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RESEARCH BULLETIN 110

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## CONTENTS

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The depreciating effects of bunt or stinking smut (*Tilletia levis* Kühn and *tritici* [Bjerk.] Wint.) upon the yield and quality of winter wheat in Nebraska and many other states are well known. The practical control of this disease through seed treatment has also been established and is being extensively practiced by growers. At the time these experiments were initiated in 1923, formaldehyde was the most commonly used disinfectant, while copper carbonate was just gaining recognition following its introduction by Darnell-Smith (1) in 1915. It has been the chief purpose of the investigations herein reported to study the relative merits of various modified treatments with these two disinfectants, and to establish the relationship between the degree of infection and grain yield of a susceptible variety. The comparative effectiveness of several other fungicides and the longevity of spores, as well as the effect of variation in several cultural practices, have also been studied.

The application of the results obtained concerning seed treatments should be restricted to regions where the wheat is not subject to infection from spores carried in the soil. So far as is known, this would exclude only the Pacific Northwest.

## HISTORICAL

The nature, ecological relations, and control of bunt have been rather fully reported by Heald (4), Leukel (6), and Woolman and Humphrey (10). These publications are accompanied by extensive literature citations. Haskell, Leukel, and Boerner (3) and others present information concerning the occurrence of bunt and the use of mechanical equipment in the application of chemicals for its control. Leukel (6) and Nelson and Leukel (8) report recent comparisons of various seed treatments with respect to both smut control and grain yield of wheat.

The relationship between degree of bunt infection and grain yield has been investigated by a number of workers. Heald and Gaines (5) summarize their results as follows:

"An average difference of 25.8 per cent of smutted heads made a difference of 23 per cent in yield. The coefficient of correlation between smut and yield was —.713±.0955 which is nearly 16 times the probable error." It is concluded that the percentage of smutted heads is a fairly accurate indication of the actual loss to the farmer.

In a test with three varieties during the 1929-30 season, Flor, Gaines, and Smith (2) found that the correlation between percentage of smut and grain yield was —.81 ± .05 for Hybrid 128 wheat, —.86 ± .04 for Turkey wheat and —.60 ± .09 for Ridit. An average increase of 16.2 per cent of bunt with Hybrid 128 caused a reduction of 20.5 per cent in yield, while with Turkey an increase of 30.3 per cent of bunt resulted in a 23.1 per cent

reduction in yield. With Ridit an average increase of 1.13 per cent of bunted heads resulted in a reduction of 11.3 per cent in yield. This difference of response was accounted for in part by "the morphological reactions of the Ridit plants to smut infection, such as dwarfing of the culms, failure to head, and distortion and partial sterility of infected heads."

From very inclusive tests in a number of states over a period of years, using several kinds of wheat and a great variety of fungicides, Leukel (6) has drawn the following conclusions as to the relation between degree of infection and yield of grain per acre: "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. 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."

## EXPERIMENTAL

### Experimental Procedure

**Yield and smut deteminations.**—Except for three nursery experiments (Tables 6, 12, and 14), all tests relating to the effects of smut infection and to the effectiveness of various seed treatments were made in duplicate or triplicate field plots, ranging in different seasons from 1/25 to 1/50 acre in size. The seed was planted on land previously in oats with a standard 7-foot grain drill during the normal planting period. The rate of sowing was regularly five pecks per acre, which is common for this region. The drill was thoroughly cleaned between lots and the planting order was so arranged as to subject the seed to the least possible reinfection in the drill. In threshing the order was from the least to the most severely infected plots as an aid in retaining within the threshed seed the normal amount of inoculum as developed in the respective plots. The separator was adjusted to thoroughly clean the grain of chaff and straw.

The severity of infection was determined by the percentage of smutted heads, based on five counts of 100 heads made in various parts of each plot. Considering replicate plots, this resulted in 10 or 15 independent counts which were averaged for each treatment.

**Preparation of the seed.**—With one exception (Table 10), the seed used in these tests has uniformly been of the Kanred variety, which is a standard hard red winter wheat for this region. Its reaction to the races of bunt occurring in Nebraska is rather similar to that of other winter varieties that are extensively grown here. Infected heads commonly become smutted throughout.

The seed had its origin annually in two lots of Kanred wheat harvested respectively from nearly smut-free and severely smut-infected plots. For studies involving different degrees of infection, various proportions of the smutty and nearly smut-free seed were mixed together.

Nearly smut-free and smutty seed of the origin indicated above were also used in the seed-treatment studies. The smut occurring in these tests was *T. levis*, which is the prevailing type found in this region. It was a mixture of a number of smut collections from various parts of Nebraska.

**Seed treatment.**—Except where otherwise indicated, unfanned seed has been used in the various seed-treatment tests herein reported. Such smutted seed therefore contained smut balls which were not removed in threshing, resembling in this respect a large percentage of the seed as planted on farms.

All dust treatments, such as copper carbonate, were applied by means of 20 revolutions in a home-made barrel mixer which resulted in thorough dusting. With the formaldehyde treatments care was taken to use full strength formalin, which approximates a 40 per cent solution of formaldehyde in preparing the desired dilutions. Details as to manner of application are stated in connection with the various seed-treatment tests.

## Effect of Smut on Yield

The relationship between smut infection and the grain yield of winter wheat was studied annually during a nine-year period, 1924-1932. Differences in spore load carried by the seed were not of primary concern but were designed to bring about various degrees of infection in the ensuing crop as determined by count of smutted heads. Nearly smut-free seed and heavily smutted seed were used as the two extremes and four intermediate degrees of inoculation were prepared annually by mixing these two lots of seed in various proportions. For the purpose of reference, these six lots of seed and their proportions of nearly smut-free to heavily smutted seed were designated as follows: Trace, 100:0; slight, 98:2; medium, 90:10; severe, 80:20; very severe, 50:50; and extreme, 0:100.

The annual and average results with respect to percentage of infected heads, test weight per bushel, and yield of grain per acre are given in Table 1. With a 9-year average percentage of smutted heads varying from 1.1 to 43.4, the weight per bushel varied from 58.7 to 55.1 pounds, and the yield per acre ranged from 26.9 to 17.0 bushels. Examination of the table discloses a rather close inverse relation between the annual as well as the average smut counts and yields. This is more evident when the results of Table 1 are calculated as in Table 2, infection being indicated in terms of smut-free heads. Here the annual results for the nearly smut-free seed are used as a base for making the calculations and are expressed as 100 per cent.

This close relationship is also readily apparent from the high correlation of $+.919 \pm .014$ calculated from the relative acre yields and percentages of *smut-free* heads reported in Table 2. A corresponding negative correlation between yield and percentage of *smutted* heads is $-.919 \pm .014$.

The rather regular decrease in weight per bushel as the degree of smut infection increased may be ascribed to a greater proportion of smut balls in the threshed grain.

