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Damping-Off Control

An Evaluation of

Seed and Soil Treatments

By K. J. Kadow and
H. W. Anderson

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UNIVERSITY OF ILLINOIS
AGRICULTURAL EXPERIMENT STATION

Bulletin 439

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For those who are not interested in the detailed report given herein, a 12-page circular has been issued (No. 481) embodying the recommendations printed here and a brief statement about the disease.

Urbana, Illinois November, 1937

Publications in the Bulletin series report the results of investigations made by or sponsored by the Experiment Station

Damping-Off Control: An Evaluation of Seed and Soil Treatments

By K. J. KADOW, Associate Pathologist, and H. W. ANDERSON, Chief in Pomological Pathology[a]

DAMPING-OFF has been recognized as a definite disease of vegetables for more than a century, but it is doubtful if even today many growers are aware of the true nature or prevalence of the disease. The actual toppling over of seedlings is the most conspicuous and consequently the most generally recognized stage of damping-off, tho as a rule more plants are killed by this disease before they appear above the ground than afterward.

Vegetable growers generally regard poor stands as indicative of poor seed germination or low vitality, and accordingly when they fail to get good stands they complain to the seedsman. Laboratory germination tests, however, usually show such seed to be of good quality, and thus indicate the presence of disease where the poor stands were obtained.

Many pathologists have worked on various phases of damping-off, and as a result a voluminous literature on the subject has appeared. Only a selected few of those references which have a direct bearing on this paper are cited herein, altho a bibliography of important references on the subject is given on pages 344 to 348.

The outstanding feature of the many studies which have been made is the decided variation among the results obtained. This fact serves to emphasize the complex nature of the problem and indicates that few workers have accorded variables their proper consideration. It has also made the problem of selecting satisfactory control measures for any given locality a matter of actual demonstration. It is not likely that the many control methods which have been evolved are equally efficient and practical. The variable performance of any particular treatment under a variety of soil and environmental conditions further complicates the general problem. Also it is evident that the many different fungi and host plants may require individual control adaptations. These and like facts and considerations are largely responsible for this attempt to evaluate and clarify the damping-off problem as it exists in Illinois.

[a]The authors acknowledge the assistance of the following students, who have shown special interest in carrying out details relative to this investigation: S. L. Hopperstead, W. H. Duis, V. H. Orum, J. Zimel, H. A. Harris, R. B. McKenzie, and C. H. Ackerman. To P. Fournie and Son, Collinsville, Illinois, and Peter Klippert, Des Plaines, Illinois, acknowledgment is due for the use of land and for assistance with field tests of seed treatments.

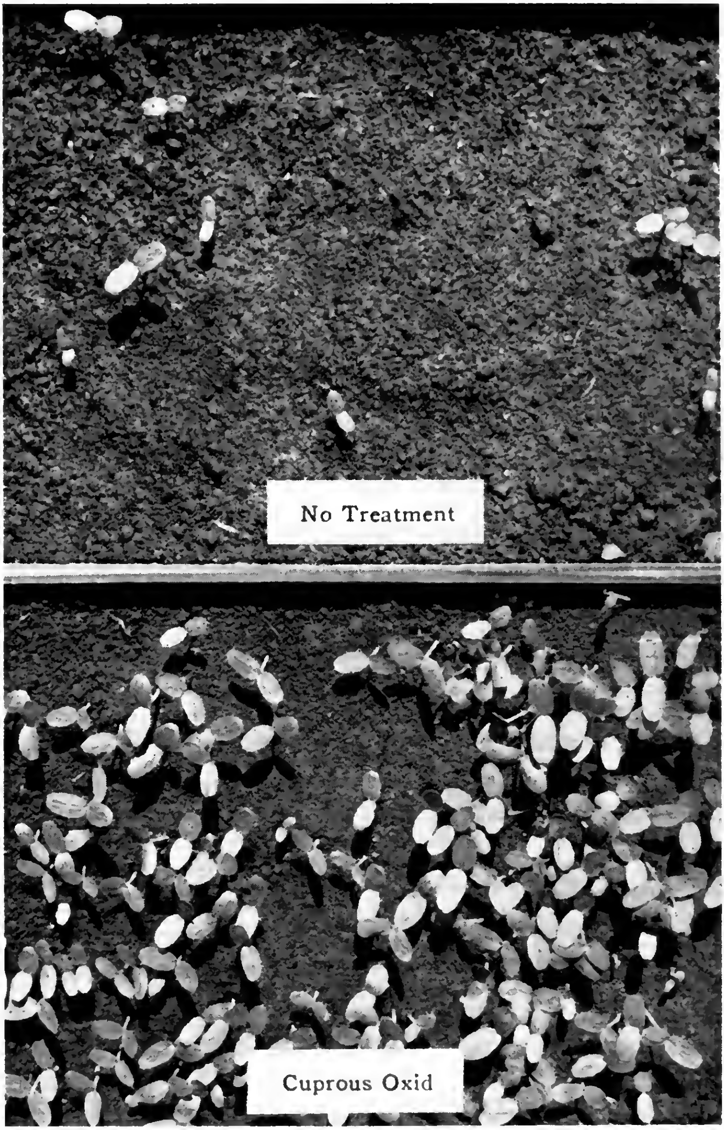

FIG. 1.—CONTROL OF PRE-EMERGENCE PHASE OF DAMPING-OFF BY CUPROUS OXID SEED TREATMENT

In the upper flat, where untreated cucumber seeds were planted, damping-off killed all but 9 of the seedlings before they reached the surface of the ground. The same number of seeds, treated with cuprous oxid, were planted in the lower flat, and nearly all produced healthy, vigorous seedlings.

DAMPING-OFF CAUSED BY SOIL FUNGI

Since De Candolle in 1815 demonstrated the relation of Rhizoctonia to root rot, much has been written concerning the causes of damping-off. Many fungi are known to be capable of causing the disease in one or all of its several aspects. The most common of these fungi are species of Pythium, Rhizoctonia, Phytophthora, Sclerotinia, Botrytis, Fusarium, Sclerotium, Thielavia, Phoma, and Glomerella. A few other species of soil-inhabiting fungi have also been listed.

Most workers agree that species of Pythium, Rhizoctonia, Phytophthora, Botrytis and Fusarium are the most important so far as the vegetable crops are concerned. Altho these organisms have been shown capable of producing damping-off on a wide variety of seedlings, very little is known concerning the interrelation of organisms found in any given soil in relation to the manifestation of the disease. The recent works of Weindling,[107-110*] and Haenseler and Allen[54*] concerning the antagonistic and parasitic action of *Trichoderma lignorum* on Rhizoctonia and other soil organisms serve to emphasize this point. Since Trichoderma may parasitize and inhibit the action of parasitic fungi on higher plants, it does not seem unreasonable to assume that a symbiotic relationship between certain soil organisms may exist in such a manner as actually to accentuate the parasitism of one or more fungi. The erratic behavior of check plants under supposedly controlled conditions thruout the four years of this study seems to have no other logical explanation than fluctuations of parasitism by the fungi involved.

The fungi found generally associated with damping-off in Illinois are discussed on page 298.

SYMPTOMS OF DAMPING-OFF

The most important symptoms of damping-off are discussed here under the headings recently proposed by Horsfall—the pre- and post-emergence phases.

Pre-emergence phase. In this phase, the young seedling is killed before it reaches the surface of the soil (Fig. 1). It may, in fact, be killed even before the hypocotyl emerges from the seed. This phase of the disease is often not recognized at all by the grower, who attributes the failure of seedlings to appear above the ground to poor germination or low vitality of seed.

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*These numbers refer to literature citations on pages 344 to 348.

Post-emergence phase. Practically everyone who has grown plants from seed is familiar with the post-emergence or "damping-off" phase (Fig. 2), since it is so generally conspicuous. This phase of the disease is characterized by the toppling over of infected seedlings at any time after they emerge from the ground until the stems have "hardened" sufficiently to resist invasion. Infections usually occur at or below the ground level and the infected tissues appear soft and water-

FIG. 2.—TYPICAL POST-EMERGENCE DAMPING-OFF

The center plant is healthy, the other two diseased. Tho better known to most growers, this phase of the disease is less common than the pre-emergence phase.

soaked. As the disease advances, the stems become constricted and the plants collapse. Seedlings that are apparently healthy one day may have collapsed by the following morning. Most generally the cotyledons and leaves wilt slightly before the seedlings are prostrated, altho frequently they remain green and turgid until collapse occurs.

In flats and cold frames, and to a limited extent under field conditions, the disease usually radiates from initial infection points, causing large spots or areas in which nearly all the seedlings are killed. In the field the disease is generally most serious when the moisture in the soil is medium to high. When conditions are favorable for the development of the disease, damping-off is often responsible for as much as a 90-percent kill of seedlings. In especially susceptible varieties seedling losses of 25 to 75 percent occur yearly. Most of these losses are the result of pre-emergence damping-off.

FIG. 3.—CABBAGE SEEDLINGS SHOWING WIRE STEM DISEASE
Wire stem is often a phase of the damping-off complex. Seedlings showing any stem discoloration or constriction should not be transplanted.

The method taken by growers to offset poor stands is usually to plant much more seed than would be required if the seedlings remained healthy. Aside from the added cost of seed, this practice necessitates thinning if damping-off is not as serious as expected, and is of little value if the disease is more destructive than anticipated.

Other diseases caused by damping-off fungi. There are other recognized diseases caused by various damping-off fungi. Sometimes these occur entirely separate from damping-off; sometimes they are additional phases of the general damping-off problem. For example, if crucifer seedlings are attacked when still succulent the young plants soon collapse and die. If, on the other hand, infection occurs after the seedlings have begun to "harden" the infected plants do not topple over —in fact, they are seldom actually killed,—but instead become stunted and of little commercial value. The invaded regions of the stem become constricted, dry and hard (Fig. 3). In humid weather this "wire-stem" condition may develop further into diseases recognized as stem rot and bottom rot. In crucifer seedlings pre-emergence and post-emergence damping-off, wire-stem, stem rot, and bottom rot all may be caused by Rhizoctonia. In many, tho by no means in all cases these diseases are traceable to the seedbed.

Similar interrelations exist between damping-off and other diseases on many other crops. They all serve to emphasize further the scope and complexity of the problem as well as the importance of producing healthy seedlings.

PURPOSE AND SCOPE OF THE EXPERIMENTS

The main purpose of these studies was to test and evaluate under Illinois conditions, and for Illinois growers, some of the recommended methods that seemed the most promising for the control of damping-off. As an aid to this end several other points were necessarily considered. Those most pertinent to the problem will be treated under the following headings:

Causes of damping-off in Illinois
Relation of temperature to damping-off
Influence of humidity on damping-off
Relation of soil moisture to damping-off
Relation of soil types to damping-off
Relation of soil acidity to damping-off

Obviously to study the influence of all these factors on all treatments and crops under controlled conditions would require a greater outlay of time and expense than would be justified. Accordingly, only a few such tests were conducted under controlled conditions during the period from 1933 to 1936. Very careful observations, however, were made of the disease and the conditions under which it developed on a serious scale in the field. Climatological data, soil temperatures, types, and acidity were studied and correlated with several generally important outbreaks of damping-off in the Chicago and East St. Louis areas during the growing season of 1932. The fungi causing the disease were identified and other factors of local importance noted.

In a few instances where the disease had proved to be an annual problem in greenhouse culture, similar records were secured in 1932 and 1933. These observations were used as guides in evaluating control measures studied under greenhouse conditions, and will be discussed under the above headings along with the experimental data.

The control measures studied consisted mainly of seed treatments and of soil treatments. The various seed-treatment materials tested were manufactured and furnished for these experiments by the following companies:

Semesan (hydroxymercurichlorophenol, or organic mercury, 30 percent)	DuPont Company, Wilmington, Del.
Vasco 4 (chiefly zinc oxid)	Virginia Smelting Company, Norfolk, Va.
Leafox (special zinc oxid)	New Jersey Zinc Company, New York City
AAZ (special zinc oxid) Cuprocide (bright red cuprous oxid)	Röhm and Haas Company, Philadelphia, Penn.
Metrox (cameo brown cuprous oxid)	Metals Refining Company, Hammond, Ind.
Cuprous oxid, bright red Zinc oxid, technical brand	Mallinckrodt Company, St. Louis, Mo.
Cuprous oxid, bright red Zinc oxid, technical brand	Merck Company, Rahway, N.J.
Copper dust, purple (cuprous oxid, 25 percent)	Ansbacher-Siegle Company, Brooklyn, N.Y.
Monohydrate copper sulfate Copper sulfate Copper carbonate	Purchased, chemically pure brands
Special flake graphite, No. 0607	Joseph Dixon Crucible Company, Jersey City, N.J.

FACTORS AFFECTING SEVERITY OF DAMPING-OFF IN ILLINOIS

Hundreds of diseased plants were examined in the various vegetable-producing areas in Illinois during the course of this study in order to determine which fungi were involved. Numerous isolations were made and the pathogenicity of typical cultures was determined. From the data thus secured it is estimated that 80 percent of the damping-off in the areas studied was caused by species of Pythium; 15 percent by Rhizoctonia; 2 percent by Botrytis; and 3 percent by Fusarium and undetermined causes. In greenhouses with winter crops of lettuce, Botrytis was second only to Pythium. If radishes were the winter crop, Rhizoctonia was usually the outstanding cause of the disease.

While these percentages represent the general order of importance of the damping-off fungi, departures from this general order were not uncommon. The type of season and the crop grown may favor the pathogenicity of one fungus over another in any given year. Also, as biologists have shown, previous crops, soil acidity, soil type, temperature, and other factors all exert a direct influence on the organisms in the soil. Accordingly, many instances were encountered where Pythium would be dominant one season, but in the following crop or season Rhizoctonia or one of the other fungi listed above would be largely responsible for damping-off.

Many times the cause of the disease could not be accurately determined since the fungi generally responsible for damping-off definitely were not present and those isolated were not pathogenic.

The one outstanding point brought out by this state-wide survey is that apparently *all soils in vegetable areas are well supplied with damping-off fungi*. Whether the disease is serious or not depends almost entirely upon the environmental conditions which prevail from the time the seeds are sowed until the seedlings are well hardened. The hardening process, and consequently the duration of seedling susceptibility to the disease, is also a variable factor dependent upon environmental conditions.

Temperature of Soil

Survey findings. Observations on the relation of temperature to damping-off caused by species of Pythium and Rhizoctonia were made in a survey of the disease in the field and in greenhouses. Pythium was found capable of infecting over a wide range of soil temperatures, but was usually most destructive at temperatures between 65° and

80° F. In the greenhouse the infections spread rapidly at temperatures as high as 85° F. Temperatures favorable to infections by Rhizoctonia were found to fall less consistently within a definite range. Under field conditions, and on cucumbers and tomatoes under glass, the latter fungus seemed most destructive at soil temperatures between 65° and 75° F., tho in winter crops of radishes, spinach, and occasionally of lettuce, it was often associated with outbreaks of damping-off at temperatures between 45° and 55° F.

