BULLETIN 520 FEBRUARY, 1933

The Use of Formaldehyde Dust in Growing Seedlings

J. D. Wilson and P. E. Tilford

OHIO
AGRICULTURAL EXPERIMENT STATION
Wooster, Ohio

This page intentionally blank.

CONTENTS

RECOMMENDATIONS FOR THE USE OF FORMALDEHYDE DUST

A. For mass treatment of soil to prevent damping-off of seedlings.

1. Mix thoroughly 8 ounces of a 6% formaldehyde dust with each bushel of medium dry soil. If highly organic soils, like muck, are to be treated, 10 ounces of dust to the bushel should be used.
2. If soil is to be treated in place in the bed, spread dust over the surface at the rate of 1½ ounces per square foot and mix thoroughly into the top 3 inches of soil.
3. All seeds with the exception of a very few (See Page 8) should be planted immediately.
4. Water thoroughly immediately after planting.

B. For row treatment to improve the stand of seedlings.

1. Place a 4½% dust in the row with the seed, at the rate of 1 ounce to each 22½ feet, when planting beets, spinach, peas, beans, tomatoes, etc.
2. For species particularly sensitive to formaldehyde, such as the crucifers (See Pages 12-16), reduce the application to 1 ounce to 30 feet of seed row.
3. For plants, such as the cucurbits, which are often planted in hills, a level tablespoonful of the 4½% dust is used in each hill.
4. Do not plant and treat the formaldehyde-sensitive species when the soil is very dry.
5. If a restricted area outdoors where certain ornamentals are to be planted is to be treated with formaldehyde dust, it should be mixed with the soil at the rate of 6 ounces of a 6% dust per cubic foot of soil; for instance, the soil in a trench 6 inches wide and 6 inches deep would require 1½ ounces of dust per linear foot.

C. For treating soil to be used for transplants.

1. Treat soil at the rate of 8 ounces of a 6% dust per bushel. Spread soil in a thin layer or place in flats or pots and wait 72 hours before setting the transplants. After transplanting, water well.

D. For treating sand in cutting bench.

1. Mix thoroughly 3 ounces of a 6% dust with each cubic foot (4 ounces per bushel) of fairly dry sand. Twenty-four hours after treatment stir the sand well. Cuttings may be set 48 hours after treatment.

E. For reducing the nematode population of soils.

1. Screen the soil to remove large root galls and soil lumps.
2. Mix thoroughly 16 ounces of a 6% dust with each bushel of soil.
3. Do not plant seeds until after 24 hours and follow directions given above for transplanting.

F. Directions for preparation of formaldehyde dust. If one wishes or finds it necessary to prepare the dust at the place of use, a satisfactory dust for mass treatment can be prepared as follows:

1. Thoroughly dry some finely screened soil like muck—finely ground charcoal is preferable to this if available.
2. In making a 6% dust use 15 parts by weight of commercial formalin to 85 parts of carrier (dry muck or charcoal).
3. Sprinkle the formalin evenly over the carrier while stirring.
4. Mix thoroughly, screen, and place in an air-tight container.

Note:—Formaldehyde adsorbed on muck exerts the maximum toxic effect, and care must be exercised in the use of this dust not to exceed the recommended application and to allow the elapse of the proper time periods between soil treatments and the planting of sensitive seeds.

THE USE OF FORMALDEHYDE DUST IN GROWING SEEDLINGS

J. D. WILSON AND P. E. TILFORD

A large percentage of the people (and they are legion) who grow plants, either for aesthetic or commercial reasons, start their own seedlings. This practice may involve only the use of some small container like a cigar box or an old pan by the housewife, or it may represent the investment of thousands of dollars in large areas under sash or in greenhouses by commercial growers. Regardless of the size of the undertaking, the grower will sooner or later have to contend with certain soil-borne organisms which are capable, under conditions favorable for their development, of attacking and destroying either seeds in the act of germinating or young seedlings. Seedlings of nearly all of the species commonly started in beds and transplanted later are susceptible to the attack of these "damping-off" fungi. Seedlings affected with the diseases caused by this group of organisms collapse in a characteristic manner and are said to have "damped-off".

These organisms belong chiefly to three genera of fungi; namely, Pythium, Rhizoctonia, and Fusarium, given in the order of their destructiveness to seedlings. The association of this group of organisms and the symptoms of damping-off have been recognized for at least half of a century. Atkinson (2) and Selby (11) were among the first to appreciate the economic importance of the losses caused by these fungi. Any or all parts of the seedling may be invaded by these damping-off fungi. If the attack occurs as the seedling emerges from the seed coat, it usually is killed before the cotyledons are pushed above the soil surface. Infection of the stem may not occur until after seedling emergence, in which case the tissue is soon so weakened that the young plant topples over in the manner characteristic of damping-off. When the roots are attacked, the seedling is stunted in its growth. Infection of the cotyledons results in growth deformations and stunting.