TABLE 1.—*Relation of the percentage of smutted heads to the yield of grain per acre—nine years, 1924-1932.*

| Degree of seed inoculation | Crop harvested | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1924 | 1925 | 1926 | 1927 | 1928 | 1929 | 1930 | 1931 | 1932 | Av. |
| | SMUTTED HEADS IN CROP *(per cent)* | | | | | | | | | |
| Trace | 0.0 | 0.2 | 0.6 | 2.1 | 2.0 | 0.7 | 1.2 | 3.0 | 0.1 | 1.1 |
| Slight | 2.8 | 2.6 | 19.0 | 5.6 | 18.1 | 2.1 | 9.4 | 19.4 | 14.3 | 10.4 |
| Medium | 7.8 | 6.2 | 26.0 | 9.8 | 24.8 | 2.6 | 19.6 | 34.5 | 26.2 | 17.5 |
| Severe | 12.4 | 8.2 | 45.4 | 16.1 | 42.7 | 8.2 | 21.5 | 49.0 | 27.4 | 25.7 |
| Very severe | 42.4 | 12.0 | 41.2 | 27.3 | 54.0 | 13.1 | 21.5 | 64.0 | 48.6 | 36.0 |
| Extreme | 62.7 | 21.4 | 61.2 | 27.8 | 58.0 | 15.0 | 27.2 | 69.0 | 47.9 | 43.4 |
| | WEIGHT PER BUSHEL *(pounds)* | | | | | | | | | |
| Trace | 59.5 | 59.5 | 61.5 | 60.0 | 59.0 | 54.8 | 60.5 | 55.3 | 58.0 | 58.7 |
| Slight | 58.5 | 58.5 | 60.0 | 60.0 | 58.0 | 54.5 | 60.5 | 55.3 | 57.3 | 58.1 |
| Medium | 58.0 | 58.5 | 60.0 | 59.0 | 56.5 | 53.3 | 60.0 | 54.3 | 57.5 | 57.5 |
| Severe | 57.0 | 58.0 | 60.0 | 58.0 | 55.0 | 53.5 | 60.3 | 53.8 | 57.5 | 57.0 |
| Very severe | 54.0 | 58.0 | 60.0 | 57.0 | 53.0 | 54.0 | 60.0 | 53.5 | 54.5 | 56.0 |
| Extreme | 49.0 | 58.0 | 59.0 | 57.0 | 51.4 | 55.5 | 60.0 | 52.5 | 53.3 | 55.1 |
| | YIELD OF GRAIN PER ACRE *(bushels)* | | | | | | | | | |
| Trace | 34.7 | 11.0 | 8.7 | 32.6 | 25.1 | 33.2 | 37.7 | 25.4 | 33.4 | 26.9 |
| Slight | 31.8 | 11.0 | 8.4 | 31.6 | 21.0 | 32.9 | 32.5 | 20.1 | 30.7 | 24.4 |
| Medium | 28.2 | 9.7 | 6.5 | 29.1 | 20.6 | 33.9 | 32.3 | 15.5 | 28.8 | 22.7 |
| Severe | 26.5 | 8.4 | 7.2 | 29.4 | 16.1 | 30.5 | 31.9 | 14.1 | 27.1 | 21.2 |
| Very severe | 20.7 | 9.0 | 5.1 | 28.3 | 14.9 | 31.7 | 30.6 | 11.6 | 23.7 | 19.5 |
| Extreme | 16.3 | 7.9 | 4.8 | 21.1 | 13.1 | 27.8 | 30.7 | 6.9 | 24.2 | 17.0 |

TABLE 2.—*Effects of progressive increases in smut infection upon the acre yield of grain—calculated from data in Table 1—nine years, 1924-1932.*

| Degree of seed inoculation | Crop harvested | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1924 | 1925 | 1926 | 1927 | 1928 | 1929 | 1930 | 1931 | 1932 | Av. |
| | RELATIVE PERCENTAGES OF SMUT-FREE HEADS | | | | | | | | | |
| Trace | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |
| Slight | 97.2 | 97.6 | 81.5 | 96.4 | 83.6 | 98.6 | 91.7 | 83.1 | 85.8 | 90.6 |
| Medium | 92.2 | 94.0 | 74.4 | 92.1 | 76.7 | 98.1 | 81.4 | 67.5 | 73.9 | 83.4 |
| Severe | 87.6 | 92.0 | 54.9 | 85.7 | 58.5 | 92.4 | 79.5 | 52.6 | 72.7 | 75.1 |
| Very severe | 57.6 | 88.2 | 59.2 | 74.3 | 46.9 | 87.5 | 79.5 | 37.1 | 51.5 | 64.6 |
| Extreme | 37.3 | 78.8 | 39.0 | 73.7 | 42.9 | 85.6 | 73.7 | 32.0 | 52.2 | 57.2 |
| | RELATIVE YIELDS OF GRAIN | | | | | | | | | |
| Trace | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |
| Slight | 91.6 | 100.0 | 96.6 | 96.9 | 83.7 | 99.1 | 86.2 | 79.1 | 91.9 | 91.7 |
| Medium | 81.3 | 88.2 | 74.7 | 89.3 | 82.1 | 102.1 | 85.7 | 61.0 | 86.2 | 83.4 |
| Severe | 76.4 | 76.4 | 82.8 | 90.2 | 64.1 | 91.9 | 84.6 | 55.5 | 81.1 | 78.1 |
| Very severe | 59.7 | 81.8 | 58.6 | 86.8 | 59.4 | 95.5 | 81.2 | 45.7 | 71.0 | 71.1 |
| Extreme | 47.0 | 71.8 | 55.2 | 64.7 | 52.2 | 83.7 | 81.4 | 27.2 | 72.5 | 61.7 |

Bearing on this same question the correlation has been calculated between the smut percentages and grain yields in the seed treatment and cultural tests reported in Tables 3, 4, 5, 6, 7, 9, and 10. The data from formaldehyde and mercuric disinfectants were omitted, since these chemicals may affect yield by action other than smut control. In order that the results from various experiments might be assembled for a single correlation, the yields and smut counts of each test were calculated on a relative basis, regarding both the highest yield and the highest count of *smut-free* heads as 100 per cent. This procedure eliminates error due to seasonal variation in size of yield. These data for 153 variates give a correlation of $+.922 \pm .008$, and a negative correlation of like magnitude when based on *smutted* heads.

**Relative Effectiveness of Formaldehyde and Copper Carbonate**

During the eight-year period, 1924-1931, standard treatments with copper carbonate and formaldehyde were compared with respect to smut control and grain yield when applied to seed varying in degree of inoculation. Nearly smut-free and heavily infected seed lots were used as they came from the thresher. An intermediate sample was prepared by mixing equal quantities of the other two.

The formaldehyde was applied by the method of sack-immersion for 30 minutes in a solution of 1 pint formalin to 40 gallons water. The seed was then spread out to dry after standing covered two hours. The copper carbonate treatment consisted of the commercial dilute copper carbonate, approximately 20 per cent copper, applied at the rate of two ounces per bushel by means of a barrel mixer.

The annual and average smut counts, test weights, and grain yields of the crops harvested are reported in Table 3. In the case of untreated seed, the three progenies contained, respectively, 1.0, 31.4, and 42.4 per cent smutted heads as an average for the eight years. Corresponding grain yields were 25.9, 20.1, and 18.0 bushels per acre. While both kinds of treatment gave very good control, the copper carbonate proved slightly less effective where the spore-load was rather high. On the other hand, the formaldehyde tended to have a somewhat depressing effect on yield. This yield reduction amounted to an average of 1.6 bushels per acre for the nearly smut-free seed, while the yield for corresponding copper-carbonate-treated seed was increased 0.2 bushel. This is evidence of smut control by copper carbonate, without injury. Although no determinations were made concerning the effects of the formaldehyde treatment on seed viability in these tests, it is possible that the yield reduction was due to such injury as found by Peltier (9) and Leukel (6). The highest average yield and lowest smut infection were obtained from the nearly smut-free seed treated with copper carbonate.

Seed treatment of smutted seed materially improved the grain quality of the ensuing crop, as indicated by increased test weight. The increase was almost identical for the formaldehyde and copper carbonate.

