain soil factors on the development and control of bunt are discussed later.

During the season of 1931–32, in extensive seed-treatment experiments at Arlington Farm, seed of Purplestraw wheat was inoculated with bunt at three spore dosages: 1 to 75, 1 to 250, and 1 to 500. The materials used as fungicides were the following: Two brands of high-grade copper carbonate, Coppercarb, Smut Bane, dehydrated copper sulphate, basic copper sulphate, copper phosphate, copper oxychloride, Ceresan, 1 and 2 percent ethyl mercuric phosphate, and a number of other experimental dusts.

Conditions after sowing apparently were not conducive to heavy infection, for the infection percentages in the controls averaged only 18, 6, and 4 percent for the three spore dosages, respectively, and all the materials referred to controlled bunt perfectly without impairing germination. Detailed data are therefore not given.

In the spring of 1933 the appearance on the market of New Improved Ceresan (5-percent ethyl mercuric phosphate) and the resultant numerous inquiries regarding its merits led to experiments designed to determine its effect on germination and bunt control. Seed of Ceres and Mindum wheat, inoculated at a 1 to 100 spore dosage with bunt collected from these varieties, were treated with copper carbonate at 2 ounces per bushel and with New Improved Ceresan at ½, 1, and 2 ounces per bushel. A portion of the seed was sown at Arlington Farm 7 days, another portion at Fargo, N. Dak.,[7] 4 days, and a third lot at Fargo 40 days after treatment. Bunt infection data are presented in table 9.

TABLE 9.—*Control of bunt in Ceres and Mindum wheats grown from seed inoculated at a 1-to-100 spore dosage and treated 4, 7, or 40 days before sowing, 1933*

Location of experiment	Treatment of seed			Total and infected heads in—					
	Material used	Rate per bushel	Storage after treatment	Ceres			Mindum		
				Total	Infected		Total	Infected	
		Oz.	*Days*	*No.*	*No.*	*Pct.*	*No.*	*No.*	*Pct.*
Fargo, N. Dak.	None			972	130	13.4	691	32	4.6
	Copper carbonate	2	4	1,230	1	.1	819	0	.0
	New Improved Ceresan	½	4	1,124	62	5.5	704	7	1.0
	do	1	4	1,059	2	.2	831	1	.1
	do	2	4	1,049	2	.2	821	0	.0
Arlington, Va.	None			1,225	443	36.2	1,230	504	41.0
	Copper carbonate	2	7	1,278	3	.2	1,265	4	.3
	New Improved Ceresan	½	7	1,262	1	.1	1,248	1	.1
	do	1	7	1,254	0	.0	1,236	0	.0
	do	2	7	1,127	0	.0	1,135	0	.0
Fargo, N. Dak.	None			1,241	119	9.6	875	25	2.9
	Copper carbonate	2	40	1,182	4	.3	736	1	.1
	New Improved Ceresan	½	40	1,211	2	.2	863	0	.0
	do	1	40	1,077	0	.0	809	0	.0
	do	2	40	973	0	.0	761	0	.0

Bunt control was excellent in all cases with the exception of the one-half-ounce-per-bushel treatment applied 4 days before sowing at Fargo. This failure may be attributed to the difficulty of accurately applying the required amount of dust to the small quantities of seed. Excellent control was effected at Arlington Farm, where the percentage of infection in the controls was much higher than it was at Fargo. The effect of treatment with New Improved Ceresan on germination will be discussed later.

Additional experiments with a number of fungicides were carried out at Arlington Farm during the period from 1933 to 1935. The pertinent data are presented in table 10. Presented here also are data regarding the effect of the various fungicides on germination and yield, which will be discussed later.

[7] The writer gratefully acknowledges the assistance of W. E. Brentzel, who did part of the treating and all of the sowing at Fargo and also recorded the data.

TABLE 10.—*Effect of seed treatment on germination, bunt control, and yield in Purplestraw wheat grown from seed inoculated with bunt at a 1-to-100 spore dosage and sown on the Arlington Experiment Farm, 1933–35*

Seed-treatment compound	Rate per bushel	Germination			Bunted heads			Yield per acre		
		1933	1934[1]	1935[2]	1923	1934	1935	1933	1934	1935
	Oz.	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Bu.*	*Bu.*	*Bu.*
Uninoculated, untreated	------	89	91	85	0.0	1.1	1.1	28	31	22
Inoculated, untreated	------	86	94	82	4.5	91.0	77.0	24	10	12
Copper carbonate	2	91	90	92	.1	.7	.2	28	30	23
Coppercarb	3	90	89	88	.2	1.3	.2	25	30	24
Smut Bane	3	88	83	90	.2	.8	.4	27	30	25
Cuprojabonite	3	92	93	92	.3	2.3	.8	25	31	24
Copper oxychloride	2	90	88	90	.0	1.1	.5	24	28	24
Copper sulphate dehydrated	2	87	87	89	.0	.6	.2	27	30	19
Copper sulphate diluted	3	84	80	------	.2	2.2	------	27	32	------
Copper sulphate monohydrate	2	------	------	83	------	------	.1	------	------	17
Copper sulphate basic	2	------	90	92	------	.5	.2	------	31	21
Cupric oxide	2	------	87	------	------	6.8	------	------	28	------
Cuprous oxide (80 percent copper)	2	------	------	91	------	------	.6	------	------	23
Cuprous oxide (40 percent copper)	3	------	------	89	------	------	.3	------	------	21
Cuprous oxide (20 percent copper)	3	------	------	86	------	------	.5	------	------	18
Ansul Dust	3	84	86	------	1.9	83.7	------	23	15	------
Smuttox	3	------	84	44	------	30.6	8.0	------	16	10
P. A. C. Dust	3	------	72	------	------	27.2	------	------	10	------
Formaldehyde 1:320	(3)	------	90	60	------	1.2	1.3	------	27	15
Ceresan	2	86	82	------	.0	.1	------	24	26	------
E. M. P. 980[4]	2	88	------	------	.0	------	------	30	------	------
E. M. P. 1,100[4]	2	80	------	------	.0	------	------	22	------	------
New Improved Ceresan	½	------	90	92	------	.3	.3	------	26	24
Do.	1	------	87	------	------	T[5]	------	------	24	------
Sanoseed	2	------	92	------	------	7.6	------	------	28	------
Grainaide	2	------	87	------	------	30.9	------	------	14	------

[1] Germination test made 12 days after treatment.
[2] Germination test made 4 days after treatment.
[3] Modified Braun (2) method used in 1934 to prevent injury; regular formaldehyde treatment used in 1935.
[4] Ethyl mercuric phosphate.
[5] T represents trace, or less than 0.1 percent.

Purplestraw wheat, inoculated with bunt at a spore dosage of 1 to 100, was used in these tests. Altogether, 21 materials were compared as to their fungicidal effectiveness. Some of them were used at different dilutions or different rates of application. Six were included in each of the 3 years' tests, seven in each of 2 years, and eight were tested for only 1 year. After treatment with the different materials the seed was sown in rod rows replicated 10 times in 1933 and 7 times each in 1934 and 1935.

In 1933, conditions were not favorable for infection, as only 4.5 percent of the heads in the controls were bunted. All the treatments except the formaldehyde dust (Ansul Dust) effected satisfactory bunt control.

In 1934, an average infection of 91 percent in the controls was reduced to less than 1 percent by Ceresan, New Improved Ceresan, basic copper sulphate, dehydrated copper sulphate, copper carbonate, and Smut Bane and to less than 2.5 percent by all the other copper dusts except cupric oxide, which allowed 6.8 percent infection. Sanoseed, Grainaide, and the formaldehyde dusts, Ansul Dust, Smuttox, and P. A. C. Dust, also failed to control bunt satisfactorily. In 1935, with one exception, all the dusts used reduced infection from an average of 77 percent in the controls to less than 1 percent. Formaldehyde dust (Smuttox) not only failed to control bunt but severely impaired germination and reduced yield, as will be mentioned later.

The results of experiments with many of the fungicidal dusts listed under Compounds Used as Fungicides do not merit publication because these dusts failed to show sufficient promise as practicable fungicides. Among the commercial dusts of foreign make and not available commercially in the United States, Höchst, made in Germany, and Vitrioline, made in France, proved very efficient and satisfactory fungicides for bunt control in the experiments in which they were included. Among American-made dusts, Wa Wa Dust, while effective in bunt control, was very injurious to seed and, in the tests previously described, was found to be highly corrosive to metal. Mercury C, Semesan, and Ceresan were moderately effective, but all three were too expensive because of their high mercury content. Sterocide was wholly ineffective and Sanoseed relatively so. Most of the other mercury dusts were injurious to the seed, highly corrosive, unstable, ineffective in bunt control, too expensive, or unsuitable for fungicides in other respects. Resorcin, combined with crystal violet, was effective but objectionable because of its coloring propensity.

Five iodine dusts were tried, but none reduced the percentage of bunt sufficiently to qualify as a bunt fungicide. Sayre and Thomas (*38*) reported control of oat smuts with iodine dust in 1928, but Horsfall (*22*) found it unsatisfactory for this purpose, while Dillon Weston (*7*) found it ineffective for controlling bunt. In addition to this, its corrosive action and other undesirable qualities should eliminate it from further consideration as a practical seed disinfectant.

Such materials as sulphur, paraformaldehyde, quinone derivatives, cresol, and naphthalene compounds were not consistently effective, although at times some of them seemed promising.

Copper compounds, as a class, seem to be specifically toxic to bunt spores, as most of the more common copper salts effected a pronounced reduction in the percentage of bunt. In preliminary experiments such compounds as copper oxychloride, copper oxalate, copper chloride, and others seemed to be slightly superior to copper carbonate in bunt control, but when they were included in more extensive tests their shortcomings became apparent.

In table 11 is presented a summary of the results obtained with a number of the fungicidal dusts used in the foregoing experiments. This table shows, for each of these compounds, the number of seasons it was tested, the total number of bunted heads grown from seed treated with it, the total number of bunted heads grown from an equal quantity of untreated seed, and finally the index of efficiency or control. The latter figure is the result of the formula:

$$100-\left[\frac{\text{smutted heads from treated seed}}{\text{smutted heads from untreated seed}}\times 100\right]$$

Where several brands of a dust were used in one experiment, the average number of bunted heads for all the brands was taken. The significance of the control index shown for any fungicide is to a great extent contingent upon the number of experiments in which that fungicide was used. For example, Vitrioline, which shows a very high index of control, was included in only a few experiments and therefore should not be considered superior to copper carbonate, which was used in 7 years' experiments and under a much greater range of conditions. Although copper chloride, one of the more frequently used dusts, rates high in effectiveness, it is ruled out on account of its hygroscopic nature and corrosive action on metal, as determined in the corrosion tests previously described. Copper oxychloride, also very effective, possesses this undesirable feature to a less degree than does copper chloride. Copper phosphate and red copper oxide were fairly effective. Copper oxalate, while very satisfactory as regards its physical and chemical properties, proved slightly inferior to copper carbonate in bunt control.

TABLE 11.—*Relative fungicidal efficiency of a number of materials in the control of bunt in experiments extending over periods of 1 to 7 years*

No.	Fungicide	Years tested	Total bunted heads from seed—		Index of efficiency
			Not treated	Treated	
1	Formaldehyde (1:320 solution)	7	34,143	187	99.5
2	Copper carbonate, pure	7	41,491	469	98.9
3	Copper carbonate, diluted	7	36,675	791	97.9
4	Copper sulphate, dehydrated	6	18,335	372	98.0
5	Copper sulphate, basic	5	13,668	130	99.0
6	Copper oxychloride	5	21,032	204	99.0
7	Formaldehyde dusts	4	3,020	1,690	44.0
8	New Improved Ceresan	3	7,417	30	99.6
9	Copper oxalate	3	25,799	547	97.9
10	Copper phosphate	3	3,730	36	97.7
11	Ceresan	3	28,912	1,075	96.3
12	Vitrioline	2	2,675	4	99.9
13	Copper chloride	2	13,832	102	99.3
14	Höchst	2	15,799	153	99.0
15	Cuprohol	2	9,232	306	96.7
16	Sanoseed	2	2,435	264	89.2
17	Sulphur	2	3,711	708	80.9
18	Copper-beta-naphthol	2	15,576	3,088	80.2
19	Abavit B	1	708	0	100.0
20	S. F. A. 225	1	708	0	100.0
21	S. F. A. 225 V	1	708	0	100.0
22	Wa Wa Dust	1	708	0	100.0
23	Crystal violet in resorcin	1	708	0	100.0
24	Copper (cuprous) oxide	1	2,320	15	99.4
25	Mercury C	1	708	21	97.0
26	Semesan	1	708	23	96.8
27	Copper (cupric) oxide	1	2,690	326	87.9
28	Iodine dusts	1	1,744	353	79.8
29	Sterocide	1	222	108	51.4
30	Paraformaldehyde dusts	1	400	225	43.8
31	Cuprous cyanide	1	444	356	19.8

Basic copper sulphate, such as is used extensively in dusting fruit and vegetable foliage, seems to be slightly superior to copper carbonate in bunt control. It also may be somewhat cheaper, but slightly more disagreeable to apply.