Observations concerning the relationship between temperatures and other damping-off fungi were too limited to permit generalization.

Temperature studies. Inasmuch as Pythium and Rhizoctonia, according to reports of other investigators and the survey findings discussed in the preceding paragraph, are so generally important as

TABLE 1.—RELATION OF TEMPERATURE TO GROWTH OF PYTHIUM AND RHIZOCTONIA ON ARTIFICIAL MEDIA UNDER CONTROLLED CONDITIONS
(Figures are averages of duplicate series)

Isolant	Growth in millimeters at—						Comments
	35° F.	45° F.	55° F.	65° F.	75° F.	85° F.	
Pythium, from—							
Cucumber growing at 75° F.	0	.5	31	79	90	90	Readings were taken after 48 hours. 90 mm. of growth completely covered petri dish.
Radish growing at 50° F...	0	.2	38	80	90	90	
Rhizoctonia,[a] from—							
Cucumber growing at 75° F.	0	0	12	62	80	58	
Radish growing at 50° F...	0	32	71	40	21	8	

[a]Note difference in growth of the two strains of Rhizoctonia.

a cause of damping-off, temperature studies[a] were conducted under controlled conditions to check the survey findings as well as the reports that had been made by other investigators.

Culture studies.—Both Pythium and Rhizoctonia were isolated from cucumbers grown at about 75° F. and from radishes grown at 50° F. The fungi were then grown in Petri dishes on 2-percent dextrose-potato agar over a range of controlled temperatures. The data obtained (Table 1) were, in general, in keeping with the observations on temperature made in the survey. Maximum growth of Pythium occurred at 75° to 85° F. One strain of Rhizoctonia showed maximum growth at 75° F. and the other at 55° F.

[a]Most of the data on temperature were obtained from a special study undertaken by Hubert A. Harris, Assistant in Botany, and conducted under the general supervision of the authors of this bulletin.

Constant temperature-humidity case.—A temperature study was also conducted in constant temperature-humidity cases[a] (Fig. 4). The soil used was a rich black silt loam that had been used for vegetable culture in the field for many years. It was high in humus and had a reaction of pH 6.5 as determined by the quinhydrone method. The soil was highly contaminated with natural infestations of both Pythium and Rhizoctonia, as had been proved by other studies. It was not sterilized, but as the seedlings damped-off they were examined to determine what organisms were associated with the disease. During the study the air was saturated and the soil moisture maintained at a medium level. All of the plantings were made in pots.

FIG. 4.—SEEDLINGS IN CONSTANT TEMPERATURE-HUMIDITY CASE

These seedlings are shown immediately before final damping-off data, given in Table 2, were taken. The temperature had been held constant at 65° F.

The chemicals used for treating the seed in this experiment were cuprous oxid (Mallinckrodt), technical zinc oxid (Mallinckrodt), and Semesan (organic mercury, 30 percent). The materials were added to the seed in excess, and that which did not adhere to the seed was screened off. Cuprous oxid gave a heavy lumpy coverage to both spinach and cabbage seed, while the coverage imparted by Semesan was smooth and even. The coverage of spinach by zinc oxid was thin,

[a]Part of the funds for equipping these cases were obtained thru a grant in aid of research to the junior author by the American Association for the Advancement of Science.

lumpy, and otherwise unsatisfactory. In later studies some other makes of zinc oxid were found to stick much better.

The seedlings were removed from the constant temperature-humidity case for examination. This removal in itself probably reduced the post-emergence damping-off listed in Table 2, since in later observation this practice was noted to have such an effect.

Results.—Many workers have studied the relation of temperature to outbreaks of damping-off as caused by species of Pythium and Rhizoctonia. Their findings may be summarized, despite slight variations, as follows: Pythium is destructive over a wide range of temperatures, but is usually most serious between 75° and 85° F.; Rhizoctonia is most destructive at temperatures between 61° and 77° F.

The observations and data herein reported are in general agreement with the findings of other workers. Under field and greenhouse conditions on many kinds of vegetables, Pythium was found to be the cause of damping-off at temperatures as low as 45° F. and as high as 90° F. and in serious form between 55° and 85° F.

In connection with the temperature studies of Rhizoctonia, attention is directed to Table 1 and the fact that the strain of Rhizoctonia isolated from cucumber grew best at about 75° F., while the optimum temperature of the strain isolated from radish was near 55° F. Very similar results have been reported by Abdel-Salam[1*] in his studies on the damping-off of lettuce. He found that a strain of Rhizoctonia isolated from tomato was most pathogenic at about 77° F. but that the strain from lettuce caused the greatest losses at 46° F. In the studies reported in Table 2 both Rhizoctonia and Pythium were recovered in about equal percentages from the diseased seedlings taken from the two cases in which the temperature was held at 55° F. and at 65° F. respectively, but only Pythium was recovered from the case in which the temperature was held at 80° F.

While these data are not entirely conclusive, they seem to indicate that temperature in itself is not the most important factor influencing the damping-off disease. Damping-off was severe in this entire series, irrespective of the temperature. In this connection it should be remembered that the air was saturated and the soil moisture moderately high. In most instances post-emergence damping-off tho severe was less severe than is usually the case in a saturated atmosphere. This condition seems to be correlated with the fact that the seedlings were removed for examination as soon as they were visibly diseased.

None of the treatments applied were outstanding in ability to control damping-off, tho the results obtained were so variable as to make

TABLE 2.—TEMPERATURE: EFFECT ON INCIDENCE OF DAMPING-OFF AND ON CONTROL OF DAMPING-OFF BY SEED TREATMENTS
(Tests conducted in constant temperature-humidity cases with saturated atmosphere at medium soil moisture. Figures are averages, expressed as percentages, of six replications of 100 seeds each.)

Crop and treatment	55° F.[a]				65° F.[a]				80° F.[b]			
	Pre-emergence[c]	Post-emergence[d]	Final stand[e]	Total emergence[f]	Pre-emergence[c]	Post-emergence[d]	Final stand[e]	Total emergence[f]	Pre-emergence[c]	Post-emergence[d]	Final stand[e]	Total emergence[f]
Spinach[g]												
Checks, seed untreated	55	4	18	22	54	8	15	23	51	16	10	26
Zinc oxid	43	5	29	34	48	8	21	29	51	22	4	26
Semesan	9	2	66	68	20	11	46	57	38	24	15	39
Cuprous oxid	12	2	63	65	26	8	43	51	29	25	23	48
Cabbage[h]												
Checks, seed untreated	41	2	23	25	47	1	18	19	43	2	21	23
Zinc oxid	21	3	42	45	23	1	42	43	37	5	24	29
Semesan	19	1	46	47	7	1	58	59	19	5	42	47
Cuprous oxid	36	0	30	30	25	1	40	41	35	7	24	31

[a]Both Rhizoctonia and Pythium were recovered, in about equal percentages. [b]Only Pythium was recovered. [c]Adjusted to seed germination (spinach, 77 percent; cabbage, 66 percent). [d]As soon as seedlings damped-off they were removed for examination. In later studies the diseased seedlings were examined and then were replaced because of their apparent effect on the post-emergence phase of the disease. [e]Number of healthy plants at end of experiment. [f]Final stand *plus* post-emergence damping-off. [g]Zinc oxid stuck very poorly to spinach seed. Other materials gave excellent coverage. [h]All materials gave satisfactory coverage on cabbage seed.

conclusions drawn from them rather uncertain. There seemed to be an indirect relation between temperature and the effectiveness of any chemical seed treatment, and this effect seemed to be a function of the relation of temperature to the proper growth of the plant treated rather than any direct influence of temperature on the chemicals used.

As a rule the best results of seed treatment on any particular crop are secured near the optimum temperature for the growth of the crop. While the data presented in Table 2 are not conclusive in this connection many observations involving damping-off under commercial conditions bear out this contention. The work of Jones[70*] adds additional weight to this point of view. He found that variations of soil temperature greatly influenced the stand of peas whether treated or not. The best stands were secured at 60° F., both from untreated seed and those treated with Semesan. This is near the temperature at which peas grew best in the studies reported here, and the stands were materially reduced at temperatures above or below the optimum for pea growth.

Humidity

The general procedure of this study was the same as that followed in the temperature experiments. The study was conducted in the constant temperature-humidity cases at 70° F. with two humidity levels—namely, 50 percent and saturated. These two levels are fairly representative of the extremes generally encountered in Illinois when damping-off is a problem, and were especially easy to maintain in the equipment used. The materials also were the same as in the temperature study, except that tomatoes were substituted for cabbage and the spinach seed was a new lot with a higher percentage of germination. Percentage of germination should not affect the results, except as it may be indicative of vigor, since all tables are adjusted to it. The results are listed in Table 3.

The data in Table 3 bring out at least two very interesting facts, which have been observed repeatedly both before and after this study was made. The first of these is that high humidity increases the amount of post-emergence damping-off in all crops which are particularly susceptible, especially at high temperatures (see Table 2). This finding is in general agreement with those of other workers who have considered humidity in damping-off studies. The other point of importance is that chemical seed treatments cannot be relied upon to control both pre-emergence and post-emergence phases of damping-off under conditions especially favorable to the development of the disease. Unless the crop is very susceptible, proper seed treatments

TABLE 3.—HUMIDITY: EFFECT ON INCIDENCE OF DAMPING-OFF AND ON CONTROL OF DAMPING-OFF BY SEED TREATMENTS
(Tests conducted in constant temperature-humidity cases at 70° F. Figures are averages, expressed as percentages, of six replications of 100 seeds each.)

Crop and treatment	50 percent relative humidity				Saturated atmosphere				Comments
	Pre-emergence[a]	Post-emergence[b]	Final stand[c]	Total emergence[d]	Pre-emergence[a]	Post-emergence[b]	Final stand[c]	Total emergence[d]	
Tomatoes									
Checks, seed untreated	61	4	32	36	60	33	4	37	
Zinc oxid	14	9	74	83	9	35	53	88	Excellent coverage
Semesan	6	1	90	91	7	29	61	90	Excellent coverage
Cuprous oxid	7	5	85	90	1	29	67	96	Excellent coverage
Spinach[e]									
Checks, seed untreated	55	10	19	29	63	13	8	21	
Zinc oxid	73	1	10	11	57	21	6	27	Poor, uneven coverage
Semesan	51	5	28	33	43	24	17	41	Excellent coverage
Cuprous oxid	34	9	41	50	45	20	19	39	Excellent coverage

[a]Adjusted to seed germination (tomatoes, 97 percent; spinach, 84 percent). [b]Plants were not removed after post-emergence damping-off since removing them seemed to reduce this phase of the disease. [c]Number of healthy plants at end of the experiment. [d]Final stand *plus* post-emergence damping-off. [e]No seed treatment which will control damping-off of spinach if the soil moisture is high and the temperature is 70° F., or above, has yet been tested.

will control pre-emergence damping-off quite well even when the environment favors the disease. This is not the case so far as the post-emergence phase is concerned.

Moisture in the Soil

Observations concerning the relation of temperature and humidity to damping-off under commercial conditions checked well with the results secured under experimental conditions, but little of value was secured from such observations on the role of soil moisture and its influence on damping-off.

A careful review of literature on damping-off seemed to indicate that the disease may occur under any moisture conditions satisfactory for plant growth, and that medium to high moisture generally favors its development. The recent work of Alexander *et al*[3*] seems to substantiate this viewpoint. That any generalization on this point would not be entirely safe is brought out by the work of Abdel-Salam.[1*] He found that medium to high soil moisture favored damping-off, but that when near saturation was reached the disease was actually retarded. This finding applied to Pythium and a strain of Rhizoctonia isolated from lettuce but did not hold for a high-temperature strain of Rhizoctonia from tomato. In this latter case damping-off was progressively more severe from high to low moisture levels, causing the heaviest losses in soil with only 20 percent moisture.

In view of these uncertainties the following study was made to determine the effect of soil moisture on the disease and on the most reliable seed treatments recommended for its control. An attempt was made to maintain three distinct moisture levels—the lowest at a point barely sufficient for plant growth; the medium level for optimum growing conditions; and the high level from 90 percent to actual saturation. The series was conducted in the greenhouse at temperatures between 70° and 80° F. on unsterilized black silt loam garden soil known to be well infested with damping-off fungi. The pH of the soil was 6.5. Spinach and tomato seed were used and the series was planted in triplicate.

The chemicals used were Vasco 4 (a special product composed of zinc compounds, and which was substituted for technical zinc oxid, Mallinckrodt, because of superior sticking qualities), Semesan (organic mercury, 30 percent), and Cuprocide (cuprous oxid). All three materials gave the seeds a good uniform coverage. The chemicals were added in excess and after shaking them thoroly with the seed the dust which did not adhere was screened off.

TABLE 4.—SOIL MOISTURE: EFFECT ON INCIDENCE OF DAMPING-OFF AND ON CONTROL OF DAMPING-OFF BY SEED TREATMENTS
(Tests conducted in greenhouse at temperatures ranging from 70° to 80° F. Figures are averages, expressed as percentages, of three replications of 250 seeds each.)

Crop and treatment	Low moisture (enough to sustain growth)				Medium moisture				High moisture (90 percent to saturation)			
	Pre-emergence[a]	Post-emergence	Final stand[b]	Total emergence[c]	Pre-emergence[a]	Post-emergence	Final stand[b]	Total emergence[c]	Pre-emergence[a]	Post-emergence	Final stand[b]	Total emergence[c]
Spinach												
Checks, seed untreated	59	10	14	24	80	1	3	4	82	1	0	1
Vasco 4	33	7	44	51	62	12	8	20	76	3	4	7
Semesan	26	10	47	57	53	18	12	28	72	7	4	11
Cuprocide	18	6	59	65	48	15	20	35	76	1	7	8
Tomatoes												
Checks, seed untreated	11	10	62	72	42	17	24	41	41	13	29	42
Vasco 4	1	1	81	82	8	7	68	75	7	15	61	76
Semesan	0	2	81	83	3	8	72	80	4	6	73	79
Cuprocide	0	0	83	83	5	4	74	78	2	6	75	81

[a]Adjusted to seed germination (spinach, 84 percent; tomatoes, 83 percent). [b]Number of healthy plants at end of the experiment. [c]Final stand *plus* post-emergence damping-off.

The fungi found associated with the post-emergence phase of the disease were Pythium and Rhizoctonia. The results of the study are listed in Table 4.

Examination of Table 4 reveals that a medium to high soil moisture favors the pre-emergence phase of damping-off. There is, however, no indication that the post-emergence phase has any direct relation to soil moisture, provided enough moisture is present to allow normal growth of the plants.