TABLE 3.—*Relative effects of formaldehyde and copper carbonate treatment of seed wheat differing in degree of bunt inoculation—eight years, 1924-31.*

| Degree of seed inoculation and kind of treatment [1] | Crop harvested | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1924 | 1925 | 1926 | 1927 | 1928 | 1929 | 1930 | 1931 | Av. |
| | SMUTTED HEADS IN CROP *(per cent)* | | | | | | | | |
| Nearly smut-free: | | | | | | | | | |
| Not treated | 0.5 | 0.1 | 0.0 | 0.8 | 1.4 | 0.1 | 0.5 | 4.6 | 1.0 |
| Formalin, 1 pint to 40 gal. water | 0.2 | 0.0 | 0.0 | 0.6 | 0.4 | 0.2 | 0.1 | 0.5 | 0.3 |
| Copper carbonate (20%), 2 oz. per bu. | 0.2 | 0.0 | 0.1 | 0.3 | 0.0 | 0.0 | 0.1 | 0.5 | 0.2 |
| Mediumly smutted: | | | | | | | | | |
| Not treated | 38.0 | 15.0 | 43.0 | 7.1 | 48.7 | 15.9 | 24.1 | 59.5 | 31.4 |
| Formalin, 1 pint to 40 gal. water | 1.0 | 0.2 | 0.1 | 3.1 | 0.0 | 0.2 | 0.8 | 1.2 | 0.8 |
| Copper carbonate (20%), 2 oz. per bu. | 2.0 | 0.5 | 4.0 | 4.0 | 1.7 | 0.4 | 1.9 | 1.2 | 2.0 |
| Severely smutted: | | | | | | | | | |
| Not treated | 63.0 | 22.6 | 53.0 | 18.0 | 64.2 | 20.0 | 28.4 | 70.0 | 42.4 |
| Formalin, 1 pint to 40 gal. water | 2.0 | 0.3 | 0.0 | 2.0 | 0.2 | 1.1 | 0.1 | 0.9 | 0.8 |
| Copper carbonate (20%), 2 oz. per bu. | 8.0 | 0.5 | 6.0 | 1.5 | 2.5 | 0.9 | 5.3 | 4.0 | 3.6 |
| | TEST WEIGHT PER BUSHEL *(pounds)* | | | | | | | | |
| Nearly smut-free: | | | | | | | | | |
| Not treated | 58.7 | 58.5 | 61.0 | 59.5 | 59.0 | 54.3 | 61.3 | 55.2 | 58.4 |
| Formalin, 1 pint to 40 gal. water | 58.2 | 58.5 | 61.5 | 58.5 | 60.0 | 54.0 | 60.2 | 55.0 | 58.2 |
| Copper carbonate (20%), 2 oz. per bu. | 58.2 | 59.0 | 61.5 | 57.0 | 59.8 | 54.0 | 61.3 | 56.0 | 58.4 |
| Mediumly smutted: | | | | | | | | | |
| Not treated | 54.0 | 59.0 | 61.0 | 57.0 | 55.3 | 55.0 | 60.8 | 53.0 | 56.9 |
| Formalin, 1 pint to 40 gal. water | 58.0 | 59.0 | 62.0 | 57.5 | 59.8 | 55.5 | 61.5 | 55.5 | 58.6 |
| Copper carbonate (20%), 2 oz. per bu. | 58.0 | 59.0 | 61.5 | 58.0 | 59.0 | 55.8 | 61.3 | 54.0 | 58.3 |
| Severely smutted: | | | | | | | | | |
| Not treated | 51.7 | 58.5 | 60.5 | 59.0 | 53.0 | 55.5 | 60.0 | 51.8 | 56.3 |
| Formalin, 1 pint to 40 gal. water | 57.5 | 58.5 | 62.0 | 55.5 | 59.8 | 55.5 | 61.0 | 55.3 | 58.1 |
| Copper carbonate (20%), 2 oz. per bu. | 57.0 | 58.0 | 61.5 | 58.0 | 58.5 | 55.5 | 61.3 | 54.8 | 58.1 |
| | YIELD OF GRAIN PER ACRE *(bushels)* | | | | | | | | |
| Nearly smut-free: | | | | | | | | | |
| Not treated | 35.0 | 10.4 | 9.6 | 36.3 | 23.7 | 33.9 | 34.5 | 23.9 | 25.9 |
| Formalin, 1 pint to 40 gal. water | 36.7 | 7.9 | 8.0 | 33.8 | 21.0 | 30.6 | 33.4 | 23.2 | 24.3 |
| Copper carbonate (20%), 2 oz. per bu. | 36.8 | 9.5 | 9.2 | 36.0 | 25.3 | 32.0 | 34.2 | 25.8 | 26.1 |
| Mediumly smutted: | | | | | | | | | |
| Not treated | 27.5 | 8.5 | 8.5 | 32.0 | 15.3 | 29.5 | 30.2 | 9.1 | 20.1 |
| Formalin, 1 pint to 40 gal. water | 33.0 | 7.7 | 10.7 | 31.7 | 23.7 | 32.0 | 32.7 | 25.3 | 24.6 |
| Copper carbonate (20%), 2 oz. per bu. | 34.0 | 8.6 | 9.3 | 25.5 | 24.0 | 32.5 | 30.8 | 27.1 | 24.0 |
| Severely smutted: | | | | | | | | | |
| Not treated | 20.5 | 6.5 | 5.6 | 33.1 | 14.4 | 29.1 | 26.8 | 8.3 | 18.0 |
| Formalin, 1 pint to 40 gal. water | 34.6 | 7.9 | 9.2 | 32.1 | 22.3 | 29.9 | 31.3 | 23.9 | 23.9 |
| Copper carbonate (20%), 2 oz. per bu. | 35.2 | 7.9 | 8.9 | 37.1 | 23.4 | 30.0 | 29.1 | 25.6 | 24.7 |

[1] Formalin solution applied by immersing in sack for half hour and spreading out to dry after standing covered two hours. Copper carbonate applied by thorough dusting in home-made barrel mixer which was given 20 revolutions.

### Effects of Fanning Naturally Inoculated Seed Before Treating

The advantages of removing smut balls either by fanning before treatment or by skimming off after placing the seed in a formaldehyde solution for treatment have been stressed by many workers. The effect of removal by means of an ordinary fanning mill has been tested during a four-year period, 1929-1932, in conjunction with both formaldehyde and copper carbonate treatments. The seed used was from a heavily smutted crop. The formaldehyde was applied by the sack-immersion method, while copper carbonate (20 per cent) was used at the rate of two ounces per bushel (Table 4).

TABLE 4.—*Effects of fanning naturally inoculated seed wheat preliminary to standard treatments with copper carbonate or formaldehyde* [1]*—four years, 1929-32.*

| Seed treatment | Crop harvested | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Smutted heads in crop | | | | | Yield of grain per acre | | | | |
| | 1929 | 1930 | 1931 | 1932 | Av. | 1929 | 1930 | 1931 | 1932 | Av. |
| | *P. ct.* | *P. ct.* | *P. ct.* | *P. ct.* | *P. ct.* | *Bu.* | *Bu.* | *Bu.* | *Bu.* | *Bu.* |
| No treatment: | | | | | | | | | | |
| Not fanned ..... | 21.6 | 18.4 | 67.2 | 31.8 | 34.8 | 26.9 | 27.5 | 8.7 | 24.4 | 21.9 |
| Formaldehyde: | | | | | | | | | | |
| Not fanned ..... | 0.0 | 0.3 | 5.8 | 7.4 | 3.4 | 31.8 | 30.2 | 22.8 | 32.8 | 29.4 |
| Fanned ..... | 0.7 | 0.0 | 0.2 | 5.4 | 1.6 | 31.9 | 31.5 | 23.5 | 34.7 | 30.4 |
| Copper carbonate: | | | | | | | | | | |
| Not fanned ..... | 2.0 | 1.0 | 9.6 | 8.1 | 5.2 | 32.8 | 34.0 | 25.1 | 34.1 | 31.5 |
| Fanned ..... | 0.8 | 0.3 | 1.6 | 0.7 | 0.9 | 34.1 | 36.0 | 24.0 | 37.0 | 32.8 |

[1] The copper carbonate (20 per cent) was applied at the rate of two ounces per bushel of seed. The formaldehyde treatment consisted of soaking 30 minutes in a solution of one pint formalin to 40 gallons water. The seed was spread out to dry after standing covered two hours.