The environmental conditions under which seedlings are commonly grown are ideal for the development of damping-off fungi. Pythium, Rhizoctonia, and Fusarium all attack seedlings vigorously at temperatures ranging from 70 to 85° F. Below 70° F. Rhizoctonia is more active than Pythium and Fusarium. Above 80° F. Rhizoctonia is less active than Pythium and Fusarium, and above

85° F. Fusarium is the most active of the three fungi, according to Alexander, Young, and Kiger (1) and Hemmi (4). Damping-off is usually most severe at high soil-moisture contents. Alexander et al. (1) found that *Pythium ultimum* Trow. attacked tomato seedlings most vigorously in soils held at moisture contents of 35 to 65 per cent of their water-holding capacities. Johnson (6) found that *Pythium debaryanum* Hesse grows on the surface of sandy soils held at high moisture contents and in the subsurface of similar soils at low moisture contents. He suggests that this probably explains why the hypocotyls of seedlings are severely attacked just at the soil surface in wet soils; whereas, in dry soils, many of the seedlings escape infection because the level of active growth of Pythium is below the hypocotyl. Many authors have noted that such environmental factors as lack of light and of air circulation, continuously high air- and soil-moisture conditions, high or widely fluctuating temperatures, heavy and poorly drained soils, and too great crowding of the young plants favor the attack and destruction of the seedlings by damping-off fungi (1, 2, 4, 5, 6, 12, 15).

The damping-off pathogens are almost universally present in soils and will persist for years, even though the soil is not used for growing seedlings. For this reason loss of seedlings commonly occurs even though the best growing conditions have been provided. Some form of soil sterilization to eliminate the organisms is necessary to reduce losses from damping-off to a minimum. Occasionally some damping-off occurs even though the soil has been thoroughly sterilized, due to the fact that recontamination may occur through watering and other sources.

Many methods to provide partial or complete sterilization of the soil have been devised and used. These may be divided into two general groups, those which make use of temperatures high enough to kill any organisms present and the use of lethally toxic chemical compounds. The high temperature methods include the use of steam, hot water drench, and dry heat or baking. Any of these methods used properly is effective. There are often certain disadvantages in the use of these, such as unavailability of equipment for steaming seedling beds or flats, insufficient amount of boiling water for the drench method, puddling of the soil due to saturating it with hot water, the possibility of increasing the soluble salt content of the soil to the point where seedlings will not grow, and the labor involved. The chemicals which have been used as sterilizing agents include such compounds as formaldehyde, carbon bisulfide, organic mercury compounds, sulfuric acid, acetic acid, copper sulfate, and a host of others. The use of most of these materials has been referred to by Alexander et al. (1), Doran (3), Horsfall (5), Johnson (6), and May (7).

Formaldehyde has been used for many years as a soil and seed disinfectant. It was recommended for use in a diluted form for the control of onion smut about 1900 and had been given various trials even earlier than this (10). It has since been used as a soil drench to destroy such organisms as *Rhizoctonia solani* Kühn (11) and as a seed disinfectant for such diseases as the cereal smuts. It was during studies on the control of these smuts that formaldehyde dust (commercial formalin adsorbed on some carrier like finely divided charcoal or infusorial earth) was developed and used by Sayre and Thomas (8, 9) with very satisfactory results. A year or two later it was used as a substitute for the liquid treatment and was placed in the seed row for the control of onion smut by Wilson (14) with some success. May (7) mixed the dust with the soil of coniferous seedbeds for the control of damping-off, but the results were conflicting. Alexander et al. (1) found that a 6% (15 per cent by weight of commercial formalin) formaldehyde dust mixed with the soil at the rate of 1½ ounces per square foot in beds 2½ to 3 inches deep gave excellent control of damping-off of tomato seedlings. Tilford (12, 13) recommended the use of a 6% formaldehyde dust mixed with the soil, at the rate of 8 ounces per bushel, for the control of damping-off of flower seedlings. Since 1 bushel constitutes a mass 1 foot square and approximately 15 inches deep, the following formula may be used to translate ounces per bushel to ounces per square foot of bed area, the bed being of any given depth:

$$\frac{\text{Ounces per bushel x bed depth in inches}}{15} = \text{Ounces per square foot}$$

Wilson (15) found that formaldehyde dust at the rate of 12 ounces per bushel of muck soil gave good control of damping-off of celery seedlings and improved the root growth. Tilford (13) and Wilson (15) have recommended its use at the rate of 16 ounces per bushel of screened soil for the reduction of the nematode population of soils.

This bulletin deals with the use of formaldehyde dust to increase the percentage of seedling emergence and to decrease the amount of damping-off. The results of a number of experiments which were designed to give a better understanding of the influence of certain soil and other factors on the toxic effects of formaldehyde on various fungi and on vegetable and flower seeds and seedlings are discussed. Finally, it gives certain recommendations concerning the use of formaldehyde dust in controlling seedling diseases.