From further study of the table it may be seen that chemical seed treatments are not always effective in controlling damping-off, especially if the plants involved and the environmental conditions favor the disease. Thus on spinach, which is especially susceptible, damping-off was not satisfactorily controlled in heavily infested soil with medium to high soil moisture. However, the same chemicals under identical conditions were very effective in preventing the disease on tomatoes, which are apparently much less susceptible to the disease than spinach. This fact seemed clearly evident thruout these studies, but it is possible that the differences in control listed in Table 4 for these crops may be a function of the amount of dust which adhered to the seed coats rather than the relative susceptibility of the seedlings. The fuzziness of tomato seed coats permits very heavy coverage compared with that obtained on the smooth surface of spinach seed.

In a study of the relation of temperature and moisture on the stand of pea seeds treated with Semesan, Jones[70*] reported that watering immediately after sowing treated seed reduced the effectiveness of the treatment. He also reported that such watering decreased the stand of untreated seed. While no appreciable effect of moderate watering shortly after planting was observed in the greenhouse studies reported here, a field series conducted at Collinsville, Illinois, on the farm of Leroy Fournie in 1936, substantiates the work of Jones so far as Semesan is concerned. This field study, discussed on page 328, demonstrates quite clearly that the effectiveness of Semesan is reduced much more by a heavy rain immediately after treated seeds are planted than is the effectiveness of other treatments.

Soil Type

Many investigators regard light sandy soils as being less favorable to damping-off than those higher in humus. The state-wide survey made in connection with the present study seemed in general to bear this out, but many exceptions to it were encountered, under both field and greenhouse conditions.

There are many excellent arguments to recommend the use of sand for the growth of seedlings. These are summarized in the recent works of Dunlap.[37, 38*] It is, of course, self-evident that there are many situations to which sand culture is not applicable, and consequently information concerning the relation of soil types to damping-off and its control by seed treatments is needed.

Many different types of soil are used in Illinois for the production of vegetable crops, but only a few were studied under controlled conditions. Those selected were a black silt loam (Urbana, pH 6.5), a loess (Collinsville, pH 6.2), a clay (Anna, pH adjusted to 6.4), and pit sand (origin unknown, pH 6.7). Since the cropping histories were not known for all the soils used, it seemed advisable to inoculate the soils with cultures of Pythium and Rhizoctonia. Accordingly agar cultures of these fungi were cut into very fine pieces and added to the soils in water. After thoro mixing, the soils were set aside for two months at temperatures between 70° and 80° F. and were watered occasionally. In one series sand was treated exactly as recommended by Dunlap[38*] and very satisfactory results were obtained, tho these results are not given detailed consideration since the sand was treated with hot water, thereby freeing it from damping-off fungi, which fact would defeat the purpose of this study.

After the soils had set for two months they were planted alternately to spinach and tomatoes until four plantings were made. The study was conducted in flats in a greenhouse which was maintained at temperatures between 70° and 80° F. The soil was kept moderately wet. The chemicals used for the treatment of the seed were Vasco 4, Semesan, and Cuprocide—the same as those used in the moisture study.

The results of this study of soil types in relation to damping-off are not listed in detail since there was no significant difference in the severity of the disease among the various soils and treatments tested. The results for each soil series did not vary more than $\pm$ 6 percent from the results listed under medium moisture in Table 4.

From the data and observations discussed, it appears that the type of soil is not an important variable in connection with the damping-off disease. Altho no significant differences existed between treatments and no visible injury resulted from any of them in any type of soil in this experiment, a few cases of injury have been reported by growers using Semesan or Cuprocide. Investigation of these cases has shown that the seedlings were grown either in sand or in definitely acid soil. The extent of chemical injury to seedlings in sand culture has not been investigated, but the relation of such chemical injury to acidity is discussed in the following pages.

Soil Acidity[a]

Materials and methods. In these studies on soil acidity a black silt loam soil was adjusted with lime and sulfuric acid to pH values as indicated in Table 5. An attempt was made to maintain one group of flats decidedly acid (around pH 5), another about pH 6.5 and a third group alkaline (around pH 7.2). Most soil used for the cultivation of vegetables in Illinois is within this range, altho a few such soils testing pH 4.5 have come to the authors' attention. After the soils were adjusted they were planted to spinach, and later the three pH levels were again determined and planted to tomatoes. The temperature of the greenhouse was maintained between 70° and 80° F., and the soil was kept fairly wet with distilled water.

The chemicals used in this series were Vasco 4 (principally zinc oxid), Semesan (organic mercury, 30 percent), Cuprocide (cuprous oxid), and Metrox (cuprous oxid). The methods of application were the same as those described on page 305, in connection with moisture studies.

Results. The data obtained on the effects of soil acidity on damping-off and its control are listed in Table 5. Damping-off in this series was caused primarily by Pythium, which the findings seem to indicate is actively parasitic over the normal acid range generally encountered under actual growing conditions. This finding is in general accord with the reports that have been made by others. Gratz,[51*] Rabinovitz,[94*] and Jackson[67*] found that Rhizoctonia would grow over an acidity range from pH 2.4 to pH 10.4, with an optimum slightly acid or near the neutral point. Jackson further reported that Pythium grew over the range of pH 3.0 to pH 8.5 with an optimum between 4.5 and 6.5. Buchholtz[19, 20*] reported that damping-off of alfalfa, caused by Pythium, was most severe on acid soils.

A general comparison of results involving different crops does not seem entirely justifiable, since any crop would be at a distinct disadvantage when grown on soils out of its normal acidity range. Such a growth handicap may render a plant more susceptible to invasion by the damping-off fungi.

Soil acidity seems not to be a very important factor in the incidence of damping-off of vegetable crops, in so far as Pythium and Rhizoctonia species are concerned, since vegetables are seldom grown commercially on soils that are extremely acid or alkaline.

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[a]The pH was determined by the quinhydrone method by either R. H. Bray or F. F. Weinard. Soil adjustments were made according to Mr. Bray's instructions.

TABLE 5.—SOIL ACIDITY: EFFECT ON INCIDENCE OF DAMPING-OFF AND ON CONTROL OF DAMPING-OFF BY SEED TREATMENTS

(Tests were conducted in greenhouse at temperatures ranging between 70° and 80° F. Plants were watered with distilled water only. Figures are averages, expressed as percentages, of six replications of 250 seeds each.)

Crop and treatment	pH 4.8				pH 6.5				pH 7.08			
	Pre-emergence[a]	Post-emergence	Final stand[b]	Total emergence[c]	Pre-emergence[a]	Post-emergence	Final stand[b]	Total emergence[c]	Pre-emergence[a]	Post-emergence	Final stand[b]	Total emergence[c]
Spinach[d]												
Checks, seed untreated	58	10	16	26	59	13	11	24	54	21	9	30
Vasco 4	11	14	59	73	13	22	49	71	20	20	44	64
Semesan	10	16	56	72	5	23	55	78	8	24	52	76
Cuprocide	15	15	53[e]	68	6	18	60	78	5	11	68	79
Metrox	12	14	58[e]	72	4	16	62	78	6	18	60	78
	pH 4.8				pH 6.4				pH 7.06			
Tomatoes[f]												
Checks, seed untreated	60	8	29	37	64	13	20	33	65	8	16	32
Vasco 4	18	8	72	80	27	2	68	70	19	4	74	79
Semesan	13	6	78	84	12	6	80	86	12	8	78	86
Cuprocide	20	2	76[g]	78	4	2	92	94	2	3	93	96
Metrox	23	3	72[g]	75	1	4	93	97	2	4	92	96

[a]Adjusted to seed germination (spinach, 84 percent; tomatoes, 97 percent). [b]Number of healthy plants at the end of the experiment. [c]Final stand *plus* post-emergence damping-off. [d]Spinach grew best at pH 6.5. [e]In two of the six plantings the plants treated with either form of cuprous oxid were burned and stunted. [f]Tomatoes grew best at pH 6.4. [g]In three of the plantings the seedlings showed distinct stunting but no burning.

Data were secured in connection with the influence of soil acidity on the chemicals used to control damping-off. Neither Vasco 4 (principally zinc oxid) nor Semesan (an organic mercury) seemed to be materially influenced by soil acidity. Cuprocide and Metrox (cuprous oxids), however, occasionally caused severe stunting and burning of plants growing on extremely acid soils. The injury was not always conspicuous; in fact, some of the planting did not show it at all.

With the idea of accentuating any injury that might occur, all materials in this series were added in excess of the amounts actually recommended by the manufacturers. Only one case of injury under commercial conditions with Cuprocide used at recommended strength on acid soil has ever come to the authors' attention. In this instance the soil tested pH 4.5 and was definitely too acid for the normal production of any vegetable crop, altho attempts were being made to grow spinach. Tho the fact that injury occurred in this particular instance probably has no great commercial significance, it may nevertheless aid materially in explaining unusual results when they are encountered.

CONTROL OF DAMPING-OFF

The following comparison of various materials and methods that are often recommended for the control of damping-off is divided for convenience into two parts. The first deals with seed-treatment materials, and the second with chemical and physical methods of soil treatment.

Greenhouse Studies of Seed Treatments

Except for one rather limited series conducted in the greenhouse of the Cook County Experiment Station at Des Plaines in 1933, these experiments on the effect of seed treatments on damping-off were run in the greenhouse of the Horticulture field laboratory at Urbana.

All the comparisons were conducted under controlled conditions. The soil used was a black silt loam that had been used many years for the culture of various vegetable crops and that was known to be infested with species of both Pythium and Rhizoctonia. The soil was not sterilized, since it was considered desirable to maintain as nearly as possible a normal biological and physiological balance. In other words, an attempt was made to duplicate actual commercial conditions. In the series conducted at Des Plaines in 1933 the soil had a pH of 6.6, while in all others it was either 6.5 or 6.4.

The plantings were watered daily in an effort to maintain optimum conditions for the development of damping-off, and accordingly the soil moisture was medium to high at all times. The houses were shaded to prevent direct sunlight from drying the soil and otherwise introducing additional variables. The humidity of the houses varied greatly, but was usually between 50 and 75 percent.

FIG. 5.—CUPROCIDE AND METROX GAVE EQUALLY SATISFACTORY CONTROL

The results of planting untreated seed may be seen in the two checks. The lower check was a flat of river sand, from which only one seedling of the 250 seeds planted came up. Some growers have erroneously believed that damping-off is never severe in sandy soil.

All the seeds were generally used commercial varieties purchased from reputable seedsmen. The percentage germination of the seed at the time each series was conducted is given in the tables along with the results. In considering the efficiency of any treatment the total stand should be compared with actual seed germination as well as with the checks.

The chemicals used have been recommended by experimental workers or have been submitted by the manufacturers as seed treatment materials satisfactory for the control of damping-off. Among the materials tested were monohydrate copper sulfate and copper carbonate used as dusts, and copper sulfate used as a soak (1½ ounces in 1 gallon water, seed soaked for one hour). These three materials were purchased and were all chemically pure grades. All other materials used were submitted by various chemical companies, listed, with the products submitted, on page 297.

Unless otherwise stated, the materials were added in excess and that which did not adhere to the seed was screened off. This practice was followed in order to give each chemical every possible chance as a seed treatment and also to accentuate possible injury.

Seed coverage. Very soon after the studies were begun, it became apparent that the effectiveness of any chemical of a similar group, such as the copper or zinc compounds (Fig. 6), and to a limited extent any dust treatment, was directly correlated with the type of coverage imparted to the seed. Semesan, Metrox, and Cuprocide stuck uniformly and well on practically all seeds tested. Vasco 4 gave the best coverage of all the zinc oxids tested, altho there was not a great deal of difference between it and Leafox or AAZ Special on the crops which respond favorably to treatment with zinc. The other materials tested gave rather spotty, uneven coverage on most seed. Some, especially the other cuprous oxids, gave rather lumpy coverage. But enough material adhered to most seed so that the results of the damping-off series should be a rather reliable index of their performance.

The results of each test are listed in a separate table and are given as percentages. Under each crop the first column of figures equals the total emergence (that is, final stand plus post-emergence damping-off), and the second column the post-emergence damping-off. The percentage of pre-emergence damping-off may be secured by subtracting total emergence from the germination percentages of the seed.

Series 1. This series was conducted at the Cook County Experiment Station, Des Plaines, Illinois, in a greenhouse maintained at 72 $\pm$ 9° F. The soil temperature varied between 68° and 75° F. until after the seedlings had emerged. The humidity was low and the post-emergence damping-off was so slight that separate records of it are not listed in the results, Table 6.

Because of limited space, only a few crops were used in this test. They were selected as representative of those generally grown in the Cook county area, and include several crops especially susceptible to damping-off. Damping-off was not severe except on especially susceptible crops.

In this series the difference between treatments was not outstanding, tho radish and cabbage were injured severely by all copper treatments, and copper sulfate soak caused severe injury to peas and onions. The actual value of each treatment can best be determined by examination of Table 6.

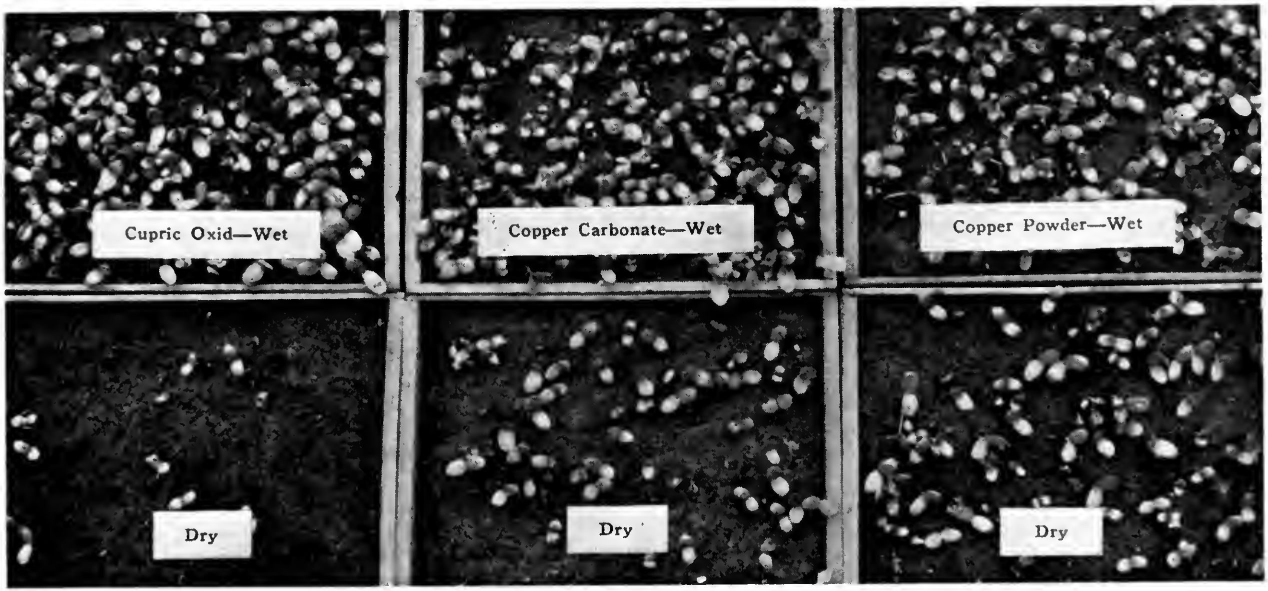

FIG. 6.—STANDS OBTAINED FROM SEED TREATED BY METHODS GIVING GOOD AND POOR COVERAGE

Unless the chemicals cover the seed uniformly and well, they cannot give adequate protection to the seedlings. Good coverage was obtained in the top row of flats by applying the treatment materials to moistened seed. The same materials were applied to the dry seed that was planted in the lower row of flats.