As an average for the four years the resultant crop from seed that was neither fanned nor treated contained 34.8 per cent smutted heads, and yielded 21.9 bushels per acre. Treated with formaldehyde, the crop harvested from unfanned and fanned seed contained 3.4 and 1.6 per cent smutted heads, respectively, and yielded 29.4 and 30.4 bushels per acre. When treated with copper carbonate, the unfanned seed produced 5.2 per cent smutted heads and 31.5 bushels of grain per acre, compared with 0.9 per cent infected heads and 32.8 bushels of grain for fanned seed.

It is evident that preliminary fanning was advantageous with both treatments, the highest average yield being secured from the combination of fanning and copper carbonate.

Although the two treatments differed but slightly in smut control, the grain yield following the use of formaldehyde was fully two bushels less per acre for both fanned and unfanned seed than in the case of copper carbonate.

## Reinoculation of Unfanned Seed after Treatment

**Field plot test.**—The objective of this test was to determine the possibility of reinoculation, by handling, of treated seed containing smut balls. This should have a bearing on the question of need for removing smut balls in connection with the treatment. Heavily infected seed just as it came from the thresher was used in this five-year test, 1928-1932.

Part of the seed was treated with formaldehyde by the sack-immersion method. Another portion had two ounces of copper carbonate (20 per cent) applied per bushel. Several days later, when the soaked seed had become dry, part of each lot was rubbed in order to determine whether such rough handling might influence the effectiveness of the treatments, by virtue of breaking smut balls with viable contents.

TABLE 5.—*Reinoculation of treated seed containing smut balls by rubbing the seed after treatment—five years, 1928-32.*

| Seed treatment | Crop harvested | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Smutted heads in crop | | | | | | Yield of grain per acre | | | | | |
| | 1928 | 1929 | 1930 | 1931 | 1932 | Av. | 1928 | 1929 | 1930 | 1931 | 1932 | Av. |
| | *P.ct.* | *P.ct.* | *P.ct.* | *P.ct.* | *P.ct.* | *P.ct.* | *Bu.* | *Bu.* | *Bu.* | *Bu.* | *Bu.* | *Bu.* |
| None..... | 46.2 | 21.6 | 18.4 | 67.2 | 31.8 | 37.0 | 14.7 | 27.8 | 27.5 | 8.7 | 24.4 | 20.6 |
| FORMALDEDYDE [1] | | | | | | | | | | | | |
| Not rubbed. | 0.3 | 0.0 | 0.3 | 5.8 | 7.4 | 2.8 | 22.9 | 31.8 | 30.2 | 22.8 | 32.8 | 28.1 |
| Rubbed.... | 0.8 | 2.9 | 3.1 | 22.3 | 5.1 | 6.8 | 22.3 | 31.5 | 30.8 | 19.3 | 33.3 | 27.4 |
| COPPER CARBONATE [2] | | | | | | | | | | | | |
| Not rubbed. | 0.7 | 2.0 | 1.0 | 9.6 | 8.1 | 4.3 | 25.7 | 32.8 | 34.0 | 25.1 | 34.1 | 30.3 |
| Rubbed ... | 0.5 | 3.8 | 1.8 | 28.0 | 8.5 | 8.5 | 23.0 | 32.5 | 35.2 | 16.5 | 35.9 | 28.6 |

[1] Formaldehyde treatment consisted of soaking 30 minutes in a solution of 1 pint formalin and 40 gallons water. After standing covered with canvas for 2 hours, the seed was spread out to dry.
[2] Two ounces copper carbonate (20 per cent) were applied per bushel.

As an average for the period (Table 5) the crop grown from untreated seed contained 37.0 per cent smutted heads and yielded 20.6 bushels per acre. When treated with formaldehyde, rubbing increased the percentage of smut from 2.8 to 6.8 per cent and lowered the yield from 28.1 to 27.4 bushels per acre. In case of seed treated with copper carbonate, rubbing increased the smut from 4.3 per cent to 8.5 per cent and lowered the yield from 30.3 bushels to 28.6 bushels.

Such reinoculation would seem readily possible in the case of formaldehyde-treated seed if the disinfectant failed to reach the interior of the smut balls. The rubbing may have lowered the efficiency of copper carbonate by removing part of the dust coating accompanied by an increase in the spore load.

While it is not likely that seed would receive such rough handling after treatment in farm practice, yet this test indicates that the presence of smut balls in treated grain may be a potential source for renewed inoculation. Smut balls also may serve as a soil inoculation causing infection of the young seedling even though the seed is treated. Removal of smut balls as a part of the seed-treatment program would seem good practice.

**Nursery test.**—A special study was made in triplicate five-row nursery plots in 1928, bearing upon the question of possible reinoculation from self-contained smut balls after seed treatment.

Heavily smutted Kanred seed was used in the same condition as it came from the thresher. This was divided into four parts which received the following respective treatments:

(1) No disinfectant,
(2) Formaldehyde spray (1 part formalin in 9 parts water),
(3) Formaldehyde soaking treatment (30 minutes in solution of 1 pint formalin to 40 gallons water),
(4) Two-ounce application of copper carbonate (50 per cent).

Each of these four samples was divided, one portion being planted without further treatment, while the smut balls were first thoroughly crushed in the other. For comparison, four samples of nearly smut-free seed were inoculated respectively with smut taken from each of the above four treated and untreated samples. This made a total of 13 samples to be com-

TABLE 6.—*Effect of seed treatment with formaldehyde and copper carbonate upon the viability of smut spores contained in the smut balls of Kanred winter wheat—1928.*

| Description of seed planted | Smutted heads in crop grown | Yield per acre | |
|---|---|---|---|
| | | Straw | Grain |
| | *P. ct.* | *Lbs.* | *Bu.* |
| SMUTTED SEED WITHOUT DISINFECTION | | | |
| Seed without additional treatment | 64.0 | 1700 | 10.2 |
| Same seed reinoculated by crushing smut balls | 61.8 | 1786 | 9.2 |
| Nearly smut-free seed inoculated with smut from No. 2 | 63.6 | 1642 | 10.6 |
| SMUTTED SEED TREATED WITH FORMALDEHYDE SPRAY (1 part formalin to 9 parts water) | | | |
| Seed without additional treatment | 8.3 | 1744 | 21.6 |
| Same seed reinoculated by crushing smut balls | 56.0 | 1670 | 13.6 |
| Nearly smut-free seed inoculated with smut from No. 2 | 69.0 | 1726 | 9.2 |
| SMUTTED SEED TREATED WITH FORMALDEHYDE SOLUTION (1 pint formalin to 40 gal. water—soaking method) | | | |
| Seed without additional treatment | 0.6 | 1618 | 22.5 |
| Same seed reinoculated by crushing smut balls | 8.9 | 1650 | 21.2 |
| Nea ly smut-free seed inoculated with smut from No. 2 | 18.4 | 1644 | 19.2 |
| SMUTTED SEED TREATED WITH COPPER CARBONATE (2 oz. per bu. of 50 per cent strength) | | | |
| Seed without additional treatment | 5.6 | 1800 | 23.4 |
| Same seed reinoculated by crushing smut balls | 58.0 | 1824 | 13.3 |
| Nearly smut-free seed inoculated with smut from No. 2 | 22.8 | 1820 | 20.8 |
| NEARLY SMUT-FREE SEED WITHOUT DISINFECTION | | | |
| Seed without additional treatment | 0.6 | 1708 | 24.2 |

Nursery test in triplicate. Yields based on three middle rows of 5-row plots, 16 feet in length.

pared, including one of nearly smut-free untreated seed. The percentages of smutted heads and the grain and straw yields of the resultant crops are reported in Table 6.