New Improved Ceresan in 3 years' experiments was very satisfactory not only in bunt control but in its effect on germination when properly applied. In 2 years' tests it was not superior to the other dusts in its effect on yield (table 10). It is cheaper than most of the other dusts, it is more easily applied, has no undesirable effect on drill action or rate of sowing, and, as will be shown later, it protects the seed against organisms other than bunt more effectively than do copper carbonate and formaldehyde. Its chief disadvantage lies in the injury it may cause to the viability of the seed or vigor of the seedlings if it is applied at an excessive rate or if the treated seed is improperly stored (*25*). The results obtained with New Improved Ceresan stress the necessity of applying it at not more than one-half ounce per bushel. If the treated seed is to be stored for several weeks, less than one-half ounce per bushel may be used (*25*). Like other fungicidal dusts that owe their effectiveness to the volatile fumes given off, it requires less thorough application than do dusts like copper carbonate, which, to be effective, must come in actual contact with the spores. This was demonstrated by the following experiment: A bushel of Purplestraw wheat was infected with bunt spores at a 1 to 100 spore dosage. Five 15-g lots of this seed were placed, untreated, in small cheesecloth bags and buried in the bushel of infected seed that had been treated with New Improved Ceresan at the rate of one-half ounce per bushel. These different lots were then sown in rod rows 2 days later. Infection from the small lots of seed ranged from 0.4 to 1.2 percent as compared with 0 to 0.5 percent from seed treated in bulk and 77 percent from untreated seed.

On the other hand, full advantage can be taken of the fineness and fluffiness of relatively inert dust fungicides only by thoroughly mixing the dusts with the seed, so that the latter is subjected to a veritable dust fog, and as a result each kernel becomes completely coated. Inadequate mixing fails to do this and hence allows many of the bunt spores adhering to the seed to escape contact with the fungicide. Similar results may follow the use of an insufficient quantity of the dust. The quantity required depends upon the spore load and upon the relative amount of toxic ingredient in the dust. High-grade copper carbonate at a rate of 2 ounces per bushel or the diluted brands at 3 ounces per bushel, for example, usually are effective when properly applied unless the spore load is very heavy, in which case heavier applications are advisable (*31*).

Extensive surveys in the spring wheat area of the United States (*16*) led to the conclusion that unsatisfactory bunt control with dust fungicides on many farms is largely caused by failure to apply the dusts properly.

The results of the experiments on bunt control point to the following general conclusions: When seed wheat carries a light or medium spore load, bunt infection generally can be effectively controlled by properly treating the seed with any one of a number of fungicidal dusts. Among these are New Improved Ceresan (5-percent ethyl mercuric phosphate), copper carbonate, both high grade and extended, basic copper sulphate, dehydrated or monohydrate copper sulphate, copper oxychloride, copper oxalate, red copper oxide (full strength or diluted), copper chloride, copper phosphate, and a number of other less commonly used copper dusts. These dusts, to be effective, must be dry and finely powdered. This practically eliminates the chlorides and some of the sulphates from consideration for ordinary farm use, since they take up moisture from the air and tend to lump unless kept dry in a tightly closed container. Few of the above copper dusts at present are on the market as dust fungicides.

When the seed carries a rather heavy spore load some of the above materials may fail to afford adequate control of bunt and it may be advisable to use only New Improved Ceresan, high-grade copper carbonate, or basic copper sulphate. The first should be applied at the rate of one-half ounce per bushel, preferably at least several days before sowing. The two latter dusts should be applied at the rate of 2, or, for very smutty seed, preferably 3 ounces per bushel, and only those brands should be used that are made specifically for seed-treatment purposes. The formaldehyde treatment, while effective, frequently causes seed injury, does not prevent recontamination, and fails to furnish to the seed any protection against soil-borne organisms.

EFFECT OF FUNGICIDES ON GERMINATION

In addition to fungicidal effectiveness, a further important consideration in determining the relative merits of different fungicides is their effect on seed viability and seedling emergence. Extensive laboratory and greenhouse studies of this nature were made in connection with the field experiments herein described. Since the data thus obtained are rather voluminous and pertain largely to materials tested only in preliminary experiments and subsequently discarded, they will not be presented in detail but will be briefly summarized. Some data relating to the effects of treatment on germination or stand are included in tables dealing with other phases of the subject.

In these experiments the better dust treatments usually increased the percentage of germination. High-grade copper carbonate in 24 tests increased it 10 percent. Ceresan, low-grade copper carbonate, and basic copper sulphate in 10 tests improved the average germination 12, 11, and 10 percent, respectively. Similar results followed the use of copper chloride, copper oxychloride, copper oxalate, and Höchst. Seed treated with the above-mentioned eight dusts and stored for a year showed an average increase of 15 percent in the percentage of germination as compared with untreated seed similarly stored. Increases in the percentages of germination also usually followed the use of other inorganic copper compounds, Vitrioline, Cuprobol, sulphur, and Semesan. Germination was not improved and usually impaired by the use of iodine dusts, copper beta-naphthol, Abavit B, Wa Wa Dust, phenyl mercuric acetate, formaldehyde dusts, and liquid formaldehyde.

In some of the earlier experiments New Improved Ceresan was observed to have an inimical effect on the viability of the seed if applied at a rate greater than one-half ounce per bushel. Ceres and Mindum, sown the day after treatment with New Improved Ceresan at the rate of 2 ounces per bushel, germinated 76 and 66 percent, respectively, compared with 87 and 88 percent in the respective controls. When sown 7 days after treatment the two varieties germinated 48 and 51 percent, respectively. When applied at the rate of 1 ounce per bushel to seed 1 day before sowing, germination was improved in both varieties, but when applied 7 days before sowing the percentage germination was reduced 8 percent. When this dust was applied at the recommended rate of one-half ounce per bushel germination was improved in both cases. The injury resulting from a heavier application stresses the advisability of adhering closely to the directions on the container.

Additional data on the effects of New Improved Ceresan on germination were obtained by applying the dust at ½, 1, and 2 ounces per bushel to 3 half-bushel lots of Purplestraw wheat, which were then covered with a canvas for 24 hours. A fourth lot was treated with copper carbonate at the rate of 2 ounces per bushel. After 24 hours part of each lot was placed in a thin cotton sack while the rest remained covered. Germination tests were made 2 days, 12 days, 22 days, 4 months, and 17 months after treatment. The data are shown in table 12. They indicate that New Improved Ceresan applied at one-half ounce per bushel to Purplestraw wheat several months before sowing will not impair germination if the treated seed is properly stored, but that a heavier rate of application may impair the viability of the seed.

Table 12.—*Effect of different periods of storage on germination of Purplestraw wheat treated with copper carbonate or New Improved Ceresan, 1933–34*

Treatment			Emergence from seed stored for—				
Compound used	Rate per bushel	Subsequent storage conditions	2 days	12 days	22 days	4 months	17 months
	Ounces		*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
None	--------	In thin cotton sacks.	74	72	79	72	68
Copper carbonate	2	In thin cotton sacks.	93	90	92	82	75
New Improved Ceresan	½	In thin cotton sacks.	86	88	86	83	81
Do	1	In thin cotton sacks.	88	77	74	48	45
Do	2	In thin cotton sacks.	82	51	51	30	25
None	--------	Under heavy canvas.	74	71	73	79	68
Copper carbonate	2	Under heavy canvas.	93	91	91	85	78
New Improved Ceresan	½	Under heavy canvas.	87	85	88	81	78
Do	1	Under heavy canvas.	85	81	68	45	40
Do	2	Under heavy canvas.	81	64	40	20	24

In the fall of 1935, 55 lots of spring wheat were collected at various points in the hard spring wheat area for the purpose of making germination studies.[8] Many of these lots were shriveled or of light weight because of the wheat-rust epidemic and the prevailing dry hot weather before the crop matured. Separate portions of each of these seed lots were treated with New Improved Ceresan and copper carbonate and sown in the greenhouse 1, 7, 42, and 360 days after treatment. Untreated seed also was sown for comparison. The data are summarized in table 13. In general, when the seed was sown the day after treatment New Improved Ceresan caused a pronounced increase in the percentage of germination as compared with that of untreated seed, the average increase for all lots being 17.8 percent. The average increase in germination following the use of copper carbonate was only 2.7 percent. As the period after treatment was prolonged, successive germination tests showed a general decrease in the benefits derived from treatment with New Improved Ceresan and an apparent increase in benefits from treatment with copper carbonate. After a year's storage the average germination of seed treated with New Improved Ceresan was decreased 5.6 percent, while that of seed treated with copper carbonate was increased 15.3 percent as compared with the germination of untreated seed. Altogether, after the 55 lots of seed had been stored for 1 year there were 15 increases and 35 decreases in germination recorded for seed treated with New Improved Ceresan, while there were 52 increases and only 2 decreases in germination recorded for seed treated with copper carbonate as compared with untreated seed. The relative test weight of the different seed lots seemed to bear no consistent relation to the percentage of germination or to their response to seed treatment. Seed of low test weight, however, produced spindling seedlings which developed more slowly than those from plumper grain.

[8] Leukel, R. W. Germination and emergence in spring wheats of the 1935 crop. U. S. Dept. Agr., Bur. Plant Indus., Div. Cereal Crops and Diseases [Unnumb. Pub.] 20 pp. 1936. [Mimeographed.]

TABLE 13.—*Effect of seed treatments and different periods of storage after treatment on germination in spring wheat*

Variety	Lots tested	Range in bushel weight	Length of storage period	Average germination from seed— Not treated	Average germination from seed— Treated with— New Improved Ceresan	Average germination from seed— Treated with— Copper carbonate	Increase or decrease following treatment with— New Improved Ceresan: Amount	New Improved Ceresan: Percent	Copper carbonate: Amount	Copper carbonate: Percent
	Number	*Pounds*	*Days*	*Percent*	*Percent*	*Percent*	*Amount*	*Percent*	*Amount*	*Percent*
Mixed	24	40 to 61	1	76	85	73	9	11.8	−3	−3.9
			7	83	91	86	8	9.6	3	3.6
			42	80	81	82	1	1.3	2	2.5
			360	75	63	83	−12	−16.0	8	10.7
Ceres	6	46 to 60	1	81	92	83	11	13.6	2	2.5
			7	84	94	91	10	11.9	7	8.3
			42	82	90	92	8	9.8	10	12.2
			360	79	78	89	−1	−1.3	10	12.7
Marquis	3	42 to 59	1	67	82	72	15	22.4	5	7.5
			7	73	88	82	15	20.5	9	12.3
			42	75	77	82	2	2.7	7	9.3
			360	66	64	78	−2	−3.0	12	18.2
Kubanka	8	42 to 59	1	69	87	75	18	26.1	6	8.7
			7	70	83	74	13	18.6	4	5.7
			42	65	79	77	14	21.5	12	18.5
			360	68	72	82	4	5.9	14	20.6
Mindum	5	54 to 60	1	69	87	79	18	26.1	10	14.5
			7	64	84	78	20	31.3	14	21.9
			42	65	80	79	15	23.1	14	21.5
			360	66	77	85	11	16.7	19	28.8
Miscellaneous durums	7	50 to 61	1	65	83	73	18	27.7	8	12.3
			7	70	77	72	7	10.0	2	2.9
			42	65	75	75	10	15.4	10	15.4
			360	69	67	80	−2	−2.9	11	15.9
Average	--------	--------	1	73	86	75	13	17.8	2	2.7
			7	78	88	82	10	12.8	4	5.1
			42	75	81	82	6	8.0	7	9.3
			360	72	68	83	−4	−5.6	11	15.3

The gradual decrease in benefits derived from treatment of the seed with New Improved Ceresan after prolonged storage of the treated seed may be due in part to the dissipation of the volatile ingredient which, when the seed is sown shortly after treatment, protects it from the attacks of soil organisms. It also is apparent that exposure of some seed lots to the fumes of this material for a whole year results in a certain degree of injury to the viability of the seed and in abnormal development of the seedlings.