TABLE 6.—CHEMICAL SEED TREATMENTS, GREENHOUSE SERIES 1: EFFECT ON DAMPING-OFF AS MEASURED BY PERCENTAGES OF SEEDLINGS TO EMERGE,[a] DES PLAINES, ILLINOIS, APRIL, 1936
(Soil temperature between 68° and 75° F.; soil pH 6.6; moisture high.)

Treatment	Lettuce	Radish	Spinach	Onions	Beets[b]	Carrots	Peas	Toma-toes	Egg-plant	Pepper	Cabbage	Cucum-ber
Checks, seed untreated	63	86	47	58	77	41	40	71	57	76	26	8
Monohydrate copper sulfate	72	*33	85	56	83	15	84	84	64	69	*32	71
Copper sulfate soak	74	*2	66	*25	107	57	*54	85	75	75	*18	83
Copper carbonate	77	*76	81	70	123	55	83	95	66	92	*56	81
Cuprocide	65	*74	95	77	128	44	86	91	67	91	*75	94
Semesan	68	92	87	80	119	42	89	85	64	82	64	89
Percentage germination, untreated seed	86	94	95	87	94	71	90	94	(?)	(?)	63	99

[a]Two hundred fifty seeds in each treatment. Total emergence equals final stand *plus* post-emergence damping-off. In this series there was practically no post-emergence damping-off. [b]Seed balls.
*Plants were injured by leaf burning, or stunting, or both.

Series 2. In this series the greenhouse was maintained at 75 ± 5° F. The soil temperature for the duration of the study ranged between 72° and 75° F.

The vegetable crops that are of general importance in Illinois were grown. All the materials which had come to the authors' attention at the time were included in the test except the zinc oxids submitted by the Mallinckrodt and the Merck chemical companies, which were not used because they failed to give satisfactory seed coverage. "Galvanizing," or coating the soil surface with zinc oxid for the control of post-emergence damping-off, was tried in conjunction with seed treatments both by zinc oxid and by cuprous oxid, as suggested by Horsfall.[64*] The zinc oxid was applied at the rate of one-half ounce to one square foot of soil. All seed treatments were applied as indicated on pages 311 to 313.

The results of Series 2, given in Table 7, indicate, as did also the results of Series 1 (Table 6), that copper treatments are not safe for use on any of the crucifers. It is also evident that the copper sulfate soak has only very limited application. The "galvanizing" of the soil surface with zinc oxid was very effective in the control of post-emergence damping-off (see spinach, Table 7), but certainly is not generally applicable because of the injury it produces. The injury produced is probably closely correlated with the type of soil treated and consequently is of local significance.

Damping-off was quite severe on the crops especially susceptible to the disease; accordingly the value of the various treatments may best be determined by examination of the results pertaining to the several crops. With spinach, cuprous oxid (Röhm and Haas, Mallinckrodt, and Merck), copper sulfate soak, and Semesan were the most satisfactory treatments. Semesan and all forms of copper, except the Ansbacher-Siegle cuprous oxid, were satisfactory treatments for the cucurbits. With the additional exception of copper carbonate, this statement also holds true for tomato and eggplant. Semesan and zinc oxid were outstanding so far as the crucifers were concerned. With Swiss chard and beets, Semesan and the cuprous oxids (excepting Ansbacher-Siegle's) gave the most satisfactory control. For comparisons on other crops the reader is referred to Table 7.

Series 3. This series was conducted in the spring of 1935 under conditions practically identical to those of Series 2. There was a 2-degree greater fluctuation in air temperature, so that the range was 75 ± 7° F. This fluctuation had little effect upon the soil temperature, which ranged between 72° and 76° F.

The same materials were used in this test as in Series 2, with the

TABLE 7.—CHEMICAL SEED TREATMENTS, GREENHOUSE SERIES 2: EFFECT ON DAMPING-OFF AS MEASURED BY PERCENTAGES OF SEEDLINGS THAT EMERGED,[a] URBANA, MARCH AND APRIL, 1934

(Temperature of soil between 72° and 75° F.; soil pH 6.5; moisture medium to high.)

Treatment	Lettuce	Endive	Cabbage	Kale	Kohlrabi	Radish	Turnip	Parsnip	Carrot	Beet	Swiss chard	Bean	Pea	Leek	Cucumber	Muskmelon	Watermelon	Tomato	Pepper	Eggplant	Spinach
Percent total emergence (first figure) and percent post-emergence damping-off (second figure)																					
Checks, seed untreated	75-1	74-1	24-1	88-0	48-0	85-3	85-5	82-0	56-1	47-24	70-6	94-0	96-0	78-0	57-11	39-0	25-2	36-2	64-0	43-10	11-10
Monohydrate copper sulfate dust	80-4	59-0	*23-1	87-0	56-0	*38-0	*83-6	77-0	55-1	65-1	114-1	91-0	99-4	75-0	92-2	90-0	86-0	88-3	76-0	86-4	69-20
Copper sulfate soak[b]	85-3	64-0	*26-0	*77-0	*38-1	* 1-0	*57-4	† 0-0	55-0	89-13	113-11	*44-0	*79-1	42-3	94-0	91-1	92-0	86-0	74-0	80-4	80-15
Copper carbonate	79-4	65-0	*46-6	86-0	48-1	*59-3	77-2	78-1	56-0	98-33	96-8	92-0	98-0	80-1	91-0	86-1	83-1	79-1	65-0	77-2	56-8
Cuprocide	86-2	64-0	*43-0	84-0	53-0	42-0	84-3	88-0	62-0	148-11	134-3	90-0	100-0	86-1	100-0	93-1	96-0	88-3	86-0	91-2	83-16
Cuprous oxid (Mallinckrodt)	....	....	....	....	....	....	....	....	....	141-9	137-2	....	....	....	94-0	....	....	83-1	....	93-4	79-11
Cuprous oxid (Merck)	....	....	....	....	....	....	....	....	....	143-6	124-1	....	....	....	96-0	....	....	86-3	....	89-3	78-12
Cuprous oxid (Ansbacher-Siegle)	....	....	....	....	....	....	....	....	....	97-12	78-1	....	....	....	79-2	....	....	41-0	....	44-4	20-3
Semesan	89-4	68-0	87-3	92-0	76-2	92-0	95-1	86-0	56-1	129-12	146-6	95-0	100-0	81-0	96-0	89-0	90-0	88-0	83-0	80-0	77-11
AAZ Special																					
Seed treatment only	78-2	72-0	80-0	87-0	56-0	86-0	86-0	79-0	51-0	72-29	*87-16	88-0	91-0	84-2	89-1	*87-1	64-1	77-0	66-0	66-1	62-25
Seed and soil treatments	*80-2	*58-1	80-0	90-0	69-0	*80-0	*56-11	82-0	54-2	*68-4	129-0	*92-0	98-0	*68-1	*87-4	*88-2	*56-0	*80-0	60-1	58-0	*71-2
Cuprocide on seed, AAZ Special on soil	84-0	*56-0	*24-2	*67-1	*36-0	*23-0	*83-25	*87-0	55-2	*91-2	143-6	*92-0	100-0	*73-2	*97-6*	*91-1	*79-1	*88-1	80-0	88-0	*87-0
Percent germination of untreated seed																					
Germination test[c]	95	80	91	91	79	97	98	93	72	99	92	96	100	88	100	98	98	91	88	98	86

[a]Five hundred seeds in each planting, except of peas, beans, watermelon, and squash, for which 100 seeds were used. Beet and Swiss chard seed are seed balls. [b]Seed soaked 1 hour in solution of 1½ ounces of copper sulfate in 1 gallon of water. [c]Determined in laboratory tests.

*Plants were injured by leaf burning, or stunting, or both.

†Seedlings failed to emerge, or seeds did not germinate, because of injury from seed treatment.

TABLE 8.—CHEMICAL SEED TREATMENTS, GREENHOUSE SERIES 3: EFFECT ON DAMPING-OFF AS MEASURED BY PERCENTAGES OF SEEDLINGS THAT EMERGED,[a] URBANA, MARCH AND APRIL, 1935

(Temperature of soil between 72° and 76° F.; soil pH 6.5; medium to high moisture.)

Treatment	Lettuce	Endive	Cabbage	Kale	Kohlrabi	Radish	Turnip	Parsnip	Carrot	Beet	Swiss chard	Bean	Pea	Leek	Cucumber	Muskmelon	Watermelon	Tomato	Pepper	Eggplant	Spinach
Percent total emergence (first figure) and percent post-emergence damping-off (second figure)																					
Checks, seed untreated	85-1	76-0	19-3	68-2	57-0	47-3	86-6	77-0	60-3	68-75	40-4	93-0	96-0	75-0	45-8	25-6	18-0	44-6	66-2	47-10	41-10
Monohydrate copper sulfate dust	90-0	62-0	*24-0	*90-0	62-0	*31-2	87-6	76-0	59-2	61-19	116-6	90-0	96-1	80-0	95-1	90-0	90-0	*84-1	76-1	81-4	55-20
Copper sulfate soak[b]	90-0	63-0	*27-1	*81-0	47-0	* 4-0	66-2	† 0-0	54-0	87-8	132-9	*22-0	*100-0	46-0	93-0	89-0	85-1	82-2	74-0	74-3	61-10
Copper carbonate	87-0	67-0	*46-5	*89-0	72-0	*69-0	91-2	78-0	55-0	95-28	86-7	94-0	99-0	85-0	92-2	90-2	89-2	76-1	67-0	75-2	62-4
Cuprocide	90-0	65-0	42-3	*90-2	65-0	71-1	84-4	86-0	60-1	124-9	124-3	92-0	99-0	82-1	98-0	92-1	89-0	81-2	85-0	90-2	77-5
Cuprous oxid (Mallinckrodt)	....	....	....	....	....	....	....	....	....	....	....	....	....	....	96-1	....	....	80-1	....	95-4	76-4
Cuprous oxid (Merck)	....	....	....	....	....	....	....	....	....	....	....	....	....	....	95-0	....	....	79-4	....	89-4	71-6
Cuprous oxid (Ansbacher-Siegle)	....	....	....	....	....	....	....	....	....	....	....	....	....	....	53-1	....	....	25-2	....	46-1	43-4
Semesan	96-0	68-1	82-0	90-0	80-1	86-0	97-1	82-0	55-0	119-8	150-2	95-0	96-0	82-0	95-2	86-3	80-1	88-1	81-1	72-4	72-12
AAZ Special	93-0	72-1	66-2	88-0	63-0	84-0	90-4	78-0	52-0	74-28	*94-22	91-0	91-0	88-0	*92-11	89-2	66-1	76-4	68-0	67-2	56-31
Vasco 4	92-0	....	80-1	89-0	76-0	86-0	92-0	....	....	84-7	....	....	90-0	....	....	....	....	78-2	....	71-1	76-16
AAZ Special, on seed and soil	89-0	63-0	68-0	91-0	73-0	76-0	*56-9	84-0	56-1	74-9	*129-2	93-0	96-0	76-0	*92-4	92-2	*59-2	80-0	74-0	80-1	*51-17
Cuprocide on seed } AAZ Special on soil }	83-0	49-0	*27-1	*67-26	62-0	75-0	*86-36	83-0	52-2	89-8	*98-5	89-0	100-0	*77-2	*95-8	89-0	*80-0	88-0	78-0	86-2	*78-2
Percent germination of untreated seed																					
Germination test[c]	92	88	90	98	88	95	98	89	74	96	98	97	100	90	99	91	99	88	88	98	79

[a]Five hundred seeds in each planting, except of peas, beans, and watermelon, for which 100 seeds were used. Beet and Swiss chard seed are seed balls. [b]Seed soaked 1 hour in solution of 1½ ounces of copper sulfate in 1 gallon of water. [c]Determined in laboratory tests.

*Plants were injured by leaf burning, or stunting, or both.

†Seedlings failed to emerge, or seeds did not germinate, because of injury from the seed treatment.

addition of Vasco 4. Vasco 4 differs from the zinc oxids tested in that it contains, in addition to a large amount of zinc oxid, other forms of zinc, of which zinc hydroxid is the most important. In this series the zinc oxid applied to the soil surface was reduced to about ⅓ ounce to a square foot of soil, instead of ½ ounce as used in Series 2.

The results of Series 3, given in Table 8, are similar in general to those of Series 2. Cuprous oxid (Röhm and Haas, Mallinckrodt, and Merck), Semesan, and Vasco 4 were quite effective in controlling damping-off of spinach. Copper sulfate soak was quite inferior on spinach, tho in Series 2 it was among the best. All treatments were effective on tomatoes, while on eggplant the cuprous oxids, excepting Ansbacher-Siegle's were outstanding. As in Series 2, all forms of copper and Semesan gave good results with the cucurbits. Beets and Swiss chard responded best to cuprous oxid and Semesan. On crucifers Semesan, Vasco 4, and zinc oxid were definitely superior. For the most part Vasco 4 was slightly better than zinc oxid, perhaps because it adhered to the seed better than zinc oxid. Differences among treatments on other crops were not particularly significant.

Even tho the amount of zinc oxid applied to the surface of the soil was materially reduced, this treatment still caused considerable injury. All crops so treated showed a peculiar spindly growth, in addition to leaf burning on some.

Series 4. The soil was changed early in the fall, and shortly after the first of October, 1935, Series 4 was under way. Owing to some unexpected warm weather, the greenhouse temperature was somewhat higher than in previous tests ($77 \pm 6°$ F.). As would be expected, the soil temperature was also higher, ranging between 74° and 77° F. All other conditions were maintained as nearly like those in previous tests as was possible. Metrox was added to the cuprous oxids tested. The surface treatments with zinc oxid were discontinued because of the injury so common from them. All other treatments were the same as in Series 3, and are listed in Table 9 along with the results.

Damping-off was generally severe in Series 4. The results were quite similar to those of previous tests, except that monohydrate copper sulfate and copper carbonate were less effective than before. Copper carbonate, however, still appeared to be one of the best treatments for use on tomatoes. Semesan, copper sulfate soak, and cuprous oxids (excepting Ansbacher-Siegle's) were satisfactory treatments for all crops except crucifers, for which Vasco 4, zinc oxid, and Semesan were outstanding. Vasco 4 was also a good treatment on spinach.