It is evident from these data that some spores remained viable in at least part of the smut balls following all treatments, and their presence in treated seed may be a source of further infection. In the use of formaldehyde, the spray method was especially ineffective. By the soaking method the formaldehyde was able to penetrate more thoroughly into the smut balls. From the high reinfection after copper carbonate, it is apparent that a coating of this chemical does not assure against further infection from the breaking of smut balls.

**Effect of the Strength and Dosage of the Copper Carbonate Application**

With an extensive adoption of the copper carbonate treatment for bunt, there developed much interest as to the proper strength and dosage to use. Two grades, differing in amount of metallic copper, are normally on the market. The one contains 50 per cent of copper and the other approximately 20 per cent of this element. The use of 20 per cent copper carbonate applied by thorough mixing at the rate of two ounces per bushel has been a rather common recommendation for farm practice, although 2½ to 3 ounces are now usually suggested for this dilute form. Since this material does not affect the germination of the seed, and the cost is relatively low, whatever strength or amount gives the most efficient control would seem advisable.

During the four years 1928-1931, both 20 and 50 per cent copper carbonate were tested at the rates of 1, 2, 3, and 4 ounces per bushel of seed. These applications were applied to heavily smutted, unfanned seed. The annual and average results are reported in Table 7.

As an average for the period, the untreated seed produced 38 per cent smutted heads and yielded 20.3 bushels per acre. With applications of 1, 2, 3, and 4 ounces, the 20 per cent copper carbonate gave respective smut counts of 7.0, 3.2, 1.9, and 1.2 per cent. Corresponding counts for the 50 per cent copper carbonate were 7.4, 2.3, 2.2, and 1.7 per cent. The grain yields for these four rates of application were progressively 27.7, 29.0, 27.5, and 27.6 bushels for the 20 per cent material, and 27.4, 27.8, 27.2, and 27.7 bushels for the 50 per cent copper carbonate.

One ounce per bushel was clearly insufficient when judged by the number of smutted heads. Two ounces were ample in case of the 50 per cent copper carbonate. On the other hand, 2 ounces were not quite as effective in controlling smut as 3 ounces in case of the 20 per cent copper carbonate. Taking into consideration the favorable results from 2-ounce applications of 20 per cent copper carbonate in other tests where the seed infection was low (Table 3), it may be deduced that such dosage is sufficient when the seed infection is known to be light, and that 2½ or 3 ounces would be advisable when the seed is heavily infected, and especially when it has not been fanned. As shown in Table 4, a combination of fanning and a 2-ounce application of 20 per cent copper carbonate was very effective.

TABLE 7.—*Relative effectiveness of 1, 2, 3, and 4 ounces each of 20 and 50 per cent copper carbonate applied per bushel of heavily smutted seed—four years, 1928-1931.*

| Copper carbonate applied per bushel | Crop harvested | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Seed treated with 20 per cent copper carbonate | | | | | Seed treated with 50 per cent copper carbonate | | | | |
| | 1928 | 1929 | 1930 | 1931 | Av. | 1928 | 1929 | 1930 | 1931 | Av. |
| | SMUTTED HEADS IN CROP (*per cent*) | | | | | | | | | |
| No treatment | 47.6 | 19.1 | 20.0 | 65.2 | 38.0 | 47.6 | 19.1 | 20.0 | 65.2 | 38.0 |
| 1 ounce | 6.8 | 0.6 | 0.9 | 19.5 | 7.0 | 2.6 | 5.2 | 1.9 | 19.7 | 7.4 |
| 2 ounces | 2.7 | 0.4 | 0.2 | 9.6 | 3.2 | 0.7 | 2.7 | 0.9 | 4.7 | 2.3 |
| 3 ounces | 1.9 | 0.7 | 0.7 | 4.4 | 1.9 | 0.2 | 3.1 | 1.1 | 4.4 | 2.2 |
| 4 ounces | 1.3 | 0.5 | 0.7 | 2.3 | 1.2 | 0.9 | 2.0 | 1.0 | 2.7 | 1.7 |
| | TEST WEIGHT PER BUSHEL (*pounds*) | | | | | | | | | |
| No treatment | 54.7 | 55.7 | 60.9 | 51.6 | 55.7 | 54.7 | 55.7 | 60.9 | 51.6 | 55.7 |
| 1 ounce | 59.8 | 56.0 | 60.5 | 55.0 | 57.8 | 58.0 | 55.5 | 59.0 | 54.5 | 56.8 |
| 2 ounces | 58.5 | 55.5 | 59.8 | 55.3 | 57.3 | 60.5 | 56.0 | 60.8 | 54.3 | 57.9 |
| 3 ounces | 58.3 | 55.3 | 60.8 | 55.0 | 57.4 | 60.0 | 56.0 | 60.8 | 54.5 | 57.8 |
| 4 ounces | 57.5 | 56.8 | 60.5 | 56.0 | 57.7 | 60.3 | 56.5 | 60.8 | 54.8 | 58.1 |
| | YIELD OF GRAIN PER ACRE (*bushels*) | | | | | | | | | |
| No treatment | 15.4 | 27.8 | 29.2 | 8.7 | 20.3 | 15.4 | 27.8 | 29.2 | 8.7 | 20.3 |
| 1 ounce | 20.9 | 34.5 | 32.6 | 22.6 | 27.7 | 23.2 | 34.4 | 30.3 | 21.8 | 27.4 |
| 2 ounces | 24.3 | 33.6 | 32.9 | 25.1 | 29.0 | 25.7 | 32.2 | 29.9 | 23.4 | 27.8 |
| 3 ounces | 22.7 | 33.7 | 30.6 | 23.1 | 27.5 | 25.4 | 29.2 | 31.5 | 22.7 | 27.2 |
| 4 ounces | 23.8 | 28.6 | 33.3 | 24.7 | 27.6 | 25.3 | 29.6 | 32.5 | 23.5 | 27.7 |

## Methods of Applying Formaldehyde to Fanned and Unfanned Seed

The use of concentrated formaldehyde solutions in the control of smut has proved so successful with the oats crop that it seemed of interest to test their value in the treatment of winter wheat. Seven methods of application were compared for a three-year period, 1929-1931. Four of these were used on fanned as well as unfanned seed. The seed was heavily smutted as indicated by an average occurrence of 35.7 per cent smutted heads in the resultant crop from untreated seed. The various treatments and results are reported in Table 8.

Two methods employing the dilute solution of 1 pint formalin to 40 gallons water were so outstandingly superior in both smut control and grain yield that no others need be considered. In one case the seed was immersed in a bag in the solution for one-half hour. After draining briefly it was covered in a pile for two hours with a canvas to retain the gas. It was then spread out thin to dry. Where numerous smut balls are present, a superior modification of this method is to pour the seed directly into the solution so that the smut balls, which are light and rise to the surface, may be skimmed off and rejected. In the second case, a similar solution was sprinkled on the piled seed at the rate of one gallon per bushel. The

seed was scooped about several times during the application in order to insure a thorough wetting. Thereafter it was covered as above for a two-hour period, then spread out to dry. The methods of spraying or sprinkling concentrated solutions are not efficient in the case of wheat.