Portions of 29 of the above-mentioned seed lots also were treated with formaldehyde and periodic germination tests were made. The average germination of formaldehyde-treated seed was decreased 33, 25, and 66 percent after storage for 1, 7, and 42 days, respectively, as compared with that of untreated seed. Much of this injury was due to the high percentage of cracked and chipped kernels.

Seeds from the five lots showing the greatest improvement in germination after treatment with New Improved Ceresan and some other mercurials were found, upon plating on nutrient agar, to harbor organisms capable of attacking the hydrolyzed food material in the sprouting seed, thus arresting germination and preventing emergence. The marked improvement in emergence from these seed lots after treatment with mercurials such as New Improved Ceresan is attributed to the elimination of these seed-borne organisms. Copper carbonate is less effective in this respect, probably because of its relative insolubility.

FACTORS AFFECTING THE EFFICIENCY OF DUST FUNGICIDES

In the literature on bunt control there are many conflicting conclusions by different investigators relative to the fungicidal efficiency and general merits of certain materials tested as fungicides. These seemingly contradictory reports may have been due to differences in the physical or chemical properties of supposedly identical dusts or to differences in the conditions under which the dusts were used in the experiments. That is, satisfactory results from the use of a dust fungicide may depend largely on one or more of the following factors: (1) The chemical composition of the dust fungicide used. This includes the relative proportions of the different ingredients and the percentage and kind of inert filler used; (2) the physical condition of the dust, its relative fineness, fluffiness, dryness, etc. (*31*, *48*); (3) the method and thoroughness of applying the dust to the seed (*16*); (4) the rate of application; (5) the length of the period between treating the seed and sowing it and the conditions of storage during that period (*20*, *25*); (6) soil conditions which may favor either the action of the fungicide or the parasite to be controlled (*5*, *9*, *19*, *26*, *37*, *43*, *47*, *48*, *49*, *50*, *52*); and (7) the presence of bunt balls in the seed or bunt infestation in the soil.

CHEMICAL COMPOSITION AND PHYSICAL CONDITION

The composition of proprietary fungicides on the market occasionally is changed by the manufacturers without such changes being indicated on the container. This may lead to seeming disagreements in the results of different investigators supposedly using the same fungicides. It is highly desirable that the chemical composition of such preparations be stated on the container and that this statement of contents be changed to correspond with any change made in the composition of the product, as suggested by Koehler (*25*).

The effectiveness of a dust fungicide may be governed largely by its physical condition. Two dust disinfectants of approximately the same chemical composition may differ widely in their relative effectiveness as bunt fungicides, because one of them may be too coarse to coat the seed adequately with dust. That extreme fineness is one of the chief requisites of a good dust fungicide has been demonstrated in experiments with copper dusts. Mackie and Briggs (*31*) concluded that copper carbonate for fungicidal use should be sufficiently fine to allow at least 99 percent in aqueous suspension to pass through a 200-mesh sieve. Twentyman (*48*), by means of an air-flotation apparatus, divided each of several commercial copper powders into six fractions based on particle size. He found the finer grades much more effective in bunt control than the coarser ones. He also found that the apparent relative density of any one of the six fractions was a convenient measure of its fineness; that is, the coarser the material the greater was its density. Extreme fineness and resultant fluffiness and low density in a dust greatly enhances its covering property and consequently its fungicidal effectiveness. The physical properties of copper carbonate, for example, may be more important in relation to its fungicidal effectiveness than are certain differences in its chemical composition, which varies somewhat with the method of making it. A product of fairly constant composition can be obtained repeatedly by mixing constant given quantities of copper sulphate, sodium hydroxide, and sodium carbonate solutions of constant concentrations.

The same relative quantities or concentrations of the solutions are not always used, however, and since variations in these respects are reflected by a change in the ratio of copper to carbon dioxide in the resulting product it seemed desirable to determine if this ratio is a factor in the efficiency of copper carbonate as a bunt fungicide. The following experiments accordingly were conducted.

Several lots of copper carbonate were made [9] by mixing solutions of copper sulphate, sodium carbonate, and sodium hydroxide in different proportions and concentrations. Stirring was accomplished by drawing a current of air through the solution, after which the flocculent precipitate was allowed to settle. The resulting products were washed by decantation until tests showed absence of sulphate in the supernatant liquid. The precipitates were dried at 100° C., ground fine enough to pass through a 200-mesh sieve, and then analyzed. These different lots of copper carbonate were applied at the rate of 2 ounces per bushel to Purplestraw wheat, inoculated with bunt at a 1 to 100 spore dosage. Two hundred and fifty seeds per rod row were sown in five replications. Germination data were obtained in the field and in the greenhouse. Since infection in the control rows was too light to test the fungicidal efficiency of the dusts adequately, the field experiments on bunt control were repeated during 2 successive years. The results are shown in table 14.

TABLE 14.—*Germination, yield, and bunt control in Purplestraw wheat grown from bunt-inoculated seed, treated with copper carbonate dusts of different composition, and sown in rod rows, Arlington Experiment Farm, 1927–30*

Composition of copper carbonates used				1927–28					1928–29, bunted heads		1929–30, bunted heads	
Copper	Carbon dioxide	Sulphur trioxide	Copper-carbon dioxide	Germination in— Field	Germination in— Greenhouse	Acre yield	Bunted heads					
Pct.	*Pct.*	*Pct.*	*Ratio*	*Pct.*	*Pct.*	*Bu.*	*No.*	*Pct.*	*No.*	*Pct.*	*No.*	*Pct.*
(1)	(1)	(1)	(1)	73	92	46	304	11.7	1,025	73.0	2,787	34.8
55.65	5.14	4.37	1:0.133	88	94	50	0	.0	3	.1	10	.1
54.83	5.62	3.43	1:0.148	90	94	53	0	.0	0	.0	9	.1
44.25	5.62	11.07	1:0.153	89	93	48	3	.1	8	.4	5	.1
52.73	10.52	1.20	1:0.288	86	100	52	0	.0	2	.1	16	.2
(1)	(1)	(1)	(1)	74	91	41	462	18.4	2,300	84.0	3,243	41.2
25.23	6.20	28.25	1:0.355	90	93	53	4	.3	15	.7	4	.1
54.80	11.65	4.58	1:0.359	89	90	54	0	.0	12	.6	6	.1
54.33	15.59	3.36	1:0.415	89	95	49	0	.0	6	.3	4	.1
32.43	15.26	16.55	1:0.680	89	100	54	0	.0	8	.4	8	.1

[1] Untreated control.

Under the conditions of these experiments neither the range in the copper-carbon dioxide ratio nor in the percentage of copper affected the fungicidal effectiveness of the copper carbonate. In a subsequent series of experiments, five different commercial brands of copper carbonate containing 50 percent and four containing 18 to 20 percent of copper were compared as to their fungicidal effectiveness over a period of 3 years. All the dusts were applied at the rate of 2 ounces per bushel. When the infection in the controls ranged from 1 to 23 percent no appreciable differences in the results from any of the

[9] These samples were made and tested by O. A. Nelson, chemist, Insecticide Division, Bureau of Chemistry and Soils, to whom acknowledgment is made.

brands were obtained. When more than 50-percent infection appeared in the controls, the high-grade dusts were slightly more effective. Similar results have been reported by Fromme and others (*13*). Mackie and Briggs (*31*) diluted separate portions of high-grade copper carbonate with different percentages of calcium sulphate or calcium carbonate, so that the resulting preparations contained 37.5, 25, or 12.5 percent, respectively, of copper. Fungicidal effectiveness was greatly reduced as a result of these dilutions. The nature of the diluents used may have been an important factor in the results. Thomas and others (*45*), on the other hand, obtained good bunt control with a dust containing only 8.5 percent of copper.

The possible effect of exposure to the atmosphere on the fungicidal efficiency of two lots of high-grade copper carbonate and two lots of diluted copper carbonate (18 to 20 percent copper) was studied. One lot of each had been freshly made and the other had been stored in the laboratory in an open container for 4 years. These different dusts were applied at 2½ ounces per bushel to Purplestraw wheat inoculated at a spore dosage of 1 to 250. The seed was sown in rod rows replicated 10 times for each of the four dusts. With 20-percent bunt infection from untreated seed, complete control was obtained in all cases. Age or exposure to the atmosphere apparently did not impair the fungicidal efficiency of the copper carbonates used in these experiments. Certain other dust fungicides, however, deteriorate rapidly on exposure to the air. This is especially true of those that give off fumes and thus disinfect the grain mostly before it is sown. The advantage of these dusts is that their effectiveness is largely independent of soil conditions after sowing. Their disadvantage lies in the uncertainty regarding their effectiveness unless they have been made shortly before being used.

PERIOD AND METHOD OF STORING TREATED SEED

In preliminary experiments it was found that dusts containing certain volatile materials were more effective in disease control if applied to the seed at least a day before sowing. This was especially true of dusts containing formaldehyde, iodine, naphthalene, paraformaldehyde, ethyl and methyl mercuric compounds, and some other volatile materials. In general, the longer the seed was stored after treatment with these materials the more thorough was the disinfection. The latter process was facilitated by covering the seed after treatment to confine the fumes, although this is not generally recommended for some dusts. Occasionally, seed injury resulted if the application was too heavy or if the seed remained covered too long. Apparently such injury is most likely to occur if the seed has a relatively high moisture content or is stored in a moist atmosphere after treatment.

Additional information was secured in an experiment in which various fungicidal dusts were applied to the seed at different intervals before seeding. The dusts used were copper carbonate, copper chloride, copper oxychloride, copper oxalate, Ceresan (2-percent ethyl mercuric chloride), Höchst (copper-arsenic-naphthol compound), and one containing 2 percent of ethyl mercuric phosphate. These were applied at 2 ounces per bushel to three lots of smutty Kota, Prelude, and Hard Federation wheats on February 8, March 8, and March 13, respectively. All three lots of seed were sown on March 13 shortly after the last lot had been treated. The storage periods were, therefore, 33 days, 5 days, and about 1 hour, respectively.

The infection from untreated seed ranged from 6 to 28 percent. Perfect control of bunt was obtained with all fungicides applied February 8 and March 8 and with the first four copper dusts applied just before sowing on March 13. Ceresan, Höchst, and ethyl mercury phosphate were not wholly effective in eliminating bunt when treating immediately preceded seeding, the average infection being 5, 3.2, and 6 percent, respectively. This showed the necessity of applying these materials to the seed at least a few hours before sowing.

Flor (*10*), in experiments with smutty seed treated September 8 with copper carbonate or formaldehyde, reports that "the effectiveness of the copper carbonate treatment decreased with each successive (weekly) sowing from 94.5 percent in the first to 64.8 percent in the 9th." The effectiveness of the formaldehyde treatment was fairly constant, ranging from 88.5 percent in the fourth sowing to 100 percent in the tenth. No satisfactory explanation is offered for the unsatisfactory control of bunt by copper carbonate in the later sowings. Similar experiments were carried out by the writer during the seasons of 1932–33 and 1933–34. In 1932, from October 3 to November 15, five periodic sowings were made of bunt-inoculated Purplestraw wheat treated with copper carbonate or formaldehyde either on September 27 or on the day the seed was sown. Untreated controls, both inoculated and uninoculated, were included. Six rod-rows of each were seeded both in noninfested soil and in soil infested with bunt spores at the time of sowing. The copper carbonate was applied at the rate of 4 ounces per bushel. The formaldehyde treatment used was similar to that employed by Flor (*10*). This consisted of soaking the seed in a 1:320 formaldehyde solution for 1 hour, after which it was covered 2 hours and dried. Soil acidity was corrected by a lime application of 4,000 pounds per acre.