TABLE 9.—CHEMICAL SEED TREATMENTS, GREENHOUSE SERIES 4: EFFECT ON DAMPING-OFF AS MEASURED BY PERCENTAGES OF SEEDLINGS THAT EMERGED,[a] URBANA, OCTOBER, 1935

(Temperature of soil between 74° and 77° F.; soil pH 6.5; medium to high moisture.)

Treatment	Lettuce	Cabbage	Kale	Kohlrabi	Radish	Carrot	Beet	Swiss chard	Onion	Cucumber	Muskmelon	Watermelon	Tomato	Pepper	Eggplant	Spinach
Percent total emergence (first figure) and percent post-emergence damping-off (second figure)																
Checks, seed untreated	34-2	5-0	19-3	25-3	80-0	26-4	20-11	43-26	49-27	2-0	6-0	0-0	39-4	42-1	30-6	5-3
Monohydrate copper sulfate dust	45-4	*10-0	12-4	*30-2	*40-2	29-2	32-18	101-70	46-15	55-30	15-2	10-1	*90-6	46-0	55-6	13-12
Copper sulfate soak[b]	92-1	....	....	†0-0	†0-0	45-1	84-54	106-36	56-2	86-17	74-7	70-7	94-16	56-0	68-9	24-2
Copper carbonate	63-3	28-5	34-8	35-0	*38-2	33-8	24-20	93-62	45-30	89-20	61-8	48-7	98-3	52-0	58-9	17-15
Cuprocide	59-3	*8-1	33-0	44-2	*60-3	41-4	110-21	125-30	52-34	89-28	77-17	86-3	96-5	57-0	77-4	40-30
Cuprous oxid (Mallinckrodt)	86-7	*39-0	*45-0	*41-0	*59-0	40-10	88-56	93-35	36-16	88-4	61-12	72-2	98-1	53-0	68-2	29-14
Cuprous oxid (Merck)	....	....	....	....	....	....	....	....	....	....	....	....	94-4	....	69-4	....
Cuprous oxid (Ansbacher-Siegle)	65-4	12-0	19-4	35-1	58-8	41-2	19-9	78-42	47-23	86-10	18-2	24-4	96-4	61-1	62-9	12-9
Cuprous oxid (Metals Rfg.)	74-2	*1-0	*10-3	*26-0	*78-1	40-2	92-41	117-32	42-14	92-19	80-10	98-18	86-4	56-0	74-7	27-22
Semesan	90-1	53-0	36-0	51-0	97-1	75-3	105-48	107-36	49-4	88-28	85-1	68-20	94-9	56-2	68-15	40-31
AAZ Special	20-1	28-0	24-3	39-1	58-0	30-4	20-14	94-48	36-14	*76-35	58-2	*1-0	52-10	48-2	65-6	14-14
Vasco 4	47-1	48-3	32-3	48-0	58-2	41-0	39-24	133-38	50-10	*65-25	*78-5	*3-0	83-5	45-0	*46-0	34-24
Percent germination of untreated seed																
Germination test[c]	90	66	66	54	91	....	86	96	68	96	94	84	95	54	80	54

[a]Five hundred seeds in each planting, except of watermelon, for which 100 seeds were used. Beet and Swiss chard seed are seed balls. [b]Seed soaked 1 hour in solution of 1½ ounces of copper sulfate in 1 gallon of water. [c]Determined in laboratory tests.

*Plants were injured by leaf burning, or stunting, or both.

†Seedlings failed to emerge, or seeds failed to germinate, or both.

Series 5. Immediately after the completion of Series 4 the soil was changed and Series 5 was begun. The greenhouse temperature during this test was $75 \pm 7°$ F., and the soil temperature ranged between 72° and 76° F. The houses were completely filled with plants, which aided in maintaining a fairly high humidity, and accordingly post-emergence damping-off was more severe than usual.

Monohydrate copper sulfate and copper carbonate were omitted in this series because of their unreliability as treatments. The variable results secured from them seemed to be directly correlated with the erratic coverage on many seeds. In one series the coverage would be quite satisfactory for a given crop, while on the same kind of seed at a later date they would not stick at all. The exact reason for this is not known, altho observations indicate that the amount of moisture in the seed and in the air influences the sticking qualities of some materials. Merck's cuprous oxid also was omitted because of the lack of material on hand. Its general texture, color, sticking qualities and performance were so similar to Mallinckrodt's cuprous oxid that further tests with it were not considered necessary so long as Mallinckrodt's was included. Aside from these omissions the materials were the same as in Series 4 and are listed in Table 10 with the results.

The results in this series were more variable than usual, which makes an evaluation of them more difficult. On spinach, tomato, muskmelon, cucumber, Swiss chard, beet, and lettuce the cuprous oxids (excepting Ansbacher-Siegle's), copper sulfate soak, and Semesan gave generally satisfactory results. Semesan and Vasco 4 were superior on cabbage. Vasco 4 was also satisfactory on spinach and tomato. On the other crops tested either the results were too variable or damping-off was not severe enough to make the data significant.

Series 6. Again the soil was changed, and in late March, 1936, a duplicate series of tests was conducted using the same treatments as in Series 5 except that Leafox was added.

The greenhouse temperature during this series was $75 \pm 6°$ F., and the soil temperature ranged between 72° and 76° F. The humidity was fairly high most of the time.

Because of the variability of results the duplicate plantings in this series are not averaged, but are listed individually in Table 11. Here again the results are practically identical to those of previous tests, altho as usual some irregularities have occurred. Both Semesan and copper sulfate soak fell down, so far as the control of damping-off on spinach was concerned, while the cuprous oxid and zinc oxid treat-

TABLE 10.—CHEMICAL SEED TREATMENTS, GREENHOUSE SERIES 5: EFFECT ON DAMPING-OFF AS MEASURED BY PERCENTAGES OF SEEDLINGS THAT EMERGED,[a] URBANA, NOVEMBER, 1935

(Temperature of soil between 72° and 76° F.; soil pH 6.4; medium to high moisture.)

Treatment	Lettuce	Cab-bage	Kale	Kohl-rabi	Radish	Carrot	Beet	Swiss chard	Onion	Cucum-ber	Musk-melon	Tomato	Pepper	Egg-plant	Spinach
Percent total emergence (first figure) and percent post-emergence damping-off (second figure)															
Checks, seed untreated	46-2	12-1	68-6	39-0	83-2	47-4	38-24	77-31	61-5	14-3	3-0	42-5	30-0	45-0	33-16
Copper sulfate soak[b]	90-10	....	....	†0-0	†0-0	60-14	88-48	116-54	73-5	87-4	82-2	89-2	36-0	64-1	63-24
Cuprocide	85-2	*20-1	22-5	36-1	*72-3	64-22	94-27	99-13	68-5	88-5	83-0	90-0	35-0	38-0	60-34
Cuprous oxid (Mallinckrodt)	82-0	*47-0	*65-2	*53-0	*43-4	52-8	97-21	134-8	53-7	94-5	75-2	89-1	56-2	64-2	72-16
Cuprous oxid (Ansbacher-Siegle)	75-11	16-1	58-2	46-0	76-1	55-6	82-3	140-24	60-11	86-7	35-3	82-2	54-1	64-2	52-28
Cuprous oxid (Metals Rfg.)	92-4	*16-0	39-5	*41-1	*76-2	59-11	110-20	121-17	54-6	89-11	76-3	92-1	54-0	38-0	64-34
Semesan	90-16	55-3	46-2	46-0	95-0	77-28	88-23	88-23	72-0	90-12	85-1	86-1	50-0	68-14	70-51
AAZ Special	53-7	26-0	43-0	42-1	92-7	54-11	75-34	75-34	58-3	*78-19	58-2	62-4	42-0	67-1	41-30
Vasco 4	68-3	56-0	68-1	49-0	91-0	54-4	69-30	69-30	69-4	*77-14	*78-5	86-0	49-0	*60-0	59-34
Percent germination of untreated seed															
Germination tests[c]	90	66	66	54	91	....	86	96	68	96	94	95	54	80	54

[a]Five hundred seeds in each planting. Beet and Swiss chard seed are seed balls. [b]Seed soaked 1 hour in solution of 1½ ounces of copper sulfate in 1 gallon of water. [c]Determined in laboratory tests.

*Plants were injured by leaf burning, or stunting, or both.

†Seedlings failed to emerge, or seeds did not germinate, because of injury from seed treatment.

TABLE 11.—CHEMICAL SEED TREATMENTS, GREENHOUSE SERIES 6: EFFECT ON DAMPING-OFF AS MEASURED BY PERCENTAGES OF SEEDLINGS THAT EMERGED,[a] URBANA, MARCH, 1936

(Temperature of soil between 72° and 76° F.; soil pH 6.5; medium to high moisture. Tests were made in duplicate.)

Treatment	Lettuce	Cab-bage	Kale	Kohl-rabi	Radish	Carrot	Beet	Swiss chard	Onion	Cucum-ber	Musk-melon	Water-melon	Tomato	Pepper	Egg-plant	Spinach
Percent total emergence (first figure) and percent post-emergence damping-off (second figure)																
Checks, seed untreated	80-0 82-0	59-0 57-2	58-6 61-2	32-2 36-0	60-0 65-0	32-0 38-0	51-14 52-26	45-27 57-37	85-0 91-0	74-41 67-23	4-0 4-0	25-0 40-0	58-0 61-0	58-0 61-0	57-3 58-1	27-14 32-16
Copper sulfate soak[b]	96-0 93-0	....	....	....	†0-0 †0-0	46-0 42-0	61-11 86-19	148-34 148-1	66-0 73-0	76-7 81-2	54-1 71-2	81-2 84-0	84-0 81-1	65-0 67-0	70-3 66-1	43-0 38-2
Cuprocide	85-0 84-0	87-0 81-10	80-0 85-4	46-0 50-0	*41-0 *46-0	41-0 47-0	66-1 77-1	153-6 141-13	80-0 87-0	90-6 93-0	48-2 70-3	92-1 94-0	86-0 74-0	52-0 57-0	67-4 66-0	75-0 68-0
Cuprous oxid (Mallinckrodt)	89-0 91-0	....	....	....	*45-0 *39-0	45-1 52-0	74-1 74-1	169-5 169-6	83-0 87-0	88-4 96-0	29-0 14-2	92-1 93-0	80-0 74-0	62-0 67-0	67-0 71-0	68-0 62-0
Cuprous oxid (Ansbacher-Siegle)	90-0 95-0	....	....	....	58-0 52-0	44-0 42-0	69-15 64-16	101-41 105-38	86-0 88-0	90-8 91-0	8-0 8-1	48-0 71-0	72-0 62-0	51-0 52-0	63-0 49-0	48-6 60-1
Cuprous oxid (Metals Rfg.)	93-0 88-0	72-0 63-0	77-2 81-1	45-0 30-0	*48-1 *51-1	49-0 47-0	98-1 86-1	156-8 164-14	88-0 88-0	89-0 93-1	45-4 80-1	93-0 94-0	78-0 64-0	57-0 63-0	56-4 56-0	73-2 81-1
Semesan	91-0 72-0	86-0 88-0	99-0 94-0	47-0 50-0	37-0 29-0	46-0 50-0	60-3 53-1	152-1 165-0	89-0 86-0	93-1 96-0	61-1 43-0	94-0 95-0	77-1 72-1	63-0 56-0	65-0 57-0	38-0 32-0
Vasco 4	88-0 94-0	88-1 92-0	80-0 89-0	53-0 55-0	76-0 74-0	52-0 44-0	66-6 68-11	90-50 87-57	86-0 90-0	94-4 95-0	49-0 62-1	23-3 79-0	85-0 80-0	58-2 61-0	59-0 66	77-1 73-0
AAZ Special	78-0 83-0	79-1 84-1	78-0 83-0	45-0 49-0	76-0 77-0	44-0 47-0	60-0 63-0	91-46 80-53	84-0 81-0	87-1 91-2	40-2 44-0	28-0 42-0	82-1 76-0	58-0 60-0	49-0 64-0	74-3 70-4
Leafox	82-0 88-0	81-2 85-1	80-0 86-0	51-0 48-0	75-0 73-0	47-0 45-0	59-0 67-0	84-42 86-61	86-0 83-0	91-2 83-1	43-0 46-0	49-1 51-0	74-2 83-0	60-0 59-1	61-0 60-0	72-0 75-1
Percent germination of untreated seed																
Germination test[c]	85	80	91	76	89	60	62	91	92	98	85	87	97	71	75	84

[a]Five hundred seeds in each planting, except of watermelon, for which 100 seeds were used. Beet and Swiss chard seed are seed balls. [b]Seed soaked 1 hour in solution of 1½ ounces of copper sulfate in 1 gallon of water. [c]Determined in laboratory tests.

*Plants were injured by leaf burning, or stunting, or both.

†Seedlings failed to emerge, or seeds did not germinate, because of injury from seed treatment.

ments gave good results. Vasco 4, Semesan, Leafox, and AAZ Special, in the order named, controlled damping-off on cabbage, tho the disease was not especially serious on cabbage or other crucifers in this test. On the other crops susceptible to damping-off the copper treatments and Semesan were the best.

Control of Pythium and Rhizoctonia on Spinach

Thruout these greenhouse tests the principal cause of damping-off was Pythium, altho Rhizoctonia was not uncommonly associated with the disease. It seemed worth while to conduct a study on a crop especially susceptible to damping-off to determine whether treatments representative of satisfactory types would control both fungi equally well. Spinach was the crop selected for the study, and the chemicals were Cuprocide, Vasco 4, and Semesan.

The soil was thoroly steamed for 1½ hours. After it had cooled, part of it was inoculated with oat cultures of Pythium previously isolated from spinach; another part with oat cultures of Rhizoctonia also isolated from spinach; and a third part was saved without inoculation. The two inoculated portions were planted in duplicate to 500 seeds of each treatment. Untreated seed were planted in duplicate on sterilized soil as one check; a second check was planted on sterilized soil which had been inoculated with each of the fungi; and a third on unsterilized soil known to contain species of both fungi.

As the plants damped off they were examined to determine the cause of the disease, and in a few cases isolations were made to facilitate a more accurate determination.

The test was conducted with a soil temperature of 72° to 76° F., which is a favorable temperature for both fungi. As in previous comparisons, the chemicals were added in excess, and that which did not adhere was screened off. The coverage was uniform and good for all three treatments. The results are given in Table 12.

This study was conducted at the same time as Series 5 (see spinach, Table 10, page 322), and brought out several interesting comparisons and facts. Even tho species of the same fungi were involved, damping-off was more severe in inoculated sterilized soil than in unsterilized soil containing a normal balance of organisms and conditions. It was evident that seed treatments will not give commercial control of damping-off when conditions favor the disease as they did in this inoculated sterilized soil. It was again evident that when conditions favor this phase of the disease, the treatments are of little value so far as post-emergence damping-off is concerned. Steaming of the soil will control damping-off provided the soil is not recontaminated. Unless

TABLE 12.—EFFECT OF SEED TREATMENTS FOR CONTROL OF RHIZOCTONIA AND PYTHIUM ON SPINACH, NOVEMBER, 1935

(Soil temperature 72° to 76° F.; soil pH 6.7; moisture medium to high; 500 seeds planted in duplicate; percentages of damping-off adjusted to 84 percent germination of seed.)