Need for care in the use of formaldehyde solutions is indicated by the results from a solution four times the standard strength applied at the rate of one gallon to the bushel by the sprinkling method. The seed was completely killed each of the three years. No such dangers accompany the use of copper carbonate.

TABLE 8.—*Effects of various methods of applying formalin to fanned and unfanned, naturally inoculated seed wheat—three-year average, 1929-31.*

| Kind, manner, and rate of treatment | | | Seed fanned | | Seed not fanned | |
|---|---|---|---|---|---|---|
| | | | Smutted heads | Yield per acre | Smutted heads | Yield per acre |
| | | | *P. ct.* | *Bu.* | *P. ct.* | *Bu.* |
| None | | | .. | ... | 35.7 | 21.0 |
| Formalin | Soaked | 1 pt. to 40 gal. water | 0.3 | 29.0 | 2.0 | 28.2 |
| Formalin | Sprayed | 1 pt. on 40 bu. seed | 9.8 | 28.3 | 24.2 | 24.2 |
| Formalin | Sprayed | 1 pt. to 1 pt. water on 40 bu. | 7.7 | 28.6 | 27.2 | 23.4 |
| Formalin | Sprayed | 1 pt. to 9 pts. water on 40 bu. | 3.3 | 29.1 | 18.8 | 25.4 |
| Formalin | Sprinkled | 1 pt. to 40 gal. water on 40 bu. | .. | ... | 1.5 | 27.9 |
| Formalin | Sprinkled | 1 pt. to 10 gal. water on 40 bu. | .. | ... | 10.5 | 26.9 |
| Formalin | Sprinkled | 1 pt. to 10 gal. water on 10 bu.[1] | 0.0 | 0.0 | 0.0 | 0.0 |

[1] Seed killed and no stand obtained due to applying too much formaldehyde per bushel of seed. Where data are lacking elsewhere in table, no tests were made.

## Copper Carbonate and Organic Mercury Dusts Compared

Earlier experiences with copper carbonate dusts at this station indicate that effectiveness is greatly reduced by lack of sufficient fineness. A coarse dust is less adhesive to the seed and does not give adequate coating. According to Melchers (7) the dust should be so fine that at least 90 per cent of it will pass through a 100-mesh screen.

During the three years, 1928-1930, three different brands of dilute copper carbonate, containing approximately 20 per cent metallic copper, and two mercuric compounds were compared on heavily smutted seed. The results (Table 9) indicate about equal smut control and yield effects for the various brands of copper carbonate and the mercury compounds.

Because of the wide interest and growing use of New Improved Ceresan, a proprietary dust fungicide with 5 per cent of ethyl mercuric phosphate as its active ingredient, it was included in tests during 1934 to 1937 in comparison with copper carbonate on both a susceptible and a resistant variety. The four-year average results (Table 10) indicate about equally good smut control and consequent yield increase when applied to smutted seed. Whereas the crop from untreated seed of a susceptible variety averaged 14.8 per cent smutted heads, this was reduced to 0.5 and 0.1 per cent, respectively, by treatment with copper carbonate and New Improved Ceresan.

TABLE 9.—*Comparative test of several commercial copper carbonate and organic mercury dust seed treatments applied to heavily smutted seed—three years, 1928-30.*

| Kind of seed treatment [1] | Smutted heads in crop harvested | | | | Yield of grain per acre | | | |
|---|---|---|---|---|---|---|---|---|
| | 1928 | 1929 | 1930 | Av. | 1928 | 1929 | 1930 | Av. |
| | *P. ct.* | *P. ct.* | *P. ct.* | *P. ct.* | *Bu.* | *Bu.* | *Bu.* | *Bu.* |
| Smutted seed: | | | | | | | | |
| No treatment | 45.9 | 21.6 | 18.4 | 28.6 | 15.2 | 26.9 | 27.5 | 23.2 |
| Copper carbonate [2] (dilute form): | | | | | | | | |
| Corona Coppercarb | 2.9 | 0.4 | 0.2 | 1.2 | 24.5 | 33.6 | 32.9 | 30.3 |
| Cupro Jabonite | 2.0 | 0.7 | 1.3 | 1.3 | 25.1 | 31.2 | 32.5 | 29.6 |
| Waco copper carbonate | 1.4 | 0.9 | 0.8 | 1.0 | 22.9 | 33.2 | 34.0 | 30.0 |
| Organic mercury: | | | | | | | | |
| Du Pont No. 68 (experimental) | 4.5 | 1.6 | 0.7 | 2.3 | 23.5 | 34.9 | 33.0 | 30.5 |
| Ceresan (1.6 p. ct. ethyl mercuric chloride) | .. | 0.3 | 0.1 | .. | ... | 35.0 | 28.5 | ... |
| Nearly smut-free seed | 2.0 | 0.7 | 0.6 | 1.1 | 25.1 | 33.2 | 34.1 | 30.8 |

[1] Treatments applied at the rate of 2 ounces per bushel.
[2] The dilute copper carbonates commonly range from 18 to 25 per cent.

TABLE 10.—*Comparative test of copper carbonate and New Improved Ceresan when applied to both smutted and nearly smut-free seed of a susceptible and a resistant variety—four years, 1934-37.*

| Seed treatment [1] | Smutted heads in crop | | | | | Yield of grain per acre | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1934 | 1935 | 1936 | 1937 | Av. | 1934 | 1935 | 1936 | 1937 | Av. |
| | *P.ct.* | *P.ct.* | *P.ct.* | *P.ct.* | *P.ct.* | *Bu.* | *Bu.* | *Bu.* | *Bu.* | *Bu.* |
| BUNT-SUSCEPTIBLE VARIETY (NEBR. 60) | | | | | | | | | | |
| Nearly smut-free seed: | | | | | | | | | | |
| No treatment | 0.6 | 0.1 | 0.0 | 0.0 | 0.18 | 23.3 | 29.5 | 21.2 | 13.1 | 19.5 |
| Copper carbonate | 0.2 | 0.0 | 0.0 | 0.1 | 0.08 | 24.1 | 21.0 | 22.1 | 13.6 | 20.2 |
| N. I. Ceresan [2] | 0.0 | 0.0 | 0.1 | 0.1 | 0.05 | 26.4 | 21.5 | 22.8 | 12.1 | 20.7 |
| Smutted seed: | | | | | | | | | | |
| No treatment | 24.0 | 4.9 | 0.7 | 29.4 | 14.75 | 21.5 | 20.1 | 23.1 | 8.9 | 18.4 |
| Copper carbonate | 0.6 | 0.0 | 0.0 | 1.5 | 0.53 | 26.6 | 20.3 | 23.6 | 10.2 | 20.2 |
| N. I. Ceresan [2] | 0.0 | 0.0 | 0.0 | 0.4 | 0.10 | 26.4 | 20.5 | 21.6 | 11.5 | 20.0 |
| VARIETY (NEBRED) RESISTANT TO LOCAL RACES OF BUNT | | | | | | | | | | |
| Nearly smut-free seed: | | | | | | | | | | |
| No treatment | 0.2 | 0.0 | 0.0 | 0.0 | 0.05 | 22.4 | 27.5 | 21.8 | 15.5 | 21.8 |
| N. I. Ceresan [2] | 0.0 | 0.0 | 0.0 | 0.1 | 0.01 | 21.2 | 29.3 | 18.9 | 15.8 | 21.3 |
| Smutted seed: | | | | | | | | | | |
| No treatment | 1.8 | 0.1 | 0.0 | 0.5 | 0.60 | 22.0 | 28.8 | 19.9 | 14.9 | 21.4 |
| Copper carbonate | 0.0 | 0.0 | 0.0 | 0.1 | 0.03 | 21.2 | 29.3 | 18.9 | 15.8 | 21.3 |

[1] Twenty per cent copper carbonate was applied at the rate of 2½ ounces per bushel of seed. New Improved Ceresan was applied at the rate of one-half ounce per bushel.
[2] New Improved Ceresan (5% ethyl mercuric phosphate).