Data on germination are given in table 15, together with infection data taken the following June. The treatment with formaldehyde caused severe injury, especially to the seed stored after treatment, as shown by the low percentages of emergence and also by the extremely poor stands.

TABLE 15.—*Effect of storing seed after treatment on the control of bunt in Purplestraw wheat grown from inoculated seed, treated, and sown periodically in noninfested and bunt-infested soil, 1932-33*

Soil- and seed-treatment compound [1]	Date applied	Average germination	Bunted heads from seed sown—				
			Oct. 3	Oct. 10	Oct. 24	Oct. 31	Nov. 15
		Pct.	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
In noninfested soil:							
Uninoculated, untreated		75	0.0	0.1	0.0	0.1	2.7
Inoculated, untreated		75	16.1	14.4	57.2	23.4	80.1
Copper carbonate	Sept. 27	77	.0	.1	2.4	.2	9.8
Do	([2])	81	.0	.0	1.4	.1	7.0
Formaldehyde	Sept. 27	34	.0	.0	.1	.0	1.7
Do	([2])	40	.0	.0	.0	.0	2.1
In infested soil:							
Uninoculated, untreated		74	5.2	53.9	63.8	17.5	83.4
Inoculated, untreated		70	25.5	65.1	70.6	51.6	90.0
Copper carbonate	Sept. 27	75	2.0	10.8	47.1	10.9	53.1
Do	([2])	75	2.3	22.0	33.7	15.2	41.7
Formaldehyde	Sept. 27	30	5.5	12.8	55.0	15.3	34.5
Do	([2])	48	5.5	26.2	52.2	16.1	51.8

[1] Copper carbonate was applied at 4 ounces per bushel; formaldehyde treatment was a 1-hour soak in a 1:320 solution; the grain was then drained, covered 2 hours, and dried.
[2] Treated on day seed was sown.

The results obtained from the two lots of seed treated with copper carbonate sown both in noninfested and infested soil indicate that the fungicidal effectiveness of copper carbonate was not significantly impaired by storing the seed after treatment.

In the fall of 1933 similar periodic sowings were made in noninfested soil only. Inoculated seed of Purplestraw wheat was treated with copper carbonate or formaldehyde on September 15 or on the day it was sown. The formaldehyde treatment was a modification of the Braun method (*2*). Included in each sowing was some of the seed that had been inoculated and treated with copper carbonate the previous year and also lots that were treated on the day sown. The seed was sown with a Columbia hand drill in rows 132 feet long, one such row being devoted to each seed lot on each date. The infection data are presented in table 16.

TABLE 16.—*Effect of storing seed after treatment on the control of bunt in Purplestraw wheat grown from inoculated seed treated and sown periodically in noninfested soil, 1933–34*

RESULTS OF TREATMENT

Seed-treatment compound [1]	Date applied	Bunted heads from seed sown—				
		Oct. 9	Oct. 16	Oct. 26	Nov. 10	Nov. 26
1932 seed:		*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
Uninoculated, untreated		0.0	0.0	1.1	0.3	1.7
Inoculated, untreated		3.2	5.2	25.7	56.8	51.2
Copper carbonate	Sept. 27, 1932	.0	.0	.3	.2	.2
Do	(2)	.0	.0	.3	.4	.2
1933 seed:						
Uninoculated, untreated		.0	.0	.2	.5	2.0
Inoculated, untreated		13.7	27.3	51.9	77.6	70.4
Copper carbonate	Sept. 15, 1933	.0	.0	.0	[3] T	.4
Do	(2)	.0	.0	.5	.6	1.5
Formaldehyde	Sept. 15, 1933	.0	.0	.1	.6	1.0
Do	(2)	.0	.0	.2	.2	.8

DATA ON ENVIRONMENT DURING EMERGENCE

Dates of sowing	Oct. 9	Oct. 16	Oct. 26	Nov. 10	Nov. 26
Soil saturation at sowing ... percent	50.0	60.0	62.0	48.0	51.0
Soil saturation at emergence ... do	70.0	75.0	50.0	53.0	80.0
Rainfall ... inches	.3	1.0	.6	.2	1.9
Mean soil temperature ... °C	13.0	13.0	0.0	5.0	3.0
Days to emerge, 1932 seed	8	8	11	13	30
Days to emerge, 1933 seed	8	8	11	12	28

[1] Copper carbonate was applied at 4 ounces per bushel; the formaldehyde treatment was a modification of the Braun (*2*) method.
[2] Treated on day seed was sown.
[3] T represents trace, or less than 0.1 percent.

In no case was the copper carbonate more effective when applied just before sowing than when applied 1 to 2 months or even a year before sowing. There was no indication of any gradual decrease in its effectiveness, as suggested by Flor (*10*).

SOIL TYPE, REACTION, AND MOISTURE CONTENT

Some of the soil conditions previously mentioned as influencing infection of wheat by bunt also may affect directly the efficacy of certain dust fungicides. Volk (*50*) found that acid soils increased the effectiveness of slowly soluble copper fungicides, while alkaline soils diminished it. He (*49*) stated further that the best fungicidal action was obtained in loose sandy or peat soils and at 20 percent of the water-holding capacity, and that the effectiveness was diminished by an excessive increase in soil moisture after sowing. In clay the effect of excessive moisture was less noticeable.

Kühl (*26*) and a number of other workers (*43, 44, 45, 48*) concluded that the efficacy of dust fungicides is more or less dependent on the nature of the soil. The disparity in results obtained in wheat grown from the same lots of treated seed sown at experiment stations in a number of States has been mentioned (tables 5 and 7). It is possible that differences in soil may have played a part in producing these differences in results.

The influence of liming on the effectiveness of several brands of copper carbonate and a number of other dust fungicides was studied in a field experiment at the Arlington Farm in 1927–28. Purplestraw wheat inoculated at a 1 to 250 spore dosage was dusted at the rate of 2½ ounces per bushel and sown in paired rod rows in limed and unlimed soil in each of three parallel series September 27, October 12, and October 22, 1927. The soil was light and sandy, with a water-holding capacity of 38 percent. The reaction of the soil in the limed and unlimed plots as determined by the colorometric method was pH 7.2 and 5.8, respectively. A fourth series was sown October 26 in 12 rod-row replications in unlimed clay soil, with a reaction of pH 6.5.

The periods required for emergence in the sowings on the dates mentioned were 4, 7, 9, and 12 days, respectively, and the corresponding average soil temperatures during these periods were 21°, 16°, 14°, and 12° C., respectively. The data on germination and infection are shown in table 17.

TABLE 17.—*Bunt control in Purplestraw wheat grown from inoculated seed sown in limed and unlimed sandy soil Oct. 12 and 22, respectively, and in unlimed clay loam Oct. 26, 1927*

Seed-treatment compound [1]	Germination	Bunted heads from seed sown in—				
		Sandy soil				Clay loam
		Oct. 12		Oct. 22		
		Limed	Unlimed	Limed	Unlimed	Oct. 26, unlimed
	Pct.	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
Average of controls	80	2.5	1.2	10.3	4.7	22.3
Copper carbonate no. 1, 50 percent copper	98	.0	.0	.2	.0	Trace
Copper carbonate no. 2, 50 percent copper	98	.0	.0	.2	.0	.0
Copper carbonate no. 3, 50 percent copper	93	.0	.0	.1	.0	.0
Copper carbonate no. 4, 50 percent copper	94	.0	.0	.0	.0	.0
Copper carbonate no. 5, 50 percent copper	68	.0	.0	.0	.0	.0
Copper carbonate no. 6, 18 percent copper	96	.0	.0	.0	.0	Trace
Copper carbonate no. 7, 20 percent copper	93	.0	.0	.0	.0	.0
Copper carbonate no. 8, 20 percent copper	97	.0	.0	.3	.0	.0
Copper carbonate no. 9, 20 percent copper	91	.1	.0	.1	.0	.0
Copper oxychloride	96	.0	.0	.5	.0	Trace
Copper sulphate (dehydrated)	92	.0	.0	.0	.0	.0
Vitrioline	95	.0	.0	.0	.0	Trace
Cuprobol	97	.0	.0	2.0	.8	2.6
Höchst	92	.0	.0	.0	.0	.0
Sulphur	95	.6	.0	1.8	.5	2.1
Formaldehyde 1:320	79	.0	.0	.0	.0	.0

[1] The dust fungicides were applied at 2¼ ounces per bushel; for the formaldehyde treatment the seed was immersed 30 minutes, drained, covered 2 hours, and dried.

Warm weather during the period required for emergence inhibited bunt infection in the first sowing (Sept. 27), and therefore data for this are omitted from the table. Heavy rains and the resulting excessive soil moisture apparently had an inhibiting effect on bunt infection or development in the October 12 and, to a lesser extent, in the October 22 sowing. Conditions were more favorable for bunt in the October 26 sowing, and a greater percentage of infection was secured. In the October 12 and 22 sowings infection was slightly greater on the limed soil, and the fungicides were somewhat less effective. The differences are small, however, and probably not significant. While clay soil, together with a slightly lower temperature, proved more favorable for bunt development, it also seemed to favor the fungicidal action of the dusts, as bunt control by the better dusts was, with few exceptions, as good in clay soil as it was in sandy soil, in spite of the higher percentage of infection from untreated seed in the clay soil.

Studies on the influence of soil type and soil moisture content on bunt control with several dusts were made the following year, 1928–29. The dusts were applied to inoculated seed of Purplestraw wheat at slightly more than 2 ounces per bushel (1 g of dust to 400 g of seed). The seed was sown October 25 and November 7, both in sandy and clay soil. In the sandy soil, 20 rod rows were devoted to each treatment. Half of each of these rows had the rain excluded from sowing to emergence by means of temporary shelters; the other half received an artificial drenching equivalent to several inches of rain. In the clay soil, 10 rod rows were sown for each treatment. Unfortunately, a wet series could not be included in this soil.

In the sandy soil the periods required for emergence in the first and second sowings were 12 and 14 days, respectively, and the corresponding average soil temperatures during these periods were 10.1° and 8.5° C., respectively. In the clay soil the corresponding emergence periods were 13 and 15 days and the average soil temperatures 7.8° and 7° C., respectively. Data relating to infection are presented in table 18.

TABLE 18.—*Control of bunt in Purplestraw wheat grown from inoculated seed sown in sandy and clay types of soil, the sandy soil either being saturated at sowing or kept relatively dry until the seedlings had emerged*

Seed-treatment compound [1]	Bunted heads grown from seed sown—											
	Oct. 25, 1928						Nov. 7, 1928					
	In sandy soil				In clay loam, unwatered		In sandy soil				In clay loam, unwatered	
	Watered		Unwatered				Watered		Unwatered			
	No.	*Pct.*	*No.*	*Pct.*	*No.*	*Pct.*	*No.*	*Pct.*	*No.*	*Pct.*	*No.*	*Pct.*
Control	68	1.2	404	7.00	1,592	27.20	209	4.5	511	10.00	804	13.60
Ceresan	0	.0	3	.04	8	.15	0	.0	0	.00	7	.12
Phenyl mercuric acetate	0	.0	0	.00	18	.34	0	.0	1	.02	4	.07
Coppercarb	0	.0	0	.00	20	.38	0	.0	0	.00	5	.09
Copper carbonate	0	.0	0	.00	18	.35	0	.0	1	.02	2	.03
Formaldehyde 1:320	5	.1	0	.00	22	.43	0	.0	0	.00	6	.10

[1] The dusts were applied at slightly more than 2 ounces per bushel; in applying the formaldehyde treatment the seed was soaked 30 minutes, drained, covered 2 hours, and dried.

In both sowings, saturating the sandy soil after sowing decreased the percentage of infection but did not seem to affect the efficiency of the fungicides. In both cases infection was greater and the fungicides were slightly less effective in the clay soil.

Additional data relating to the influence of soil moisture on the control of bunt by dusts were obtained in another experiment designed primarily to study the effect of bunt balls in the seed and bunt spores in the soil. As in the previous experiment, saturating the soil after sowing greatly reduced the percentage of bunted heads from untreated inoculated seed, the percentages of infection in saturated and in unwatered soil being 6.5 and 31.4, respectively, for Purplestraw and 1 and 10.1, respectively, for Fulcaster. Saturating the soil in this case did not affect the action of the fungicides, as 100-percent control was obtained with all of them. However, when the seed was infested with unbroken bunt balls or when it was sown in infested soil, the relative reduction in the percentage of bunt by means of the dust fungicides was, with few exceptions, less in the saturated soil, even though the percentage of infection here also was greatly reduced by excessive soil moisture.