Treatment[a]	Pre-emergence damping-off	Post-emergence damping-off	Final stand	Total emergence	Comments
		Rhizoctonia series, percent damping-off			
Checks, seed untreated					
Soil not inoculated.......	3 2	0 30	81 52	81 82	One flat was recontaminated with Pythium, and all seedlings in one area of the flat died.
Soil inoculated[b].........	76 72	1 3	7 9	8 12	Only Rhizoctonia was isolated from diseased seedlings.
Semesan.................	30 23	13 32	41 29	54 61	Only Rhizoctonia was isolated from diseased seedlings.
Cuprocide................	21 12	16 32	37 40	63 72	Only Rhizoctonia was isolated from diseased seedlings.
Vasco 4..................	34 38	18 18	32 28	50 46	Pythium also isolated from a few seedlings in one flat.
		Pythium series, percent damping-off			
Checks, seed untreated					
Soil not inoculated.......	6 1	67 9	11 74	78 83	Both flats were contaminated late in the study. Good control until then. Pythium recovered.
Soil inoculated[c].........	84 64	0 17	0 3	0 20	Only Pythium isolated from diseased seedlings.
Soil unsterilized and uninoculated..........	49 56	18 11	17 17	35 28	Disease caused largely by Pythium. Rhizoctonia also present.
Semesan.................	45 43	3 7	36 32	39 41	Only Pythium isolated from diseased seedlings.
Cuprocide................	45 36	11 2	28 46	39 48	Only Pythium isolated from diseased seedlings.
Vasco 4..................	43 48	19 6	22 30	41 36	Only Pythium isolated from diseased seedlings.

[a]All chemicals stuck to seed uniformly and well. [b]Inoculated with oat cultures of Rhizoctonia. [c]Inoculated with oat cultures of Pythium.

special precautions are taken, recontaminations are likely to occur, in which event the disease will probably cause heavier losses than if no treatment of any kind had been applied.

The data indicate that the seed treatments used are more effective in the control of the disease when caused by Rhizoctonia than when caused by Pythium. The treatments were effective in the control of the disease caused by both fungi, in the order named: Cuprocide, Semesan, and Vasco 4.

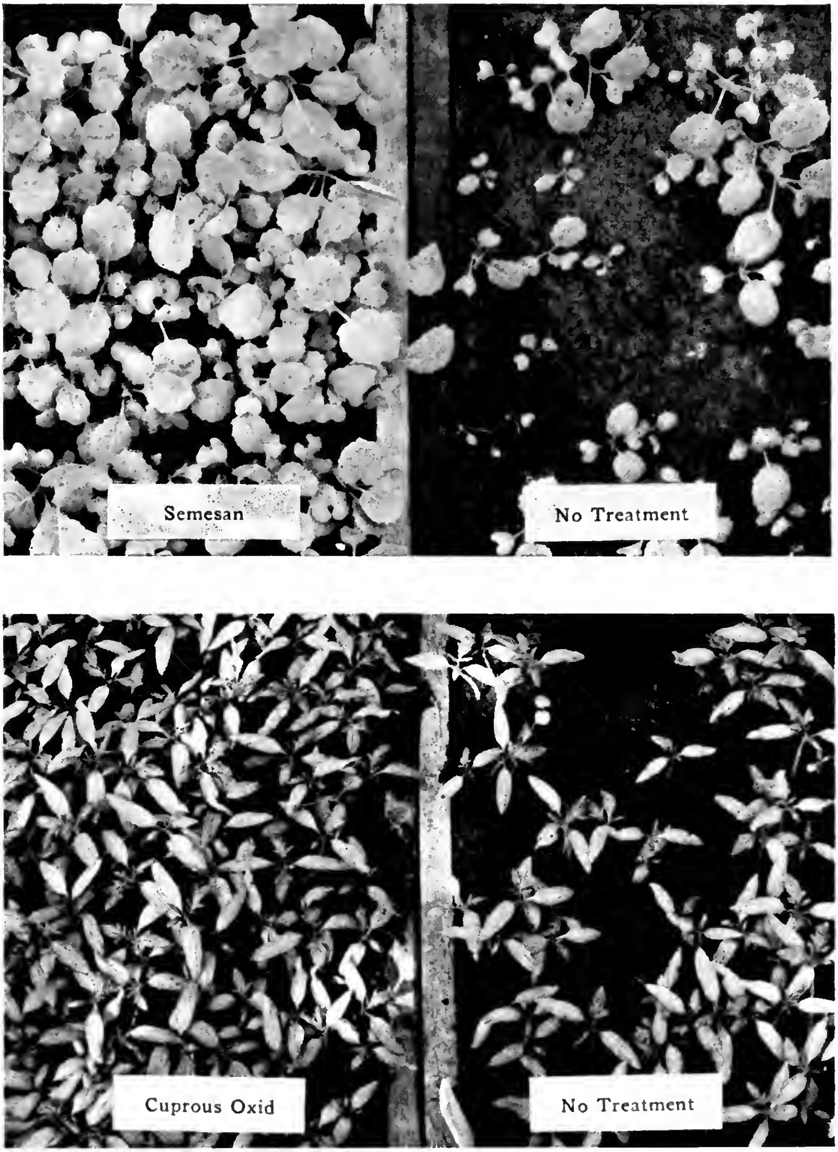

FIG. 7.—EFFECT OF TREATING CABBAGE AND TOMATO SEED FOR CONTROL OF PRE-EMERGENCE DAMPING-OFF

In each flat 250 seeds were planted. From the treated seed, 213 cabbage seedlings and 203 tomato seedlings emerged, and 4 of each later damped off. From the untreated seed 74 cabbage seedlings and 91 tomato seedlings came up, and the post-emergence damping-off was 8 and 6 plants respectively. Vasco 4 on cabbage and Semesan on greenhouse tomatoes gave control similar to that shown here.

Field Studies of Seed Treatments

Each spring during the last three years of this study attempts were made under field conditions to determine the relative value of the most promising seed treatments. Altho many and extensive tests were conducted, only a few yielded significant results. In 1934 a dust storm and dry weather ruined the experiments at Des Plaines and at East St. Louis. In the spring of 1935 some information of value was secured at the Peter Klippert farm, Des Plaines, Illinois, and in 1936 in tests at Urbana on the University farm, and at Collinsville, Illinois, on the farm of P. Fournie and Son. Other tests at Des Plaines, Urbana, and East St. Louis were of little value since conditions were such that no damping-off occurred. The checks were just as good or better than the treatments.

Field Test 1. This test was conducted on the farm and with the aid of Peter Klippert, a vegetable grower southwest of Des Plaines, Illinois. The soil was a brown silt loam on which vegetables, especially spinach and beets, had been grown for many years. Damping-off was always a problem when conditions favored it.

Spinach seed was treated with seven different materials, about 15 pounds of seed in each treatment. The materials and rates of applications were as follows:

Copper sulfate soak: 1½ ounces of copper sulfate dissolved in one gallon of water; seed soaked in the solution for one hour.
Monohydrate copper sulfate dust: 3/10 ounce per pound of seed.
Copper carbonate dust: 3/10 ounce per pound of seed.
Cuprocide: Added according to recommendation of manufacturer, 4/10 ounce (1 level teaspoonful) per pound of seed.
Semesan: added according to recommendation of manufacturer, 1/18 ounce (½ teaspoonful) per pound of seed.
AAZ Special: 3/10 ounce per pound of seed.
Vasco 4: 3/10 ounce per pound of seed.

The checks consisted of seed planted without treatment.

Five plantings were made from each batch of seed at intervals of about two weeks, the first being made on April 25. Equal amounts of seed of each treatment were drilled in at each planting. Data were taken from a unit of row adjusted in length in proportion to the total number of feet seeded from a given amount of seed. Five different counts were made of each treatment from each planting in comparable locations in the field.

The plantings of April 25 and May 11 were the only ones from which significant results were obtained (Table 13). The three other plantings either drowned or dried out. The figures in Table 13 equal the actual number of seedlings per unit of row.

TABLE 13.—CHEMICAL SEED TREATMENTS, FIELD TEST 1: EFFECT ON DAMPING-OFF OF SPINACH AS INDICATED BY STAND ONE MONTH AFTER SEEDING
(Tests conducted in duplicate at Peter Klippert farm, Des Plaines, Illinois, 1935.)

Treatment and planting date	Number of seedlings in 20 feet of row[a]					
	1st count	2nd count	3rd count	4th count	5th count	Average
Checks, seed untreated						
April 25	81	56	59	48	80	65
May 11	64	55	47	69	70	61
Copper sulfate soak[b]						
April 25	90	124	102	114	107	107
May 11	160	134	150	148	152	149
Monohydrate copper sulfate dust[c]						
April 25	99	118	124	147	109	119
May 11	121	146	130	124	128	129
Copper carbonate dust[c]						
April 25	109	146	147	121	119	128
May 11	109	95	104	113	−97	104
Cuprous oxid dust[d]						
April 25	167	198	165	177	174	176
May 11	161	169	161	175	164	166
Semesan dust[e]						
April 25	95	145	125	163	134	133
May 11	126	117	121	130	113	121
Zinc oxid dust[f]						
April 25	105	124	87	124	92	106
May 11	119	95	104	113	97	104
Vasco 4 dust[c]						
April 25	161	157	149	169	148	157
May 11	176	156	132	148	161	155

[a]The units of rows from which records were taken were adjusted to the various rates of sowing that resulted because of the presence of the chemicals on the seed. [b]Seed soaked 1 hour in solution of 1½ ounces of copper sulfate in 1 gallon of water. [c]Three-tenths ounce per pound of seed. [d]Four-tenths ounce per pound of seed, Röhm and Haas product. [e]One-eighteenth ounce per pound of seed. [f]Three-tenths ounce per pound of seed, Röhm and Haas product.

All treatments were of considerable value in controlling damping-off, but cuprous oxid and Vasco 4 were outstanding. Semesan did not perform nearly as well as it had previously in greenhouse tests.

Field Test 2. This comparison was made on the farm and with the help of P. Fournie and Son, general growers located north and west of Collinsville, Illinois. The soil was of the loess type with a pH of 5.8. All plots were drilled in, and the results adjusted to the various seeding rates induced by the different chemicals used. The treatments were limited to a selected few, and were applied in amounts recommended by the manufacturers. All treatments were planted in long parallel rows. The treatments and results are given in Table 14.

The outstanding result in this test was the nearly complete failure of Semesan to control damping-off on beets and spinach. Inasmuch as heavy rains fell 16 hours after the beet and spinach seeds were planted,

TABLE 14.—CHEMICAL SEED TREATMENTS, FIELD TEST 2: EFFECT ON DAMPING-OFF ON CARROTS, BEETS, AND SPINACH AS INDICATED BY STAND PER UNIT OF ROW[a]
(Tests conducted at farm of P. Fournie and Son, Collinsville, Illinois, 1935. Soil pH was 5.8. All plots were drilled in.)

Crop	Number of seedlings per unit of row when seed was treated with—					Comments
	Un-treated, checks	Cupro-cide	Metrox	Semesan	Vasco 4	
Carrots.....	50	117	67	61	93	Row unit was 25 feet.[a] Plants were 1½ to 2 inches tall when records were taken. Weather dry for 1½ weeks after planting, then a heavy rain.
	44	175	105	149	102	
	101	165	93	9	41	
	109	145	156	91	145	
	0	89	165	154	123	
	52	91	133	86	56	
	1	111	125	85	89	
	41	66	239	138	147	
	63	244	119	6	117	
	124	115	97	209	201	
Average...	59	132	130	99	112	
Beets.......	30	439	533	38	197	Row unit was 99 feet.[a] Plants were 2 inches tall when records were taken. Heavy rains occurred 16 hours after planting, and thereafter temperatures ranged from 70° to 80° F.
	20	394	339	67	188	
Average...	25	417	436	53	192	
Spinach.....	100	639	711	257	561	Records and conditions as for beets. Plants about 3 inches tall when records were taken.
	164	474	505	232	520	
Average...	132	557	608	245	541	

[a]The row unit from which records were taken was adjusted to allow for the different rate of seeding that occurred when chemicals were on the seeds. The standard for each crop was the number of untreated seeds dropped from the drill in the length of row selected as the unit.

these data seem to bear out the findings of Jones,[70*] who, working with peas in Washington state, found that the effectiveness of Semesan was greatly reduced if treated seeds were watered soon after planting. In all the greenhouse studies (pages 311 to 326) plants were given a moderate watering daily, but in spite of this fact Semesan was consistently among the most satisfactory treatments.

Another point of importance, which was well illustrated by the results of this test, is that the color of a cuprous oxid is not always a reliable index of its possible performance as a seed treatment. The cuprous oxid (Metrox) of the Metals Refining Company is cameo brown in color and in all tests by the authors has proved as good as the bright red cuprous oxids of the Röhm and Haas, Mallinckrodt, or Merck companies. In this test the cuprous oxids used gave excellent results on all three crops. Vasco 4 was effective only on spinach.

Field Test 3. This was the most comprehensive of all the field tests reported herein and was designed primarily as a final test of those treatments which had shown the most promise thruout the studies. The materials tested were copper sulfate soak, Cuprocide and Metrox (cuprous oxids), Semesan (organic mercury), Leafox (special zinc

FIG. 8.—CONTROL OF DAMPING-OFF OF PEAS BY CUPROUS OXID

In each of these pots of garden soil 100 seeds of Surprise variety were planted. Of the untreated seeds *(left)*, only 23 seedlings came up; but from the seed treated with Metrox *(right)* 94 seedlings emerged.

FIG. 9.—EFFECT OF SEED TREATMENT ON THE COTYLEDONS AND ON THE GROWTH AND VIGOR OF PEAS

The seedlings on the left, taken from the untreated pot in Fig. 8, have badly rotted cotyledons and in some cases disease invasion at the point of attachment. The seedlings on the right, from the treated pot in Fig. 8, have cotyledons somewhat shriveled, but in perfect condition.

oxid), and Vasco 4 (chiefly zinc oxid). All materials were applied in amounts comparable to similar treatments in Field Test 1.

Field Test 3 was conducted under the overhead irrigation system on the University farm with a large variety of vegetable crops. The first planting was made on May 6, and the second on May 21, 1936. Additional plantings of other crops were made on similar land not equipped for irrigation. Of these plantings, records were taken only on spinach and peas, the others being of no value. The actual number of seeds planted was known in all cases. The plantings under irrigation were watered daily. Four weeks after planting, counts of the final stand of seedlings were made. The pH of the soil under irrigation was 6.5, while that of the unirrigated soil was 6.6.

The results of the study, listed as percentages in Table 15, were in general accord with those of previous tests. The actual number of seeds planted is given under each crop in the table heading.