The average yields for these three respective lots of seed were 18.4, 20.2, and 20.0 bushels per acre. There were no significant effects from treating nearly smut-free seed of a smut-susceptible variety or from treating either inoculated or uninoculated seed of a variety that is highly resistant to the local races of bunt.

It is apparent that losses from bunt would be greatly reduced in this region through the extensive use of a resistant variety such as the new Nebraska Turkey selection known as Nebred. As an average for four years it developed only 0.6 per cent smutted heads from heavily inoculated untreated seed. This was reduced to 0.03 per cent through treatment with copper carbonate.

Seed treated with recommended dosages of copper carbonate and New Improved Ceresan has been stored for periods up to a year without loss of viability. Excessive applications of the latter may prove harmful.

### Miscellaneous Treatments

The effectiveness of five seed treatments not previously included in Nebraska tests was studied in 1938 in comparison with three established treatments when applied to heavily smutted seed of Nebraska No. 60 winter wheat. While the untreated seed produced a crop with 46.6 per cent smutted heads, the number of such heads ranged from 0.3 to 22.7 per cent for the various treatments, as determined from 15 random counts of 100 heads each. Although the tests were made in triplicate field plots, no grain yields were taken because of severe and unequal winterkilling in this portion of the field. Under the circumstances no conclusions are drawn. The percentages of bunted heads are reported in Table 11.

TABLE 11.—*Comparative test of miscellaneous seed treatment when applied to heavily smutted seed wheat, 1938.*

| Treatment applied to the seed | Bunted heads |
|---|---|
| | *Per cent* |
| 1. No treatment | 46.6 |
| 2. Formaldehyde applied by the soaking method (dilution 1 pt. to 40 gal.) | 0.4 |
| 3. Copper carbonate (20%), 2½ oz. per bu. | 1.5 |
| 4. New Improved Ceresan (5% ethyl mercuric phosphate) ½ oz. per bu. | 0.4 |
| 5. Cuprocide (red copper oxide) 2½ oz. per bu. | 0.3 |
| 6. Monohydrated copper sulphate (35% metallic copper) 2½ oz. per bu. | 2.5 |
| 7. Barbak C (8% mercuric phenyl cyanamid and 2½% cadmium oxide 2½ oz. per bu. | 8.8 |
| 8. Leafox 200 (zinc oxide 98.5%) 2½ oz. per bu. | 22.7 |
| 9. Leafox 200A (zinc oxide, experimental) 2½ oz. per bu. | 19.3 |

### Effect of Planting Depth upon the Occurrence of Bunt

In 1928 heavily infected seed was compared in triplicate nursery blocks at the respective planting depths of 1.5 and 4 inches. While the shallow planting resulted in 38 per cent smutted heads and a yield of 15.1 bushels per acre (Table 12), the crop from the deep planting contained 78 per

cent smutted heads and yielded only 9.4 bushels. The difference in degree of plant infection is attributed to more favorable temperatures for smut development at the greater depth at the time of seed germination. It would seem that the reverse might hold under different weather conditions. A relatively low soil temperature at the time of seed germination is conducive to a high smut infection.

TABLE 12.—*Effect of the planting depth of smutted seed upon the degree of smut infection and grain and straw yield of the ensuing crop, 1928.*

| Kind of seed and depth of planting | Smutted heads | Yield per acre | |
|---|---|---|---|
| | | Straw | Grain |
| | *P. ct.* | *Lbs.* | *Bu.* |
| Nearly smut-free seed: | | | |
| Shallow | 0.6 | 1708 | 24.4 |
| Smutted seed: | | | |
| Shallow | 38.0 | 1660 | 15.1 |
| Deep | 78.0 | 1592 | 9.4 |

Test made in triplicate, 5-row nursery plots.

## Effect of the Time of Planting Smut-Inoculated Seed

During two years, 1929 and 1930, smutted seed wheat was sown comparably at the normal planting date (Table 13), and approximately three weeks later. While soil temperature records are not available, the mean air temperature during the week after late planting was 8° F. lower in 1929 and 22° F. lower in 1930 than on the corresponding earlier planting dates.

In general accordance with recognized temperature relationships, the delayed planting resulted in 22.6 per cent greater smut infection and lowered the grain yield 53.9 per cent as an average for the two years. In comparison, nearly smut-free seed was reduced 18 per cent in yield by correspondingly late planting.

TABLE 13.—*Effect of the time of planting smutted seed upon smut development in winter wheat—two years, 1929-30.*

| | Time of planting | | Smutted heads | | | Grain per acre | | |
|---|---|---|---|---|---|---|---|---|
| | 1929 | 1930 | 1929 | 1930 | Av. | 1929 | 1930 | Av. |
| | | | *P. ct.* | *P. ct.* | *P. ct.* | *Bu.* | *Bu.* | *Bu.* |
| | | | SMUTTED SEED | | | | | |
| Normal | Oct. 4 | Sept. 27 | 15.0 | 27.2 | 21.1 | 27.8 | 30.7 | 29.3 |
| Late | Oct. 23 | Oct. 20 | 43.8 | 43.5 | 43.7 | 10.0 | 16.9 | 13.5 |
| | | | NEARLY SMUT-FREE SEED | | | | | |
| Normal | Oct. 4 | Sept. 27 | 0.7 | 1.2 | 1.0 | 33.2 | 37.7 | 35.5 |
| Late | Oct. 23 | Oct. 20 | 1.2 | 1.7 | 1.5 | 24.6 | 33.5 | 29.1 |

Mean air temperatures during week following early and late sowing, respectively, were: 1929, 56° F. and 48° F.; 1930, 66° F. and 44° F.

## Longevity of Smut Spores

Tests were made in 1931 to determine the effect of age upon the viability of smut spores. For this purpose threshed grain from heavily infected wheat plots was saved annually during eight consecutive years. In 1931 the annual samples that had accumulated during the preceding eight-year period were planted in triplicate, five-row nursery plots for progeny smut determinations. Too much importance should not be attached to the variations in smut percentage obtained from the annual lots of field-infected seed since the spore load carried was not constant for the various samples. In conjunction with this experiment, eight duplicate samples of smut-free seed were inoculated, respectively, in the fall of 1930 with uniform and heavy dosages of inoculum taken from smut-balls contained in the field-inoculated grain of the eight preceding crops. The eight inoculated samples were then planted to determine the effect of age upon the ability of the smut to germinate and invade the host plant.

The results are reported in Table 14. It is apparent that smut ranging from one up to at least seven years old was able to infect wheat plants. However, the degree of infection obtained has lowered with age of the spores.

TABLE 14.—*Longevity of smut spores as tested through the progenies of naturally field-inoculated seed that was produced during eight previous years, and seed artificially inoculated with smut spores taken from the infected grain of various ages.*[1]

| Description of inoculum | | | Smutted heads in 1931 crop harvested from | |
|---|---|---|---|---|
| Age of spores | When produced | Smutted heads in crop supplying inoculum | Naturally field-inoculated seed of same age as inoculum | Seed artificially inoculated with smut spores of year and age indicated [2] |
| *Years* | *Year* | *P.ct.* | *P.ct.* | *P.ct.* |
| . . [3] | 1930 | 27 | 87.0 | 91.0 |
| 1 | 1929 | 15 | 67.0 | 80.7 |
| 2 | 1928 | 58 | 33.7 | 75.0 |
| 3 | 1927 | 27 | 68.0 | 69.3 |
| 4 | 1926 | 26 | 7.3 | 43.0 |
| 5 | 1925 | 12 | 12.0 | 33.3 |
| 6 | 1924 | 42 | 30.7 | 38.0 |
| 7 | 1923 | 10 | 5.3 | 13.7 |

[1] Test made in triplicate, 5-row nursery plots.
[2] Smut-free seed used in the artificial inoculation tests.
[3] Smut produced in current year.