Thus, on the whole, the results indicate (1) that acid sandy soil tended to inhibit bunt development, but favored bunt control by dust fungicides; (2) that limed sandy soil was more conducive to bunt development but less favorable to the action of the dusts in bunt control; (3) that clay loam was more conducive to bunt development than was sandy soil but did not differ from it consistently in its effect on bunt control; and (4) that saturating the soil after sowing materially decreased the percentage of bunt but did not decrease the efficiency of the dust fungicides except where the seed contained unbroken bunt balls or the soil was infested.

BUNT BALLS IN SEED AND SOIL INFESTATION

Directions for treating seed to prevent bunt usually include the recommendation that unbroken bunt balls should be removed from the seed before treatment, especially if liquid fungicides are to be used (*16*). Dust treatments are generally supposed to offer some measure of protection against recontamination of the seed after treatment or against infection due to soil infestation. Although soil infestation is considered of major importance only in the Pacific Northwest, it is thought that at times unbroken bunt balls in the soil may be responsible for some infection in other areas when wheat follows wheat in the rotation and especially when relatively dry weather has prevailed from the time of harvesting or threshing to the time of sowing.

Experiments therefore were begun at Arlington Farm in the fall of 1930 to study the relative effectiveness of several fungicides in bunt control when the seed contained unbroken bunt balls and the soil was infested with bunt spores. For this purpose seed of Purplestraw and of Fulcaster, inoculated with bunt at a spore dosage of 1 to 250 and treated with various fungicides, was sown in bunt-free and in artificially bunt-infested soil. The bunt spores were applied to the soil after the seed had been sown and before it had been covered. To half of the seed sown in noninfested soil, bunt balls were added at the heavy rate of one bunt ball to about every three seeds. The dust fungicides were applied at 2 or 3 ounces per bushel. Copper sulphate was applied as a 2.5 percent solution in which the seed was soaked for 10 minutes followed by immersion for 5 minutes in limewater. The formaldehyde treatment consisted of a half-hour soak in a 1-to-320 solution, after which the seed was covered 2 hours and dried. The seed to be treated with the liquid fungicides was contained in cheesecloth bags, so that unbroken bunt balls were not removed in the process of treatment. The liquid treatments were applied the day before sowing.

The plots were seeded October 22 in two parallel series. In one, the soil was heavily watered immediately after sowing, so that it was saturated to a depth of 5 inches. In the other there was no artificial watering, and the soil, which was 40-percent saturated, received less than half an inch of rain before emergence, which occurred on November 13. The mean soil temperature from sowing to emergence was 5.9° C., with a maximum of 19° C. on October 28 and a minimum of −5° C. on November 8. A gradient in soil fertility was reflected in the total number of heads, which are shown in table 19, together with the data on infection.

TABLE 19.—*Bunt infection and control in 2 varieties of winter wheat grown from seed infested with bunt spores, or with both spores and unbroken bunt balls, treated with one of several fungicides, and sown in noninfested soil or in soil infested with bunt spores, half of each plot being saturated after sowing, 1930–31*

Variety and seed-treatment compound	Rate per bushel	Total and infected heads grown in—											
		Noninfested soil								Infested soil			
		No bunt balls added and seed sown in—				Bunt balls added and seed sown in—				No bunt balls added and seed sown in—			
		Wet soil		Dry soil		Wet soil		Dry soil		Wet soil		Dry soil	
		Total	Bunted	Total	Bunted	Total	Bunted	Total	Bunted	Total	Bunted	Total	Bunted
	Oz.	*Number*	*Percent*	*Number*	*Percent*	*Number*	*Percent*	*Number*	*Percent*	*Number*	*Percent*	*Number*	*Percent*
Purplestraw:													
Uninoculated control	----	1,630	0.1	1,800	0.0	1,328	4.6	2,750	45.1	2,029	22.2	3,040	52.2
Inoculated control	----	1,515	6.5	1,782	31.4	1,318	8.1	2,480	50.2	2,323	28.0	3,088	54.3
Copper carbonate	2	1,490	.0	------	.0	1,299	.4	2,042	4.8	2,291	12.3	2,542	16.8
Coppercarb	2	1,580	.0	------	.0	1,408	1.8	2,116	5.3	2,281	10.9	2,502	19.3
Do	3	1,550	.0	------	.0	1,310	.8	2,130	3.3	2,084	11.7	2,406	20.0
Basic copper sulphate	2	1,580	.0	------	.0	1,365	1.3	2,015	3.6	2,277	8.9	2,518	17.1
Do	3	1,620	.0	------	.0	1,459	.6	2,029	4.1	2,391	12.2	2,354	16.9
Cuprojabonite	3	1,710	.0	------	.0	1,505	1.0	2,130	5.4	2,359	14.2	2,475	20.4
Copper sulphate solution	(1)	1,540	.0	------	.0	1,706	.8	2,354	9.9	2,774	13.6	2,787	32.5
Formaldehyde solution	(2)	1,420	.0	1,690	.0	1,472	5.1	2,060	28.0	2,087	22.5	2,569	45.1
Fulcaster:													
Uninoculated control	----	1,000	.0	1,186	.0	1,466	2.0	1,603	31.6	1,709	12.3	1,672	28.5
Inoculated control	----	1,070	1.0	1,185	10.1	1,332	3.2	1,646	36.9	1,752	16.9	1,653	35.3
Copper carbonate	2	1,130	.0	------	.0	1,252	.8	1,552	3.0	1,698	9.0	1,616	6.9
Coppercarb	2	1,215	.0	------	.0	1,208	.8	1,531	2.3	1,781	7.5	1,694	13.8
Do	3	1,232	.0	------	.0	1,259	.2	1,583	2.4	1,690	6.9	1,738	11.3
Basic copper sulphate	2	1,210	.0	------	.0	1,224	.6	1,434	1.5	1,679	6.0	1,702	9.9
Do	3	1,218	.0	------	.0	1,265	.3	1,588	1.4	1,807	5.8	1,603	7.9
Cuprojabonite	3	1,254	.0	------	.0	1,280	T[3]	1,516	3.5	1,975	8.1	1,570	10.2
Copper sulphate solution	(1)	1,017	.0	------	.0	1,056	.1	1,507	4.1	1,649	9.0	1,394	10.0
Formaldehyde solution	(2)	940	.0	1,092	.0	948	4.8	1,381	11.4	1,188	17.3	1,395	25.2

[1] Soaked in a 1:40 (2.5 percent) solution 10 minutes, dipped in limewater 5 minutes, and dried.
[2] Soaked in a 1:320 solution ½ hour, drained, covered 2 hours, and dried.
[3] T represents trace, or less than 0.1 percent.

When the only inoculum consisted of spores applied to the seed, all of the treatments controlled bunt perfectly. The controls, however, showed less infection than when additional inoculum had been used, either in the form of bunt balls added to the seed or spores applied to the soil, especially in the heavily watered soil.

Where smut balls were added to the seed the dust fungicides averaged 88 and 91 percent control in the watered and unwatered soil, respectively, for Purplestraw and 86 and 94 percent for Fulcaster. The copper sulphate solution was, in both cases, slightly more effective than the dusts in the wet soil and somewhat less effective in the unwatered soil. Formaldehyde was relatively inefficient, for with one exception it failed to reduce the percentage of infection to less than half of that present in the controls.

That bunt balls in the seed may bring about considerable infection is shown by the fact that adding them to the bunt-free seed resulted in 45.1 and 31.6 percent bunt in Purplestraw and Fulcaster, respectively, when no artificial watering was used. Considering the heavy infestation, however, bunt control was not affected as much as might have been expected.

The highest infection, with two exceptions, and the most unsatisfactory bunt control occurred where the soil had been infested with spores. In this series relatively more infection occurred after heavy watering than where only seed infestation was employed. The dust fungicides averaged 58- and 66-percent control in the watered and unwatered soil, respectively, for Purplestraw and 56- and 72-percent for Fulcaster. Except in the case of Fulcaster in unwatered soil the percentage efficiency of copper sulphate solution was less than the average of that of the dusts. Formaldehyde again was highly ineffective in this series.

As previously noted in an earlier experiment, saturating the soil after sowing greatly reduced the percentage of infection. It also reduced somewhat the relative effectiveness of most of the fungicides when the seed contained bunt balls or the soil was infested. In the latter cases, as already noted, treatment with dust fungicides or with copper sulphate solution was more effective than was treatment with formaldehyde. There appear to be no outstanding or consistent differences between the results obtained from the various dust fungicides or from the different rates of application.

Experiments in which seed and soil were infested with bunt spores and with unbroken bunt balls were carried out in the seasons 1931–32 and 1932–33. In 1931 a plot of soil 10 by 132 feet was artificially infested with unbroken bunt balls on October 6. An adjacent plot was similarly infested with spores. Beginning October 13, clean untreated wheat and smutted untreated and treated wheat were sown in duplicate 8-foot rows in each plot at weekly intervals. The data are shown in table 20. Infection was very light in all cases. In both plots some infection was caused by the infested soil even when seed was sown as late as November 10. With the low percentage of infection in the controls and the somewhat erratic and inconsistent results obtained with the fungicides no definite conclusions can be drawn regarding their relative merits in this experiment. Clean seed sown in this area the following year (October 1932) produced no bunted plants, indicating that even in unbroken bunt balls the spores do not retain their viability in the soil for 1 year under the conditions at the Arlington Experiment Farm.

TABLE 20.—*Bunt infection in Purplestraw wheat grown from treated and untreated seed sown at successive dates after the application of unbroken bunt balls or loose bunt spores to the soil Oct. 6, 1931*

Seed-treatment compound	Rate per bushel	Bunted heads from seed sown on dates shown and in soil artificially infested with—									
		Unbroken bunt balls					Powdered bunt spores				
		Oct. 13	Oct. 20	Oct. 26	Nov. 3	Nov. 10	Oct. 13	Oct. 20	Oct. 26	Nov. 3	Nov. 10
	Ounces	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Uninoculated, untreated		0.0	1.7	0.0	0.2	0.8	2.2	0.5	0.5	0.0	0.2
Inoculated, untreated		8.6	7.7	6.3	10.0	0.5	9.0	7.4	8.7	9.2	7.1
Ceresan	2	.0	1.0	.7	.0	.0	.7	.4	.2	.9	.0
Copper carbonate	2	1.2	.4	.0	.0	.0	.0	.9	1.2	.7	.6
Coppercarb	3	.7	.4	1.0	.0	.0	.5	.0	1.0	.0	.0
Basic copper sulphate	2	.0	.0	.7	.0	.0	.2	.6	1.2	.4	.0
Formaldehyde 1:320	(1)	1.3	1.6	1.0	.0	.5	.7	.6	1.2	.0	.0
Copper sulphate 1:49	(2)	2.6	1.5	.0	.0	.0	.0	.0	.0	.0	.0

[1] Seed soaked 30 minutes, drained, covered 2 hours, and dried.
[2] Seed soaked 10 minutes, dipped in limewater 5 minutes, and dried.

In another experiment in 1931 two sowings were made, one on October 13 and another on October 26. In each case one half of the plot had been artificially infested with bunt spores October 6 and the other half was similarly infested at the time of sowing. Here again, as shown in table 21, infesting the soil greatly increased the prevalence of bunt. This was greatest when seed and spores were sown the same day. Some infection resulted from soil infested on October 6 when wheat was sown October 13, but very little when it was sown October 26. With the exception of formaldehyde, which was the least effective, the various fungicides did not differ greatly in efficiency. They all furnished the poorest control when the seed was sown October 13 in soil inoculated the same day and with one exception perfect control when the seed was sown October 26 in soil inoculated October 6.