In this test the cuprous oxids and copper sulfate soak gave the best control of damping-off on spinach, squash, muskmelon and beets. These same treatments, and Semesan, were the best on Swiss chard, cucumbers, watermelons, and, with the exception of copper sulfate soak, were outstanding on peas. The crucifers (cabbage and kale) responded the best to treatment with Vasco 4, zinc oxid, and Semesan. Treatments on other crops were not outstanding.

Effect of seed treatments on nodulation of peas.—In the tests with peas it was further observed that there was a decided difference in vine growth and vigor between the seedlings from treated and from untreated seed. Close examination indicated that the cotyledons of the untreated seed were badly or completely rotted, while those of the treated were still in good condition. To check this point a little further some of the same soil was used for greenhouse plantings. The results were similar to those observed in the field plantings and are clearly shown in Figs. 8 and 9.

Rotting and stem infections seldom occurred where the seeds were properly treated. The difference in vine size and vigor shown in Fig. 9 is typical of the differences observed in the field experiments. Thus it is apparent that the benefit from treating pea seed is not limited to damping-off control, but extends to the general welfare of the entire plant. Other workers have come to a similar conclusion. It is not unreasonable to suppose that proper treatment of pea seed may materially reduce stem and root rots, which are so common to peas in Illinois.

Results of studies recently published by Kadow *et al*[71*] indicate

TABLE 15.—CHEMICAL SEED TREATMENTS, FIELD TEST 3: EFFECT ON DAMPING-OFF AS INDICATED BY PERCENTAGES OF SURVIVING PLANTS IN STANDS OF DIFFERENT CROPS, URBANA, 1936
(Soil pH was 6.5.)

Treatment and planting date	Lettuce (500 seeds)	Cabbage (500 seeds)	Kale (500 seeds)	Kohlrabi (500 seeds)	Turnip (500 seeds)	Radish (500 seeds)	Carrot (500 seeds)	Beet (1000 seeds)	Swiss chard (1000 seeds)	Bean (500 seeds)	Pea (500 seeds)	Onion (500 seeds)	Cucumber (1000 seeds)	Muskmelon (1000 seeds)	Watermelon (1000 seeds)	Squash (1000 seeds)	Tomato (500 seeds)	Eggplant (500 seeds)	Spinach (500 seeds)	Spinach on dry field (6077 seeds)	Peas on dry field (1410 seeds)
Checks, seed untreated																					
May 6	39	24	57	29	54	49	48	23	48	95	56	64	35	14	24	44	65	21	17	16	74
May 6	45	36	48	27	62	45	40	..	..	..	50	68	..	..	..	..	66	44	15	..	..
May 21	60	54	..	..	..	..	..	36	76	..	31	..	44	12	12	51	68	..	7	..	..
May 21	62	..	..	..	..	..	..	40	..	..	24	..	..	..	..	..	..	..	8	..	..
Copper sulfate soak[a]																					
May 6	57	..	..	..	..	..	51	63	114	*79	*48	59	76	81	90	90	67	50	40	65	*12
May 6	45	..	..	..	..	..	50	..	..	..	*65	54	..	..	..	..	62	37	38	..	..
May 21	60	..	..	..	..	..	..	99	137	..	*31	..	74	59	83	89	72	..	27	..	..
May 21	62	..	..	..	..	..	..	74	..	..	*24	..	..	..	..	..	..	..	21	..	..
Cuprous oxid dust (Cuprocide)[b]																					
May 6	57	41	53	32	65	38	52	66	146	97	86	74	88	67	95	65	65	54	35	64	84
May 6	58	38	47	28	*61	41	58	..	..	..	87	65	..	..	..	..	69	53	34	..	..
May 21	49	48	..	..	..	..	..	76	144	..	84	..	86	46	85	59	74	..	29	..	..
May 21	65	..	..	..	..	..	..	70	..	..	92	..	..	..	..	..	..	..	19	..	..
Cuprous oxid dust (Metrox)[b]																					
May 6	56	..	69	..	..	..	54	69	113	96	83	68	79	81	94	75	73	40	33	63	84
May 6	59	..	56	..	..	..	60	..	..	..	90	72	..	..	..	..	72	48	39	..	..
May 21	59	..	..	..	..	..	..	52	139	..	81	..	88	59	84	52	78	..	20	..	..
May 21	68	..	..	..	..	..	..	67	..	..	87	..	..	..	..	..	..	..	29	..	..
Semesan (organic mercury)[c]																					
May 6	51	37	74	26	55	57	52	39	122	99	85	78	84	40	94	61	69	47	28	50	88
May 6	58	61	70	33	64	58	51	..	..	..	87	72	..	..	..	..	68	43	26	..	..
May 21	60	56	..	..	..	..	..	36	143	..	89	..	80	35	84	59	62	..	14	..	..
May 21	60	..	..	..	..	..	..	46	..	..	83	..	..	..	..	..	..	..	15	..	..
Zinc oxid dust (Leafox)[b]																					
May 6	51	53	70	29	79	59	50	52	83	97	65	70	77	49	24	47	68	41	32	51	..
May 6	..	49	69	35	73	61	43	..	..	..	80	63	..	..	..	..	63	47	35	..	..
May 21	55	60	..	..	..	..	..	65	60	..	67	..	60	50	50	38	68	..	16	..	..
May 21	60	..	..	..	..	..	..	70	..	..	64	..	..	..	..	..	..	..	19	..	..
Vasco 4 dust[b]																					
May 6	51	48	80	32	68	51	49	42	68	95	64	73	77	56	27	56	68	38	33	52	84
May 6	47	41	82	38	71	60	46	..	..	..	75	66	..	..	..	..	60	48	33	..	..
May 21	60	61	..	..	..	..	..	38	109	..	66	..	53	46	55	52	70	..	25	..	..
May 21	60	..	..	..	..	..	..	50	..	..	66	..	..	..	..	..	..	..	13	..	..
Percentage germination, untreated seed	75	80	90	76	99	89	61	62	91	100	99	92	98	85	96	97	88	75	59	59	99

[a]Seed soaked 1 hour in solution of 1½ ounces of copper sulfate in 1 gallon of water. [b]Four-tenths ounce per pound of seed. [c]One-eighteenth ounce per pound of seed.
*Plants injured by leaf burning, or stunting, or both.

that peas which have been inoculated with the nitrogen-fixing bacterium, *Rhizobium leguminosarum*, should not be treated with chemicals to increase the stands. The application of either Semesan or cuprous oxid to inoculated peas so reduces the nodulation as to render the inoculation of limited value to the crop. Zinc oxid, the least inhibitive of the three chemicals used, reduced nodulation 50 to 85 percent. Chemical seed treatments do not materially affect nodulation, however, if the proper bacteria are present in the soil or are added to it as a culture suspension at planting time.

Horsfall reports that of the pea varieties so far tested in New York state, Surprise and Wisconsin Early Sweet are the ones which may be most beneficially and safely treated. Varietal tests in Illinois (limited to five varieties: Alcross, Alaska, Surprise, Wisconsin Early Sweet, and Perfection) lead to the same conclusions. Alcross and Alaska varieties were neither benefited nor injured by the treatments. Surprise, Wisconsin Early Sweet, and Perfection responded favorably to treatment up to 1936, but during the 1937 season some injury on Perfection and Wisconsin Early Sweet was reported, tho the injury to Wisconsin Early Sweet was not commercially significant.

Graphite recommended with treatment of pea seed.—Treating pea seed with cuprous oxid often causes the drill to clog and crack the seed. To prevent this condition Arnold and Horsfall[8*] have recommended the use of flake graphite, pulverized to pass a 325-mesh screen, at the rate of 1½ ounces per bushel of seed, added at the time of treatment. Special flake graphite No. 0607 supplied by the Joseph Dixon Crucible Company, Jersey City, New Jersey has proved satisfactory for this purpose.

H. T. Cook,[a] of the Virginia Truck Experiment Station, has further demonstrated the value of graphite in connection with spinach and crucifer seed treated with red copper oxid, zinc oxid, and Vasco 4. In all cases the addition of graphite prevented clogging of the drill and cracking of the seed. The use of graphite was especially beneficial with the crucifers since the cracking of this seed reduced germination. One-fourth to one-half as much graphite as fungicide should be used, and both may be applied at the same time.

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[a]Correspondence of December 9, 1936.

CHEMICAL AND PHYSICAL METHODS OF TREATING SOIL FOR DAMPING-OFF CONTROL

A great many methods have been recommended by experimental workers for the treatment of soil to rid it of the damping-off and certain other fungi. As would be expected, not all these methods are equally efficient or commercially adaptable.

The purpose of this part of the study was to determine the relative value of a few of the most generally used of these soil-treatment methods. Limitations of time and space would not permit trying all treatments recommended, nor trying those that were selected with more than a relatively few crops. Accordingly crops were selected which are normally grown in flats or cold frames and later transplanted, since, as a rule, soil-treatment is most applicable under such conditions.

Methods. In determining the relative value of soil treatments all operations were performed under conditions as nearly comparable to those of the commercial grower as possible. All ordinary precautions to prevent recontamination were exercised. Other conditions, except humidity, were maintained so as to be most favorable to the damping-off disease and were practically indentical to those maintained in the seed-treatment studies (Series 6, page 321) which were being conducted at the same time in an adjacent greenhouse. After the specifications of any particular treatment were met, the seeds were planted and the flats watered daily. The greenhouses were shaded and the temperature for tomatoes, eggplant, and peppers was maintained between 75° and 85° F., and for cabbage, kale, and kohlrabi between 65° and 75° F. The soil used in this study was the same as that used in previous studies—a black silt loam which had been used many years for vegetable culture and which was known to be infested with damping-off species of Pythium and Rhizoctonia. The checks were flats of untreated soil planted to untreated seed.

The treatments applied were as follows:

Steam sterilization—1½ hours of steaming 48 hours before planting.

Boiling water—3½ gallons per flat (15 by 20 by 2 inches) 5 days prior to planting.

Liquid formaldehyde—1 pint to 20 gallons of water (1 part to 160) 7 days before planting.

Formaldehyde dust 6 percent—8 ounces of dust to 1 cubic foot of soil (3 ounces per flat) 48 hours before planting.

Soil pasteurization—8 hours at 125° F. in a vinegar pasteurizer 48 hours before planting.

Soil baking (dry heat)—by open fire till surface of soil reached 160° F.; planting 48 hours after treatment.

Zinc oxid—2 ounces of zinc oxid mixed with the top 1 inch of soil per square foot.

Several other treatments also were applied, but the results obtained indicated that more work and tests were necessary before accurate judgment could be passed on them. The concentrations recommended apparently were not satisfactorily adjusted to Illinois soils.

TABLE 16.—SOIL TREATMENTS: EFFECT ON DAMPING-OFF AS MEASURED BY PERCENTAGES OF SEEDLINGS THAT EMERGED, GREENHOUSE STUDIES, URBANA

Treatment, year, and series	Tomato	Eggplant	Pepper	Cabbage	Kale	Kohlrabi
Percent total emergence (1st figure) and percent post-emergence damping-off (2d figure)						
Checks, seed and soil untreated						
1934, Series 1	36-2	43-10	....	....	....	....
1934, Series 2	33-11	42-3	....	....	....	....
1935, Series 1	39-4	30-6	42-1	5-0	19-3	25-3
1935, Series 2	47-8	43-0	43-1	15-0	42-9	40-1
1935, Series 3	39-4	47-0	33-0	10-0	42-4	37-0
Steam sterilization[a]						
1934, Series 1	81-1	80-2	....	....	....	....
1934, Series 2	90-3	79-0	....	....	....	....
1935, Series 1	96-0	50-10	48-1	64-0	62-0	49-0
1935, Series 2	86-3	63-0	48-0	70-0	75-1	50-0
1935, Series 3	84-1	70-1	50-0	68-0	68-0	40-0
Boiling water[b]						
1934, Series 1	69-0	68-0	....	....	....	....
1934, Series 2	73-0	69-0	....	....	....	....
1935, Series 1	92-3	46-13	44-1	56-6	35-6	54-4
1935, Series 2	47-6	54-1	35-0	6-0	23-1	48-0
1935, Series 3	51-7	58-3	30-0	6-0	22-0	46-0
Liquid formaldehyde[c]						
1934, Series 1	75-0	73-0	....	....	....	....
1934, Series 2	73-1	75-0	....	....	....	....
1935, Series 1	97-2	67-1	52-0	62-0	57-0	46-1
1935, Series 2	87-1	69-0	48-1	58-0	56-0	49-0
1935, Series 3	85-3	68-0	53-2	*46-0	52-0	46-0
Formaldehyde dust, 6%[d]						
1934, Series 1	77-1	80-0	....	....	....	....
1934, Series 2	74-3	78-1	....	....	....	....
1935, Series 1	91-0	66-0	55-1	45-0	*39-0	*44-0
1935, Series 2	88-3	66-1	50-0	*52-3	75-0	*48-0
1935, Series 3	78-4	68-4	51-1	*60-0	69-0	*52-1
Soil pasteurization[e]						
1935, Series 1	62-0	75-1	51-0	67-2	42-0	48-0
1935, Series 2	93-2	44-0	53-0	30-6	45-0	44-1
1935, Series 3	88-2	40-3	47-0	25-4	57-0	46-0
Soil baking[f]						
1934, Series 1	76-1	77-18	....	....	....	....
1934, Series 2	79-0	72-1	....	....	....	....
Zinc oxid soil treatment[g]						
1934, Series 1	80-0	*62-3	....	....	....	....
1934, Series 2	*73-1	*63-0	....	....	....	....
Percent germination of untreated seed						
Germination test						
1934, all series	91	98	...	...	...	...
1935, all series	95	80	54	68	66	54

[a]Steamed for 1½ hours; seeds planted 48 hours later. [b]Three and one-half gallons boiling water per flat 5 days before planting. [c]One part to 160 parts water 7 days before planting. [d]Eight ounces dust to 1 cu. ft. soil 48 hours before planting. [e]Temperature of soil held at 125° F. for 8 hours 48 hours before planting. [f]Dry heat by open fire until surface soil reached temperature of 180° F., 48 hours before planting. [g]Two ounces per square foot applied to top 1 inch of soil.

*Plants injured by leaf burning, or stunting, or both.

Results. The results of the study, given in Table 16, indicate that most of the treatments listed gave fairly good control when recontamination was prevented. The limiting factors of such treatments as soil baking or pasteurization are the time and the facilities needed for their application. Zinc oxid caused spindling plant growth and a little leaf burning. Liquid and, to a greater extent, dust formaldehyde caused considerable leaf burn on crucifers. This injury could have been avoided by allowing more time between the treatment and the planting of the seed. The effectiveness of hot-water treatment depends largely upon the actual temperature reached in the soil. This treatment is seldom satisfactory unless enough water is added to bring the soil temperature up to at least 140° F. The actual amount of boiling water needed depends upon the type of the soil and its temperature at the time of treatment.