## Effect of Smut Infection on Straw Yields

Since grain yields are so decidedly reduced by heavy infections of smut, some interest attaches to the question of whether straw yields may also be affected thereby. Certain data obtained in 1928 in connection with the re-inoculation and depth of planting nursery experiments, reported in Tables 6 and 12, furnish some evidence regarding this. In the first of

these there were three parallel tests in which treated seed was compared with similar but re-inoculated seed. The seed and planting conditions within each test were identical except for the degree of inoculation. The data of interest are summarized in Table 15. As an average for the three tests, the light and the heavy infections resulted respectively in 4.8 and 41.0 per cent smutted heads. Whereas the greater smut infection lowered the grain yield 29 per cent, the straw yield was reduced only 0.3 per cent. Doubtless no significance can be attached to this small difference in yield of straw.

In case of the planting-depth study, reported in Table 12, comparable shallow plantings of nearly smut-free and heavily smutted seed may be compared. The heavy infection resulted in 37.4 per cent more of the heads being smutted and a reduction of 38 per cent in grain yield. In contrast, the straw yield was lowered only three per cent.

It appears from these tests that the races of bunt prevailing in Nebraska do not materially affect the straw yield of the infected culms of a susceptible variety, although the grain yield may be entirely destroyed.

TABLE 15.—*Comparative grain and straw yields in relation to degree of smut infection—1928—data compiled from Table 6.*

| Kind of seed | Test No. 1 | Test No. 2 | Test No. 3 | Average Actual | Average Relative |
|---|---|---|---|---|---|
| PER CENT SMUT | | | | | |
| Treated | 8.3 | 0.6 | 5.6 | 4.8 | ... |
| Treated and reinoculated | 56.0 | 8.9 | 58.0 | 41.0 | ... |
| GRAIN YIELD *(bushels)* | | | | | |
| Treated | 21.6 | 22.5 | 23.4 | 22.5 | 100.0 |
| Treated and reinoculated | 13.6 | 21.2 | 13.3 | 16.0 | 71.1 |
| STRAW YIELDS *(pounds)* | | | | | |
| Treated | 1744 | 1618 | 1800 | 1721 | 100.0 |
| Treated and reinoculated | 1670 | 1650 | 1824 | 1715 | 99.7 |

## SUMMARY

These studies concern primarily the reactions of a standard susceptible variety of winter wheat to (1) infection with the races of bunt (*T. levis*) prevailing in Nebraska, and (2) seed treatment for bunt control.

The percentages of smutted heads occurring in the crops grown from six lots of seed wheat differing in degree of inoculation were 1.1, 10.4, 17.5, 25.7, 36.0, and 43.4 as an average for nine years, while the corresponding grain yields were 26.9, 24.4, 22.7, 21.2, 19.5, and 17.0 bushels per acre. Smut balls retained in the threshed grain reduced the test weight, resulting in the respective weights of 58.7, 58.1, 57.5, 57.0, 56.0, and 55.1 pounds per bushel. The correlation coefficient for the 54 relative grain yields and smut percentages obtained in these tests was —.919 ± .014. A high negative correlation might be expected since infected heads under these conditions are usually smutted throughout and bear no grain. An average increase of 25.8 per cent of smutted heads during 9 years was accompanied by an average decrease in grain yield of 22.8 per cent.

As further evidence of this relationship, 153 determinations reported in the various seed treatment and cultural tests gave a correlation of —.922 ± .008.

Of various fungicides which have been tested for three to eight years, the copper carbonate and New Improved Ceresan dust treatments have proved most practical and are highly effective in smut control without causing seed injury. Formaldehyde applied in proper dosage by either the immersion or the sprinkling method, using a solution of 1 pint formalin to 40 gallons water, gave effective control but caused sufficient seed injury to lower the grain yield significantly.

The most practical dosages of copper carbonate per bushel of seed were 2½ to 3 ounces of the dilute form (approximately 20 per cent) and 2 ounces of the concentrated form (50 per cent). One-half ounce of New Improved Ceresan per bushel has proved ample and this amount should not be exceeded.

The application of a concentrated formaldehyde solution in the form of a spray was decidedly ineffective and cannot be recommended for wheat.

Of 115 lots of medium to heavily smutted seed that were disinfected with recommended treatments, only 10 produced entirely smut-free crops. The others ranged from a mere trace up to 9.6 per cent smutted heads. From this it may be concluded that treatment during two successive years is commonly needed for a complete clean-up. Treatments at frequent intervals thereafter may be necessary to retain a smut-free condition.

Removal of smut balls by means of a fanning mill in connection with the seed treatment program during four years lowered the smut infection 1.8 and 4.3 per cent more, respectively, than did formaldehyde-soaking and copper-carbonate-dusting treatments alone. The respective increases in grain yield from treatments accompanying the fanning were 1.0 bushel with the formaldehyde and 1.3 bushels with the copper carbonate.

In a five-year test with heavily infected, unfanned wheat, containing smut balls just as it came from the thresher, it was found that seed may be reinfected after treatment with either formaldehyde or copper carbonate by rough handling, which causes the rupturing of smut balls with viable contents. Such reinfection would seem impossible if the smut balls were first removed by thorough fanning or by "skimming off" in case of a soak treatment.

In a supplementary nursery test it was found possible to cause a heavy infection of nearly smut-free seed by using smut balls taken from other wheat after it had been treated with either formaldehyde or copper carbonate.

Deep planting of heavily smutted seed increased the smut in the resultant crop by 40 per cent and lowered the yield 38 per cent, as compared with shallow planting. This result is attributed to the temperature conditions being more favorable for the smut development at the greater soil depth.

The crop from smutted seed sown about three weeks later than the normal planting date during two years suffered a 23 per cent greater smut infection and 54 per cent yield reduction. Nearly smut-free seed sown late in comparison was reduced only 18 per cent in yield by correspondingly late planting. The great increase in smut infection of the crop is attributed to the lower soil temperature at that time, which is more favorable for the development of the smut organism.

All of the progenies grown from naturally inoculated seed wheat ranging up to seven years of age developed smut, which is evidence that smut spores may retain their germinative power for a period of at least seven years.

When smut-free seed was inoculated with smut varying in age up to seven years, the resultant crop developed smut in all cases. As the smut became older the degree of infection was reduced rather gradually so that seven-year-old spores resulted in 13.7 per cent smutted heads compared with 91 per cent for spores taken from the previous year's crop.

As an average for three tests in 1928, an increase of 36.2 per cent smutted heads lowered the yield of straw only 0.3 per cent, whereas the grain yield was reduced 29 per cent. The straw weight of infected culms does not appear to be materially affected by forms of smut (*T. levis*) prevailing in this state, even though the grain yield be entirely destroyed.

As an average for four years, the new bunt-resistant variety known as Nebred, selected and distributed by the Nebraska Agricultural Experiment Station, produced only 0.6 per cent smutted heads from artificially inoculated seed compared with 14.8 per cent for similarly smutted seed of a standard susceptible variety. Such results illustrate the possibilities of breeding for disease resistance.

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