TABLE 21.—*Bunt infection in Purplestraw wheat grown from treated and untreated seed and sown in soil artificially infested with loose bunt spores 1 or 3 weeks before sowing or at time of sowing*

Seed-treatment compound [1]	Bunted heads from seed sown— Oct. 13, 1931, in soil inoculated— Oct. 6	Oct. 13	Oct. 26, 1931, in soil inoculated— Oct. 6	Oct. 26
	Percent	*Percent*	*Percent*	*Percent*
Uninoculated, untreated	3.8	28.5	0.2	5.8
Inoculated, untreated	11.4	34.0	13.0	17.7
Ceresan	.1	2.9	.0	3.0
Copper carbonate	1.2	5.9	.7	1.2
Coppercarb	1.2	9.3	.0	5.6
Basic copper sulphate	1.6	12.4	.0	2.7
Formaldehyde 1:320	2.7	27.4	.0	7.1
Copper sulphate 1:40	.2	5.8	.0	1.1

[1] The dusts were applied at 2½ ounces per bushel; in applying formaldehyde the seed was soaked 30 minutes, drained, covered 2 hours, and dried; copper sulphate was applied as a 10-minute dip after which the seed was immersed in limewater 5 minutes, drained, and dried.

The data from another experiment conducted in 1931, involving the presence of unbroken bunt balls in the seed, are shown in table 22. The smaller proportion of bunt balls used (30 bunt balls to 70 g of seed), together with conditions apparently less favorable for bunt development than those of the previous year, resulted in scarcely any bunt infection traceable directly to the presence of bunt balls in the seed.

TABLE 22.—*Bunt infection in Purplestraw wheat as affected by unbroken bunt balls in the seed*

Seed-treatment compound [1]	Bunted heads from seed sown— Oct. 13, 1931: Without bunt balls	With bunt balls	Oct. 26, 1931: Without bunt balls	With bunt balls
	Percent	*Percent*	*Percent*	*Percent*
Uninoculated, untreated	0.0	0.0	0.0	0.3
Inoculated, untreated	7.6	7.4	8.5	8.8
Ceresan	.0	.0	.0	.0
Copper carbonate	.0	.2	.0	.0
Coppercarb	.0	.0	.0	.0
Basic copper sulphate	.0	.0	.0	.0
Formaldehyde 1:320	.0	.6	.0	.3
Copper sulphate 1:40	.0	.0	.0	.0

[1] The dusts were applied at 2½ ounces per bushel; in applying formaldehyde the seed was soaked 30 minutes, drained, covered 2 hours, and dried; copper sulphate was applied as a 10-minute dip after which the seed was immersed in limewater 5 minutes, drained, and dried.

In June 1932 two adjacent plots each 50 feet long by 5 feet wide were divided into sections 6 by 8 feet by inserting partitions to prevent washing from one section to another. On July 1, August 1, September 1, October 1, October 10, and October 26 a section in one bed was artificially infested with bunt balls and a section in the other bed was infested with loose bunt spores. These materials were mixed with the surface 3 inches of soil. On October 26 clean and inoculated seed of Purplestraw wheat, untreated and treated with copper carbonate or formaldehyde, was sown in each of these 12 sections, 150 seeds being sown in each 5-foot row. Infection data are presented in table 23.

TABLE 23.—*Effect of periodically infesting the soil with bunt spores or unbroken bunt balls on infection by bunt in Purplestraw wheat grown from clean or inoculated seed, untreated or treated with copper carbonate* [1] *or formaldehyde* [2], *and sown Oct. 26, 1932*

Seed-treatment compound	Soil infested with—	Bunted heads from clean and inoculated seed sown in soil artificially infested on—						Weighted average
		July 1	Aug. 1	Sept. 1	Oct. 1	Oct. 10	Oct. 26	
Clean seed:		*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
Untreated	Bunt spores.	0.0	5.1	2.1	2.9	16.3	63.6	35.0
Copper carbonate	Bunt spores.	.0	.0	.6	.0	8.8	38.9	8.1
Formaldehyde	Bunt spores.	.0	10.3	1.6	1.7	32.8	43.6	15.0
Untreated	Bunt spores.	.0	1.5	1.8	3.8	37.6	56.6	16.9
Do	Bunt balls	1.8	3.3	.6	2.6	5.0	12.8	4.3
Copper carbonate	Bunt balls	3.6	1.4	1.1	.0	.7	9.0	2.6
Formaldehyde	Bunt balls	6.3	6.8	1.3	.0	4.2	4.3	3.8
Untreated	Bunt balls	6.6	1.7	1.3	6.6	3.0	12.8	5.3
Inoculated seed:								
Untreated	Bunt spores.	33.9	57.1	43.2	38.0	50.6	57.8	47.1
Copper carbonate	Bunt spores.	1.3	1.5	.0	.7	1.0	35.2	6.7
Formaldehyde	Bunt spores.	1.5	1.5	3.8	.7	4.0	35.0	7.8
Untreated	Bunt spores.	31.4	47.1	45.3	35.6	39.0	36.7	30.6
Do	Bunt balls	32.6	30.9	34.6	23.9	21.7	25.2	20.4
Copper carbonate	Bunt balls	5.5	3.6	0	.6	5.2	13.2	4.7
Formaldehyde	Bunt balls	4.5	3.7	0	.0	7.5	12.8	4.8
Untreated	Bunt balls	25.0	30.2	28.2	45.8	17.0	17.7	27.3

[1] Applied at 2 ounces per bushel.
[2] Seed immersed in a 1: 320 solution 30 minutes, drained, covered 2 hours, and dried.

Spores placed in the soil as early as July 1 caused no infection, but unbroken bunt balls did. Infection resulted from soil infested August 1 or later with either spores or bunt balls. In the plots infested August 1, September 1, and October 1 there was no consistent difference in the amount of infection resulting from the use of spores or bunt balls. In the plots infested October 10 and 26, however, the spores caused approximately seven and five times as much bunt, respectively, as did the bunt balls. With two exceptions, where infection was caused wholly by soil infestation, copper carbonate furnished better control than did formaldehyde.

Further data on the effect of bunt balls in smutty seed were obtained from other field experiments designed to determine the effect of seed treatment on yield and the relation between bunt and yield. In these experiments, which will be discussed more fully later, the presence of bunt balls in the seed (1.5 percent by weight, or about one bunt ball to 4 g of seed) increased the average percentage of bunt at eight stations from 10.3 to 17.6 percent, or an average increase of 70.9 percent. It decreased the average fungicidal efficiency of three dusts from 98.7 to 96.8 percent. The fungicidal efficiency of formaldehyde was reduced from 97.1 to 90.9 percent.

In another experiment, formaldehyde and three dusts were used to treat different portions of two lots of smutty durum wheat, one free from unbroken bunt balls and the other containing about 4 percent by volume. The bunt balls in the durum wheat used were observed to be harder and more solid than those in Purplestraw wheat. Their specific gravity apparently also was greater, as very few rose to the surface of the solution while the formaldehyde treatment was being applied. The treated and untreated seed was sown in rod rows at the Arlington Farm and at Fargo and Langdon, N. Dak. The plots from untreated seed containing no bunt balls showed 6, 6.2, and 27 percent infection, respectively, at the three stations, as shown in table 24. The corresponding percentages of infection from seed containing bunt balls were 10.3, 36.7, and 22.9, respectively. Smut balls in the seed reduced the average fungicidal efficiency of formaldehyde from 84.8 to 74.7 percent, whereas that of the dusts was reduced from 99.5 to 93.6 percent. With one exception the dusts were superior to formaldehyde in bunt control.

TABLE 24.—*Control of bunt in durum wheat grown from inoculated seed, treated with a number of fungicides,[1] and sown in rows at several stations, 1932*

Series and seed-treatment compound	Total and smutted heads and percentage of smut at—								
	Arlington Farm			Fargo			Langdon		
	Total heads	Smutted heads		Total heads	Smutted heads		Total heads	Smutted heads	
	Number	*Number*	*Percent*	*Number*	*Number*	*Percent*	*Number*	*Number*	*Percent*
Series 1:[2]									
Formaldehyde	300	0	0.0	600	1	0.2	600	32	5.3
Coppercarb	300	0	.0	600	0	.0	600	1	.2
Copper carbonate	300	0	.0	600	0	.0	600	2	.3
Ceresan	300	0	.0	600	0	.0	600	0	.0
Control	300	18	6.0	600	37	6.2	600	162	27.0
Series 2:[3]									
Formaldehyde	200	13	6.5	600	15	2.5	1,390	94	6.8
Coppercarb	200	1	.5	600	35	5.8	1,257	28	2.2
Copper carbonate	200	0	.0	600	8	1.3	1,155	14	1.2
Ceresan	200	0	.0	600	8	1.3	1,107	3	.3
Control	300	31	10.3	600	220	36.7	1,225	280	22.9

[1] In applying formaldehyde, seed was immersed in a 1:320 solution 30 minutes, drained, covered 2 hours, and dried. Coppercarb was applied at 3 ounces and copper carbonate and Ceresan at 2 ounces per bushel.
[2] Series 1. Seed free from unbroken bunt balls.
[3] Series 2. Seed containing 4 percent of bunt balls by volume.

In the fall of 1933 a quantity of Fulcaster wheat infested with bunt balls was obtained to study equipment for removing bunt balls from wheat (*24*). Two lots of this wheat were prepared, one containing 30 bunt balls per 50 g of seed and the other with the bunt balls removed. Separate portions of each lot were treated with copper carbonate, Coppercarb, or New Improved Ceresan at 2, 3, and ½ ounces per bushel, respectively, or with formaldehyde and sown in one-eightieth-acre plots together with untreated seed of each lot. The following June no bunted heads could be found in any of the plots grown from treated seed. The plots grown from untreated seed with and without bunt balls contained 30 and 22 percent of bunted heads, respectively.

In a parallel experiment bunt balls secured from the above lot of infested wheat were added to different lots of relatively bunt-free Purplestraw wheat in the following proportions: 0, 1, 5, 10, 25, and 50 bunt balls per 50 g of wheat. Separate portions of these different lots were treated as described above and sown in paired drill rows together with untreated wheat of each lot and with wheat infested at a 1 to 100 spore dosage with bunt from Purplestraw wheat. The infection data are shown in table 25. The different proportions of bunt balls in treated seed seemed to have little effect on the percentage of bunted heads from this seed. They did increase somewhat the small percentage of bunt in the plots sown to untreated seed, but not in proportion to the number of bunt balls added. The much higher percentage of bunt resulting from infesting the seed with loose spores from Purplestraw indicates that this variety may have been somewhat resistant to the strain of smut obtained from Fulcaster or that the spores in this particular lot of smut were of low viability.

In the fall of 1934, different proportions of unbroken bunt balls obtained from Purplestraw wheat were added to separate lots of bunt-free seed of that variety, as in the preceding experiment. Another lot of this seed was infested with bunt spores at a spore dosage of 1 to 100. Separate portions of these different lots of wheat were treated with New Improved Ceresan, copper carbonate, and formaldehyde and sown as before in paired 132-foot drill rows. The data on the percentage of bunted heads also are shown in table 25.

TABLE 25.—*Bunted heads in Purplestraw wheat grown from relatively bunt-free seed, separate lots of which had been infested with different proportions of bunt balls and portions of each treated with different fungicides and sown in paired 132-foot drill rows, together with spore-infested seed similarly treated, 1933–34 and 1934–35*

Period and number of bunt balls per 50 g of seed	Bunted heads grown from seed									
	Not treated		Treated with—							
			Copper carbonate[1]		Coppercarb[2]		New Improved Ceresan[3]		Formaldehyde[4]	
	Number	*Percent*	*Number*	*Percent*	*Number*	*Percent*	*Number*	*Percent*	*Number*	*Percent*
1933–34:										
None	40	0.8	0	0.0	3	0.1	4	0.1	0	0.0
1	50	1.0	3	.1	0	.0	0	.0	5	.1
5	182	3.6	0	.0	0	.0	3	.1	5	.1
10	260	5.2	2	[5]T	0	.0	0	.0	0	.0
25	308	6.2	0	.0	5	.1	0	.0	13	.3
50	150	3.0	0	.0	2	T	0	.0	35	.7
None[6]	4,320	85.0	5	.2	21	.5	5	.2	4	.1
1934–35:										
None	0	.0	0	.0			0	.0	0	.0
1	2	.4	0	.0			0	.0	0	.0
5	161	3.3	0	.0			0	.0	0	.0
10	536	9.4	0	.0			2	T	7	.1
25	1,032	18.3	0	.0			9	.2	12	.2
50	1,083	20.4	0	.0			9	.3	14	.3
None[6]	5,330	88.3	6	.1			2	T	20	.7

[1] Applied at 2 ounces per bushel.
[2] Applied at 3 ounces per bushel.
[3] Applied at ½ ounce per bushel.
[4] Immersed in a 1:320 solution 30 minutes, drained, covered 2 hours, and dried.
[5] T=trace.
[6] Seed infested with spores at a spore dosage of 1 to 100.