Soil steaming and treatments with formaldehyde were the most generally satisfactory of the soil-treatment methods tested. All treatments, with the possible exception of zinc oxid, require extra precautions to prevent recontaminations. This fact alone makes soil-treatment methods of limited value in the hands of the average grower.

Some of the chemical seed treatments gave results as good as the best in this test under conditions practically identical (see Tables 7, 8, and 9).

CONTROL OF POST-EMERGENCE DAMPING-OFF

All attempts to study the control of the post-emergence phase of damping-off under controlled conditions gave unreliable data, altho some very good results were obtained under commercial conditions.

A few tests were conducted in cooperation with commercial greenhouse men who were suffering heavy losses from this phase of the disease. In all of these trials the disease was caused by Pythium or Rhizoctonia or both. The humidity was high and the temperature between 60° and 80° F. The crops involved were tomato, pepper, eggplant, and cabbage.

Methods. None of the seeds were treated before planting. In each test two applications of the liquid treatments were made at intervals of three days. The materials were applied with an ordinary sprinkling can at the rate of about ½ gallon per flat (15 by 20 inches). During the course of this study, and for some time afterwards, no more watering was done than was absolutely necessary. The checks used were flats of untreated soil planted to untreated seed.

The treatments applied were as follows:

Semesan drench: 1 ounce of Semesan to 3 gallons of water.

Cheshunt solution: powdered copper sulfate 2 parts, mixed thoroly with 11 parts of *fresh,* finely ground ammonium carbonate, and the mixture set aside for 24 hours in a tightly stoppered bottle; 1 ounce of the mixture to 2 gallons of water.

Copper carbonate: 1 ounce to 3 gallons of water.

Cuprous oxid: 1 ounce to 3 gallons of water.

Bordeaux mixture: 3 ounces of copper sulfate and 1½ ounces of hydrated lime in 5 gallons of water.

Zinc oxid (soil-surface treatment): 1 ounce spread evenly over 1 square foot of soil surface.

All treatments were applied after the disease had made its appearance.

Results. Detailed records were not taken, but results were figured on the basis of relative control of post-emergence damping-off, general plant growth, and condition of plants after treatment.

All treatments except zinc oxid gave fairly good control. Bordeaux mixture was consistently the outstanding treatment. Within four days after the first application damping-off was completely arrested in all tests where bordeaux was used. No other treatment completely stopped the disease, altho losses from it were greatly reduced by all of them except zinc oxid.

It is recognized that more study is needed on this phase of the damping-off problem before generally satisfactory control measures may be found. If bordeaux is used some stunting of growth may result, especially on crucifers and cucurbits. Under no conditions should bordeaux be used later than 5 days before transplanting, since its effect on normal physiological plant processes during this period might cause excessive losses of transplanted seedlings. If treatment is necessary within 5 days of transplanting, one of the other treatments listed above (except zinc oxid) should be used. All the treatments listed have been observed to cause some injury, but the injury has been of little significance compared with the losses that result when treatment is needed but is not applied.

Aside from practices that give good aeration, low humidity, and thoro but infrequent watering, no treatment is recommended for post-emergence damping-off unless the disease definitely becomes a problem. If it does become a problem, weak bordeaux, with the exceptions mentioned above, has been the most reliable treatment.

SUMMARY AND CONCLUSIONS

The purpose of the studies reported in this bulletin was to evaluate for Illinois growers some of the most promising methods that have been recommended for the control of damping-off, and to discover the relation between certain variables—temperature, humidity, soil moisture, soil type, and soil acidity—and the incidence and control of the disease. Correlations between these variables and several generally important outbreaks of damping-off in the Chicago and East St. Louis vegetable-producing areas were made during the growing season of 1932. Then over the period from 1933 to 1936 the effects of the different variables on the fungus species found in the survey to be the most important causes of damping-off in Illinois were studied in greenhouses under controlled conditions and also in the field. Observations in the principal vegetable-producing areas were continued during the period of the controlled studies.

In the surveys damping-off was found to be a problem of general importance thruout the state whenever environmental conditions favored the development of the disease. It was estimated that 80 percent of the cases of damping-off in Illinois were caused by Pythium species and 15 percent by Rhizoctonia species. Species of Botrytis or of Fusarium were the cause in a few instances. The pre-emergence phase of the disease was found to cause much more damage than the post-emergence phase, tho this fact was not generally recognized by the growers.

Effect of variables on incidence of damping-off. Soil moisture and temperature were found to be the most important of the variables influencing the pre-emergence phase of damping-off. High humidity and high temperature were the chief factors in the occurrence of the post-emergence phase of the disease, tho soil moisture also was important, especially if the seeds were not treated before planting.

Soil type and acidity did not seem to be important factors in the occurrence of either the pre- or the post-emergence phase of damping-off, altho under actual field conditions the disease is not so generally prevalent in sandy soils as in heavier soils high in humus. Nevertheless, when the season favors the disease, heavy losses usually occur irrespective of soil type, unless proper treatments have been applied.

Altho data are not given in this bulletin to substantiate the point, it appears from extensive observations that the interrelation of soil organisms has a great deal to do with the incidence of damping-off. Striking fluctuations of parasitism by fungi in soils under similar environmental conditions seem to bear out this contention. In some instances the interrelations among soil organisms are such as to accentuate the parasitism of the damping-off fungi, while in others the same fungi seem to be held in check.

Effect of variables on control measures. Of the variables studied, only moisture and soil acidity appeared to have any direct effect upon the control obtained by cuprous oxid, Semesan (organic mercury, 30 percent), or Vasco 4 (zinc compound). Cuprous oxid may cause considerable injury if the soil acidity is greater than pH 5, but this fact is of little economic importance, since few vegetables are grown on extremely acid soil. Soil acidity appeared to have no effect on the control by Semesan or Vasco 4 under similar conditions. In field studies it was observed that heavy rains soon after planting greatly reduced the value of Semesan as a seed treatment but did not materially influence the value of cuprous oxid or Vasco 4. There is some indication that when Semesan or cuprous oxid is used at concentrations stronger than recommended by the manufacturer, injury may result if the seedlings are produced in typical pit sand. One instance of injury to tomatoes so treated and produced has come to the attention of the authors, altho no such injury occurred in the studies herein reported.

Evaluation of seed treatments. Materials for seed treatments should not be judged solely on the ability of the chemicals to control the damping-off fungi. In the experiments reported here, the sticking qualities of the materials and possible injurious effects on the seedlings were taken into consideration. Because of factors not clearly understood but probably related to seed and air moisture, some materials varied greatly in their sticking abilities from time to time as well as on different lots of the same kind of seed. The effects of this variance in sticking quality was often evident in the results of the tests. Some of the treatments also affected adversely the general appearance and condition of the plants of some crops. If injury from a given treatment was observed even once, that treatment was considered to be of doubtful value on that crop. (Recommendations concerning treatments suitable for different crops are given on pages 341 to 342.)

In a comparison of the various cuprous oxids available it was found that the color of the compound was not always a reliable index of fungicidal efficiency. The actual copper present and the sticking qualities of the compound are more accurate criteria. Metrox, cameo brown in color, has proved in all these tests fully as efficient as bright red cuprous oxid. Another product of light purple color was of little value as a fungicide. This was probably due to the fact that it contained only about 25 percent active ingredient (cuprous oxid) instead of the 95 percent minimum contained in the products mentioned above.

In limited tests on spinach, cuprous oxid (Cuprocide), organic mercury (Semesan), and zinc oxid (Vasco 4) were all more effective in controlling damping-off when the disease was caused by Rhizoctonia than when it was caused by species of Pythium. In either case the chemicals were effective in the order named.

Despite the definite value of seed treatments for the control of damping-off, no seed treatment thus far tested will give outstanding control on a susceptible crop when conditions are especially conducive to damping-off. Control under such conditions can be obtained, for a while at least, by using soil treatments to rid the soil of the damping-off fungi. Even if the latter method is used, however, it is practically impossible to prevent recontamination unless the conditions favorable to the disease are changed.

Under *ordinary* growing conditions proper seed treatments are just as effective as soil sterilization in the control of damping-off. If, however, soil sterilization is practiced for other reasons, it is neither necessary nor advisable to treat the seed with chemicals for the control of damping-off.

Soil treatments. In greenhouses it is occasionally necessary to sterilize the soil in order to control the disease adequately. Of a number of methods tried, steaming the soil or treating it with liquid or dust formaldehyde gave the most satisfactory results. If soil-sterilization methods are used it is imperative that extra precautions be taken to prevent recontaminations. This fact alone makes soil-treatment methods of limited value for damping-off control in the hands of the average commercial grower. When recontaminations occur the disease is often more serious than it would have been had the seed been planted in unsterilized soil.

Special treatments for post-emergence phase. No seed treatment that has so far been used will adequately control post-emergence damping-off if the seedlings are poorly aerated and the humidity is high. Under such conditions, which are sometimes unavoidable, and if the disease is present, special post-emergence treatments should be applied.

In limited tests of several such special treatments a weak bordeaux mixture sprayed on the plants gave nearly perfect control. Two applications to the seedlings and soil at an interval of three days were made after the disease became apparent. Other plant treatments were of considerable value but were definitely inferior to bordeaux.

RECOMMENDATIONS AND PRECAUTIONS

Actual control of damping-off in commercial plantings requires the intelligent application of several important measures. In order to obtain the best results from any particular control method, good cultural practices must be maintained. Crops that are especially susceptible to damping-off—such as beets, spinach, cucumbers, peas—should not follow each other in the planting rotation, but should be interplanted with crops not very susceptible, such as corn, onions, radishes, turnips, carrots, or beans. When it is possible to control the conditions under which seedlings are produced, the temperature should be maintained at a level most satisfactory for the particular crop being grown. After the soil is in proper condition for planting, the seeds should be planted and should be watered as little as is compatible with good growth until after the seedlings have hardened off. At no time should they be watered heavily. Good aeration and low humidity are essential, especially if the temperature rises above 70° F.

These general cultural practices alone will not solve all phases of the damping-off problem, and they should therefore be supplemented by other measures, either the treatment of the seed with materials to protect the seed and seedlings or the treatment of the soil to kill the damping-off fungi present. When the seedlings are grown out-of-doors, the use of soil treatments to control damping-off is not, as a rule, very practical. The seeds of all plants generally susceptible to damping-off should therefore be treated with chemicals specifically recommended for them. Lists of treatments to be used with different crops are given below.

Recommended Seed Treatments

Seed treatment for the control of damping-off should be regarded as an inexpensive satisfactory type of crop insurance. The cost is extremely low compared with the benefits—increased yields, savings of seed from the lower rates of seeding that can be used, and savings of time, labor, and seed by avoiding the replanting that is often necessary when untreated seed is used. In some seasons, when the weather does not favor the development of the disease, the seed treatments may prove to have been not so much needed as in others; but often the treatment of the seed with the proper chemicals is the means of saving entire plantings of crops susceptible to damping-off.

The following recommendations are based upon the results of the studies reported in this bulletin. Several vegetable crops of only minor importance in Illinois have not been included. Such crops may, as a rule, be treated similarly to the botanically related crops which are listed. The treatments recommended for the various crops are listed in the order of their effectiveness in the experiments reported in this bulletin, tho all that are listed gave commercially satisfactory control.

Lettuce, endive, carrots, beet, Swiss chard, muskmelon, watermelon, cucumber, tomato, pepper, eggplant

1. **Cuprous oxid.** Follow instructions of manufacturers.
2. **Copper sulfate soak.** Dissolve 1½ ounces of copper sulfate in 1 gallon of water; soak seed at least 1 hour in twice their volume of liquid.
3. **Semesan** is a very good treatment if crops are grown under glass and are watered lightly.

Squash

1. **Copper sulfate soak.** See No. 2 above for lettuce.
2. **Cuprous oxid.** Follow instructions of manufacturers.

Cabbage, kale, kohlrabi

1. **Zinc oxid** especially prepared for seed treatments, such as Vasco 4, Leafox, or AAZ Special. Use an amount equal to 2 to 2½ percent of weight of seed.
2. **Semesan** is even better than the foregoing treatment, if the crops are grown under glass and watered lightly.

Radish, turnip

Treatments are of doubtful value, but if applied, use those recommended for cabbage and other crucifers.

Pea (Surprise and Wisconsin Early Sweet[a])

Cuprous oxid. Follow instructions of manufacturers.

(Peas that have been treated with nodule-producing bacteria should not be treated with chemicals—see p. 331.)

Spinach

1. **Cuprous oxid.** Follow instructions of manufacturers.
2. **Zinc oxid.** See No. 1, above, for cabbage.
3. **Copper sulfate soak.** See No. 2, above, for lettuce.
4. **Semesan** is a very good treatment if the crop is grown under glass and is watered lightly.

Bean, leek, onion, parsnip

No treatments recommended.

Recommended Soil Treatments

When vegetable crops are grown under glass, the seed treatments recommended above may be used, or the soil may be sterilized with *steam* or with *liquid or dust formaldehyde.* But if damping-off is the only control problem involved it is doubtful, except in unusual instances, whether the output of time and expense necessary for adequate

[a]Some seeds, especially peas, have a tendency to clog drills when they have been treated with chemicals. The clogging often results in cracking the seed and in irregular sowing. The clogging can be largely prevented by adding small amounts of special flake graphite at the time of treatment.

soil treatment is justified. Details of soil-treatment methods are given in Illinois Circular 454, "Diseases and Insect Pests of Cabbage and Related Plants."

Control of Post-Emergence Damping-off

Post-emergence damping-off (toppling over of seedlings) may be controlled under ordinary conditions by two or three applications of a weak bordeaux mixture (see page 336) applied with a sprinkling can or sprayer at three-day intervals.

Precautions

1. Semesan, altho an excellent treatment, *will not* give adequate protection to seedlings if heavy rains follow soon after plantings are made.

2. No copper treatments should ever be used on the seed of crucifers—such treatments are almost certain to cause injury.

3. Cuprous oxids which contain more than 5 percent inert ingredients are of doubtful value as seed treatments.

4. Cuprous oxid should not be used in soil more acid than pH 5. If such condition exists, the soil should be limed to lower the acidity.

5. All chemical treatments should be used in Illinois *exactly* as recommended by the manufacturer on the *crops listed herein,* pages 342 and 343.

6. No chemical treatment should be used unless it covers the seed uniformly and well at recommended strengths.

7. All chemicals should be kept in air-tight containers and their application to seed should be made as near planting time as possible.

8. Specific treatments should be used only on those crops for which they are recommended.

9. If soil-sterilization methods are used, extra precautions must be exercised to prevent recontamination.

10. For practical control of damping-off *under glass,* seed treatments or soil treatments must be supplemented by proper cultural practices. Watering should be held at a minimum after the seeds are planted. Good aeration and low humidity should be provided. The temperature should be maintained at a level most favorable to the crop which is being produced.

11. All chemicals recommended for the treatments for damping-off are POISON, and should be kept completely away from children and animals.

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