As in the previous experiment, the different proportions of unbroken bunt balls in the seed produced little or no infection when the seed was treated with any one of the three fungicides used. When the seed was not treated, however, increasing the relative number of bunt balls caused more or less corresponding increases in the percentage of bunt, but these increases were not strictly proportional to the increases in the number of bunt balls added to the seed. The maximum infection resulting from infesting the seed with bunt balls amounted to only 20.4 percent of bunt. The failure of the bunt balls to cause heavier infection must be attributed to the fact that most of them remained intact during the handling of the seed incidental to treating and sowing. This was shown by a subsequent examination of samples of seed collected from the drill spouts. That conditions for smut infection again were very favorable is shown by the heavy infection that resulted from inoculating the seed with loose bunt spores.

These various experiments involving bunt spores in the soil and unbroken bunt balls in the seed and in the soil point to the general conclusions that fungicidal dusts and copper sulphate solution used as seed treatments afford considerable but not complete protection in such cases and that formaldehyde is less effective. Infection resulting from the presence of unbroken bunt balls in treated seed depends upon the extent to which they are broken after treatment and before sowing. This, in turn, is contingent on the brittleness of the bunt ball covering and the amount and kind of handling the treated grain receives.

Bunt balls from durum wheat seem to be less easily crushed than those from other wheats. They also are relatively heavier and do not readily rise to the surface when a liquid treatment is used.

In these experiments a small percentage of unbroken bunt balls in the seed did not greatly increase the percentage of infection or decrease the degree of bunt control secured by the more effective dust fungicides. It must be borne in mind, however, that these experiments were confined mostly to an area of relatively high humidity, and the results are not necessarily applicable to more arid regions where the bunt spore covering may be more brittle.

Although bunt spores in the soil in the form of unbroken bunt balls retained their viability longer than did the loose spores, the latter caused more infection. In regions with an average rainfall equivalent to that of Maryland or Virginia it seems that there is but slight danger of bunt infection from soil infestation except when little or no rain falls between the time of harvesting or threshing and the time of sowing. It is highly improbable that spores in the soil survive the winter at the Arlington Farm except in the form of bunt balls in unthreshed wheat heads protected to some extent by straw or other litter. In one case under observation a plot of smutty wheat plowed under in the fall resulted in infection in the wheat sown in the same plot a year later.

EFFECT OF SEED TREATMENTS AND BUNT INFECTION ON YIELD OF GRAIN

Studies on the effects of seed treatments on the yield of wheat included observations on the relation between the percentage of bunt in and the percentage decrease in yield from wheat grown from untreated smutty seed, compared with yields from treated smutty seed or untreated smut-free seed.

The first data of this nature are presented in table 14 in connection with the experiment designed to determine the effect of the copper-carbon-dioxide ratio on the efficiency of copper carbonate. In this case 15 percent of bunt in the control corresponded with a reduction in yield of 16.9 percent, as compared with the average yield from treated seed.

In another experiment inoculated seed of Purplestraw wheat was treated with copper carbonate, Coppercarb, or formaldehyde and sown in rod rows. The data are given in table 26. The rows grown from untreated seed contained 21.2 percent of bunt and yielded 34.4 bushels per acre as compared with a trace of bunt in and an average yield of 39.6 bushels per acre from the rows grown from seed treated with the copper dusts. That is, 21.2 percent of bunt presumably caused a reduction in yield of about 13 percent. The formaldehyde-treated seed evidently suffered considerable reduction in viability, as the average number of heads per row was only 74.4 percent of that from untreated seed, and to this fact may be attributed the low yield from this seed. The slightly greater number of heads per row from untreated smutty seed as compared with that from the seed treated with the copper compounds may be explained by the fact that bunt-infected plants often stool more abundantly than do uninfected ones.

TABLE 26.—*Bunt occurrence, heads per row, and yield of grain in Purplestraw wheat grown from inoculated seed, untreated or treated with one of several fungicides*[1], *and sown at Arlington Experiment Farm Oct. 20, 1927*

Seed-treatment compound	Rod rows	Bunted heads		Heads per row		Yield per acre	Increase or decrease in yield[2]	
	Number	*Number*	*Percent*	*Number*	*Index*	*Bushels*	*Bushels*	*Percent*
Control	10	1,834	21.2	867	100.0	34.4	----------	----------
Coppercarb	20	0	.0	808	93.1	40.1	5.7	16.6
Copper carbonate	20	4	[3] T	807	93.0	39.0	4.6	13.4
Formaldehyde	50	14	T	645	74.4	33.1	—1.3	—3.8

[1] Coppercarb and copper carbonate were applied at 3 and 2 ounces per bushel, respectively; formaldehyde was applied by soaking the seed in a 1:320 solution 30 minutes; seed was drained, covered 2 hours, and dried.
[2] The yield from untreated seed was 13 percent below the average yield from dusted seed.
[3] T represents trace, or less than 0.1 percent.

Field experiments[10] conducted during the seasons of 1928–29 and 1929–30 to compare the relative efficiency of Ceresan and copper carbonate in bunt control under field conditions were used also to determine to what extent these dusts affect the yield of grain when applied to bunt-free seed. It was thought the experiment also would show the relation between the percentage of bunt in a crop and the resultant percentage reduction in yield.

Seed of Purplestraw wheat, clean and bunt-inoculated, and either untreated or treated with Ceresan or with copper carbonate, was sown in parallel one-eightieth-acre plots. Each plot sown to treated seed was adjacent to a plot sown to untreated seed from the same lot. There were five replications for each set of paired plots. A similar sowing of Fulcaster was made with the exception of the clean seed treated with Ceresan. The percentage of bunt infection in the various plots was obtained by counting the bunted heads in a total of 2,500 heads selected at random in each plot. These results together with the data on yield per acre are summarized in table 27. This experiment was repeated the following year when only Purplestraw wheat was used and 10 replications were employed for each pair of plots. The results obtained are included in table 27 to facilitate comparison.

[10] These experiments were carried out in cooperation with J. W. Taylor, agronomist, at Arlington Experiment Farm.

TABLE 27.—*Average percentage of bunt in and yield of grain from Fulcaster and Purplestraw wheats grown from clean or bunt-inoculated seed which was treated*[1] *or not treated and sown in 1/80-acre plots, and the average increase or decrease in yield from plots sown to untreated seed compared with the yield from adjacent plots sown to treated seed*

Variety, year, and seed-treatment compound	Bunt-free seed				Bunt-inoculated seed			
	Bunted heads	Acre yield	Increase or decrease of control compared with treated seed		Bunted heads	Acre yield	Decrease of control compared with treated seed	
	Percent	*Bushels*	*Bushels*	*Percent*	*Percent*	*Bushels*	*Bushels*	*Percent*
Fulcaster (1928-29):								
Untreated control	0.0	16.2			45.7	11.2	7.7	40.7
Ceresan					.2	18.9		
Copper carbonate	.0	16.8			.0	18.5		
Untreated control	.0	17.6	.8	4.8	45.7	10.9	7.6	41.1
Purplestraw (1928-29):								
Untreated control	[2] 2.1	20.4	-.9	-4.2	91.3	3.6	21.9	85.9
Ceresan	[2] 1.0	21.3			3.4	25.5		
Copper carbonate	[2] .4	21.0			3.6	23.4		
Untreated control	[2] 2.1	23.0	1.4	6.5	95.5	3.2	20.2	86.3
Purplestraw (1929-30):								
Untreated control	[3] T	20.9	-1.2	-5.4	14.6	17.5	2.5	12.5
Ceresan	.0	22.1			1.4	20.0		
Copper carbonate	.0	22.8			.7	20.1		
Untreated control	[3] T	23.0	.2	.9	13.5	17.4	2.7	13.4

[1] Both fungicides applied at 2 ounces per bushel.
[2] Soil infestation present because of heavy infection in previous crop.
[3] T represents trace, or less than 0.1 percent.

No significant superiority was displayed by either dust in the control of bunt or in its effect on the yield of grain. Also, neither dust affected the yield to a significant degree other than by controlling bunt. The yields from clean uninoculated seed were in no case significantly affected by treatment.

There was, however, a fairly consistent relation between the percentage of bunt and the percentage decrease in yield from smutty untreated seed as compared with the yields from clean untreated seed or smutty treated seed. The percentage of bunt from smutty untreated seed invariably was somewhat greater than the corresponding percentage reduction in yield.

Data on the effect of certain seed treatments on the yield of spring wheat and the relation between the percentage of bunt and the percentage decrease in yield were secured from field experiments at a number of stations during the years 1931 and 1932.

In 1931, seed of Ceres wheat uninoculated and inoculated with loose spores only, and with both loose spores and bunt balls, was treated at the Arlington Farm and sent to eight experiment stations in the Great Plains for seeding in rod rows. Data regarding infection were taken by the writer and, later, yield records were secured by the cooperators at the different stations. Average yields of the uninoculated, untreated controls, and the corresponding average increases or decreases in yield from the rows sown to treated seed are given in table 28.

TABLE 28.—*Comparison of yields from Ceres wheat grown from clean untreated seed and clean treated*[1] *seed sown in rod rows replicated 5 times for each treatment at each of 8 stations in 1931*

Station	Average rod-row yield of controls	Increase or decrease in yield from seed treated with—							
		Formaldehyde		Copper carbonate		Ceresan		Basic copper sulphate	
	Grams	*Grams*	*Percent*	*Grams*	*Percent*	*Grams*	*Percent*	*Grams*	*Percent*
St. Paul	165±5.7	3± 8.1	1.8	−11± 7.8	−6.7	−1± 8.0	−0.6	−4± 7.9	−2.4
Brookings	156±5.7	−9± 7.9	−5.8	−16± 7.6	−10.3	−10± 7.8	−6.4	−2± 8.0	−1.3
Redfield	126±2.5	−12± 3.3	−9.5	−15± 3.3	−11.9	−13± 3.3	−10.3	−12± 3.3	−9.5
Fargo[2]	203±5.5	20± 8.1	9.9	29± 8.4	14.3	31± 8.4	15.3	33± 8.4	16.3
Langdon	157±4.0	−7± 6.8	−4.5	14± 7.3	8.9	7± 7.1	4.5	0± 6.9	--------
Dickinson	146±7.8	−15±10.5	−10.3	2±11.1	1.4	−12±10.5	−8.2	9±11.3	6.2
Moccasin	77±3.0	−7± 4.9	−9.1	−11± 4.8	−14.3	−3± 5.0	−3.9	−3± 5.0	−3.9
Bozeman	501±4.8	−21± 6.0	−4.2	−98± 6.2	−19.6	33± 7.0	6.6	10± 6.9	2.0

[1] The dust fungicides were applied at 2 ounces per bushel. The formaldehyde was applied according to a modification of Braun's (2) method.
[2] The controls at Fargo contained more than 6 percent of bunt.

The untreated controls at Fargo showed slightly more than 6 percent of bunt. As no bunt developed in this series at the other stations, this seems to indicate either soil infestation at Fargo or accidental contamination of the seed. At Brookings, Redfield, and Moccasin the average yield from untreated seed exceeded that from seed treated with each of the four disinfectants. At St. Paul the same was true with the exception of the formaldehyde-treated seed. At Langdon, Dickinson, and Bozeman two treatments showed increases in yield; while at Fargo, where some bunt occurred, increases were recorded for all of the treatments, three of them being significant. At Redfield, on the other hand, significant decreases in yield were recorded for all of the treatments.

Excluding the results from Fargo, it seems that treating, on the whole, reduced the yield, and there appears to be no appreciable difference among the different fungicides in this respect. Altogether, there are 20 cases in which a decrease in yield was recorded. In six of these the difference is more than three times the probable error. Excluding the results from Fargo, there are seven cases in which an increase in yield was recorded, of which only one reaches the level of significance.

Data relating to bunt infection and yield from seed inoculated with bunt spores and with both spores and bunt balls are shown in table 29. Inoculation with spores alone resulted in infection ranging from 0.1 to 31.5 percent, or an average of 10.3 percent for all of the stations. The average yield of 17.5 bushels per acre from untreated seed represented a reduction of 12.1, 10.7, 9.3, and 6.9 percent as compared with yields from seed treated with formaldehyde, copper carbonate, Ceresan, and basic copper sulphate, respectively. The corresponding coefficients of correlation between these average percentages of reduction and the average percentage of bunt in the controls were 0.6950±0.18, 0.7650±0.15, 0.8467±0.12, and 0.6630±0.07, respectively. With the exception of formaldehyde and copper carbonate at Fargo, highly satisfactory bunt control was secured with all the fungicides at all of the stations.

TABLE 29.—*Bunt control in and acre yields of grain from Ceres wheat grown from bunt-inoculated seed, separate lots of which were treated with different fungicides*[1] *and sown in rod rows replicated 5 times for each treatment at each of several stations in 1931*

Inoculum used	Station	Untreated		Seed treated with—							
				Formaldehyde		Copper carbonate		Ceresan		Basic copper sulphate	
		Bunt	Yield	Bunt	Yield	Bunt	Yield	Bunt	Yield	Bunt	Yield
		Pct.	*Bu.*	*Pct.*	*Bu.*	*Pct.*	*Bu.*	*Pct.*	*Bu.*	*Pct.*	*Bu.*
Bunt spores	Brookings	4.0	13.5	0.0	14.5	0.0	14.1	0.0	13.8	0.0	12.6
	Redfield	2.4	11.1	.0	12.0	.0	10.4	.0	10.3	.0	10.6
	St. Paul	.1	17.1	.0	16.0	.0	17.6	.0	17.4	.0	16.1
	Fargo	31.5	15.5	1.8	23.5	1.4	22.8	.2	23.8	.4	22.4
	Langdon	13.2	15.1	.2	14.1	.1	14.9	[2] T	14.9	.4	14.4
	Dickinson	11.4	13.5	.1	14.6	.1	15.2	.0	15.2	.0	14.0
	Moccasin	11.8	9.0	.2	9.5	.3	9.3	.1	10.0	.3	9.2
	Bozeman	7.7	45.1	.1	54.1	.2	52.3	.0	48.8	.0	51.1
	Average	10.3	17.5	.3	19.9	.3	19.6	T	19.3	.1	18.8
Bunt spores and bunt balls	Brookings	7.1	14.2	0.2	14.3	0.4	14.3	0.1	15.5	0.0	14.7
	Redfield[3]	5.1	------	.7	------	.1	------	.1	------	.0	------
	St. Paul	.5	17.6	.0	19.0	.0	17.9	.0	17.9	.0	16.9
	Fargo	40.3	9.5	1.4	21.2	2.6	21.2	.9	20.0	.5	19.4
	Langdon	24.5	14.1	3.1	16.5	1.4	14.8	.8	17.1	1.7	16.3
	Dickinson	21.8	11.7	.9	15.2	.8	14.8	.0	15.2	.1	15.3
	Moccasin	14.6	7.7	3.2	8.2	.9	7.1	.3	7.9	2.1	6.7
	Bozeman	8.4	36.4	2.4	50.3	.5	45.4	.0	46.4	.1	44.7
	Average	17.6	15.9	1.6	20.7	.9	19.4	.3	20.0	.5	19.1

[1] The dust fungicides were applied at 2 ounces per bushel. The formaldehyde was applied according to a modification of Braun's (*2*) method.
[2] T represents trace, or less than 0.1 percent.
[3] Not included in averages.

Despite this, however, there were two decreases in yield each from seed treated with formaldehyde, copper carbonate, and Ceresan, and four decreases from seed treated with basic copper sulphate. At Langdon, where there was 13.2-percent infection from untreated seed and an average of less than 0.5-percent from treated seed, none of the treatments seemed to increase the yield. The greatest benefits from treatment were obtained at Fargo, where 31.5-percent infection in the controls was reflected by an average yield of 32.9 percent less than the average yield from treated seed.

In the series in which the seed was infested both with spores and bunt balls (table 29) the percentage of bunt in the controls was higher, the average yields of the controls were lower, and the decrease in yield due to bunt was more pronounced even though control of bunt by the fungicides was somewhat less satisfactory. The yields from untreated seed exceeded those from treated seed in only three cases. There was an average of 17.6 percent of bunt in the controls at the eight stations. The reduction in yield from untreated seed as compared with that from seed treated with formaldehyde, copper carbonate, Ceresan, and basic copper sulphate was 23.2, 18.0, 20.5, and 16.7 percent, respectively, and the corresponding coefficients of correlation between percentage of bunt and the reductions in yield were 0.8263 ± 0.12, 0.8411 ± 0.11, 0.8790 ± 0.09, and 0.8895 ± 0.08, respectively.

Similar experiments the following year were limited to a study of the effects of Ceresan and two grades of copper carbonate on the yields from clean seed of Ceres, Marquis, and Mindum wheat at five stations. The seed was treated at Arlington Farm and sown in rod rows replicated five times at each station. The yield data are shown in table 30.

TABLE 30.—*Comparison of yields from clean treated [1] seed and clean untreated seed of 3 varieties of wheat sown at 5 stations in rod rows replicated 5 times from each treatment applied to each variety, 1932*

Variety	Station	Average yield of control	Increase or decrease in yield from seed treated with—					
			Copper carbonate		Ceresan		Coppercarb	
		Grams	*Grams*	*Percent*	*Grams*	*Percent*	*Grams*	*Percent*
Ceres	St. Paul	188± 6.4	−35± 7.0	−18.6	0± 7.6	0.0	−24± 7.2	−12.8
	Fargo	351±11.0	−60±15.4	−17.1	−18±16.4	−5.1	−35±16.0	−10.0
	Dickinson	353±16.9	−75±21.5	−21.2	−102±20.7	−28.9	−53±22.2	−15.0
	Brookings	205±11.3	4±16.1	2.0	11±16.4	5.4	−10±15.6	−4.9
	Redfield	178± 9.8	−17±13.2	−9.6	−20±13.1	−11.2	−16±13.2	−9.0
Marquis	St. Paul	156± 3.6	−30± 4.0	−19.2	−5± 5.0	−3.2	−25± 4.7	−16.0
	Fargo	256± 3.9	−6± 5.4	−2.3	−14± 5.3	−5.5	−9± 5.4	−3.5
	Dickinson	274± 9.7	−48±12.6	−17.5	−11±13.4	−4.0	−23±13.2	−8.4
	Brookings	162± 6.6	−1± 9.3	−.6	−24± 8.6	−14.8	−22± 8.7	−13.6
	Redfield	128± 9.5	−19±12.5	−14.8	−17±12.6	−13.3	−15±12.7	−11.7
Mindum	St. Paul	165±17.3	−36±21.9	−21.8	−13±23.5	−7.9	−32±22.2	−19.4
	Fargo	320±11.4	−49±14.9	−15.3	−27±15.4	−8.4	−16±15.7	−5.0
	Dickinson	248± 6.1	−35± 8.1	−14.1	−21± 8.3	−8.5	−59± 7.7	−23.8
	Brookings	172±13.2	−22±17.4	−12.8	−5±18.3	−2.9	10±19.2	5.8
	Redfield	90± 3.9	−16± 6.0	−17.8	−5± 5.4	−5.6	−2± 5.5	−2.2

[1] Copper carbonate and Ceresan were applied at 2 ounces and Coppercarb at 3 ounces per bushel.

Bunt infection was entirely absent in the rows from untreated seed. A comparison of yields from treated and untreated seed of all three varieties at the five stations reveals only three cases (all at Brookings) in which treating the seed resulted in increased yields. None of these, however, is significant. In 41 cases treatment was followed by decreased yields as compared with the yields from untreated seed. Only 11 of these decreases appear to be statistically significant.

The foregoing results of experiments relating to the effects of treatments on yields indicate that treatments as a rule did not increase the average yields of grain except approximately to the extent to which they reduced the percentage of bunted heads. The relation between the percentage of bunt and the resultant percentage reduction in yield presumably caused by it is by no means constant, as shown by a comparison between a considerable number of such percentages in these and other experiments. The percentage of bunt in the majority of cases exceeds the corresponding reduction in yield, the averages of the percentages in 10 experiments being 39 and 32, respectively. More abundant stooling in the infected plants from untreated seed probably accounts for this to some extent. No explanation is offered for the many cases of decreased yields from dusted seed compared with yields from untreated seed encountered in these experiments. A series of tests with a planter of the type used failed to show sufficient differences in the rate of flow of untreated seed and that of seed treated with different dust fungicides to appreciably affect the yield.

SUMMARY

Soil temperatures from about 6° to 15° C. from sowing to emergence were found most favorable for bunt infection, the highest average infection with both bunt species occurring at 10° in the four varieties of wheat used. Temperatures above 20° or below 5° were found highly unfavorable to bunt development. At any given temperature there was no positive correlation between length of emergence period and percentage of bunt. Soil-temperature conditions after emergence did not affect the percentage of infection in the variety used.

Excessive soil moisture tended to inhibit infection; wheat will germinate in soil too wet to bring about abundant germination of bunt spores.

Sandy soil was found less conducive to bunt infection than clay soil.

The application of lime to acid sandy soil increased the percentage of bunt from inoculated seed. Acid soil seemed to inhibit bunt infection. The percentage of infection was roughly proportional to the spore load. This relation was affected in each case by the date of sowing and the relative susceptibility of the variety.

More than 50 dust fungicides were tested for efficacy in bunt control over a period of 7 years. While many of them controlled bunt in the experiments in which they were used, most of them must be eliminated from consideration as practical bunt fungicides for use in the United States because of excessive cost, extreme poisonousness, corrosiveness, hygroscopicity, injury to seed, rapid deterioration, or unavailability.

Considering relative cost, availability, freedom from objectionable features, and general effectiveness in numerous experiments, copper carbonate or basic copper sulphate of the proper degree of fineness and containing not less than 50 percent of metallic copper, and New Improved Ceresan proved to be among the most practical dust fungicides for bunt control on the market in the United States. The diluted brands of copper carbonate, if of sufficient fineness and containing not less than 18 percent of copper, are equally effective if used at about a 50-percent heavier rate of application. Other copper salts, such as phosphate, red oxide, oxychloride, and oxalate, also were fairly effective, but are not generally available as bunt fungicides. Dusts containing formaldehyde, paraformaldehyde, naphthalene, iodine, or sulphur as the toxic ingredients were relatively ineffective.

Bunt control by means of fungicidal dusts was governed largely not only by the factors conducive or unfavorable to bunt infection but also by the rate or thoroughness of applying the dust, by the physical condition of the dust, by the period and manner of storage after treatment in the case of some dusts, and by certain soil conditions.

The fungicidal efficiency of copper carbonate was not affected by its copper-carbon dioxide ratio, its age or exposure to air, a range of 25 to 50 percent in its copper content, or by the length of the period between treating and sowing. Copper carbonate and some other dusts proved more effective in unlimed sandy acid soil than when lime was applied. Relatively dry soil after sowing did not affect the fungicidal action of the dusts used; neither did saturation of the soil except when the seed contained unbroken bunt balls or when the soil was infested. Under the latter conditions seed treatment with fungicidal dusts and to some extent with copper-sulphate solution effected a better degree of control than was secured by treatment with formaldehyde.

A small percentage of unbroken bunt balls in the seed did not greatly reduce the percentage of bunt control secured by dust fungicides. Soil infestation, however, reduced it considerably.

The effectiveness of certain volatile dusts was increased by storing the treated seed for some time after treatment, but prolonged storage with some dusts impaired germination. Storage of seed treated with copper carbonate or a number of other copper dusts or Ceresan for 5 weeks did not reduce the fungicidal effectiveness of these dusts, and storage for 1 year did not impair the viability of the seed.

Although the better treatments usually improved germination and controlled bunt, they did not increase the average yields from clean seed compared with yields from clean untreated seed.

In general, there was a high degree of correlation between the percentage of bunt in the crop from untreated seed and the percentage reduction in yield of the same crop as compared with the yields from seed adequately treated or from bunt-free seed.

Usually the average percentage of bunt was slightly greater than the percentage reduction in yield.

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