EFFECT OF TREATMENT ON THE STAND OF SEEDLINGS IN THE SEEDBED AND IN THE FIELD

The area available for the growing of seedlings in greenhouses or cold frames is usually limited in extent and is costly to prepare and maintain; and, because of this, it is important that the most efficient use possible be made of it. Also, in growing vegetables out-of-doors, it is important that an even stand of proper density be obtained if the most efficient use of the area is to be made and a product of uniform quality and size produced. This can not be done in either case if the seeds which are planted come up poorly and damp-off badly. Thus, the use of any seed or soil treatment which will insure the emergence and development as seedlings of a large percentage of the seeds planted is well worth considering. Alexander et al. (1), Tilford (12), and Wilson (15) have shown that the formaldehyde dust treatment is effective and the most generally satisfactory, when considered from all angles, of the various treatments which have been suggested for the control of damping-off in the seedbed or seedling flats.

STANDARD MASS TREATMENT

Formaldehyde dust as commonly prepared carries 6 per cent of formaldehyde, or approximately 15 per cent of commercial formalin (40% formaldehyde) by weight, adsorbed on finely divided charcoal, infusorial earth, or some similar material. The standard treatment, as recommended by the authors mentioned above, for soil already in place in the plant bed is at the rate of 1½ ounces per square foot. The dust should be spread evenly over the surface of the bed and immediately worked into the first 3 inches of soil with a hoe or rake. If a quantity of soil is to be treated before it is placed in pots, flats, beds, or other containers, the dust should be used at the rate of 8 ounces per bushel of soil and immediately mixed with it by shoveling or screening. Regardless of which procedure is followed, the treated soil may be planted at once, except in the case of certain very formaldehyde-sensitive seeds which will be mentioned later. In fact, it is desirable to plant immediately following treatment, since the formaldehyde gas in the soil has a sterilizing effect on the seed surfaces and thus eliminates the necessity of treating the seed for surface-borne pathogens.

In the course of the investigations reported in this bulletin, seeds of a considerable number of species of plants have been used, and, in nearly every instance, larger numbers of seedlings have been obtained in soils treated with formaldehyde dust than in untreated soils. Damping-off has been very markedly reduced in most instances by soil treatment. It has been noted that most seedlings emerge about 24 hours later when planted in treated soil than when planted in untreated soil; however, at the time of removing the seedlings from the beds preparatory to transplanting, those growing in treated soil were larger and possessed more extensive root systems than those of the same age grown in untreated soil. In Table 1 a number of ornamentals is enumerated, the seeds of which were planted in flats containing a soil mixture of ⅓ compost, ⅓ sand, and ⅓ peat moss. The soil in one-half of each flat was treated with a 6% formaldehyde dust at the rate of 8 ounces per bushel, and that in the other half was left untreated. Table 2 includes a list of vegetables planted in treated and untreated flats of compost and of muck.

TABLE 1.—Effect of Soil Treatment with Formaldehyde Dust on the Production of Seedlings of Various Ornamentals

Plant	Percentage of seeds planted which produced good seedlings		Plant	Percentage of seeds planted which produced good seedlings	
	Check	Treatment		Check	Treatment
Anthemis	18	69	Larkspur	42	62
Aquilegia	28	52	Marigold	67	82
Aster	10	40	Mignonette	5	57
Calendula	36	69	Pansy	2	49
Calliopsis	29	61	Petunia	55	49
Campanula	40	30	Phlox	12	24
Celosia	4	80	Portulaca	15	90
Clarkia	27	73	Salpiglossis	27	70
Coreopsis	26	37	Scabiosa	13	40
Cyclamen	32	51	Schizanthus	18	58
Cynoglossum	68	80	Snapdragon	46	65
Delphinium	63	64	Stevia	8	30
Didiscus	27	75	Stocks	50	80
Digitalis	25	75	Sweet William	8	41
Gaillardia	82	86	Verbena	22	42
Gypsophila	25	90	Vinca	37	72
Helichrysum	49	87	Zinnia	48	85
Kochia	3	46			

With few exceptions more seedlings were obtained from treated than from untreated soils. Celosia, Clarkia, Gypsophila, Kochia, mignonette, Portulaca, pansy, Stevia, sweet William, and Salvia among the ornamentals and beet, cucumber, pea, spinach, and tomato among the vegetables were greatly benefited by the treatment. Figure 1 illustrates the effectiveness of treating the soil with formaldehyde dust (left half of the flat) in improving the

TABLE 2.—Effect of Soil Treatment with Formaldehyde Dust on the Production of Seedlings of Various Vegetables

Plant	Percentage of seeds planted which produced good seedlings			
	Compost		Muck	
	Check	Treatment	Check	Treatment
Bean	60	84	55	69
Beet	36	80	38	69
Cabbage	36	70	48	67
Carrot	40	50	61	73
Corn	96	96	96	98
Cucumber	52	88	69	89
Lettuce	39	45	50	48
Muskmelon	47	80	84	88
Onion	53	63	50	73
Pea	27	87	58	85
Pepper	48	60	60	66
Radish	65	85	92	90
Spinach	13	73	18	78
Tomato	59	74	67	78
Turnip	60	66	67	60
Watermelon	56	79	60	84

stand (beginning at the left) of mignonette, Clarkia, Godetia, and Kochia. The soil in the right half of the flat was not treated, and the number of good seedlings finally obtained was only a small percentage of the number of seeds planted.

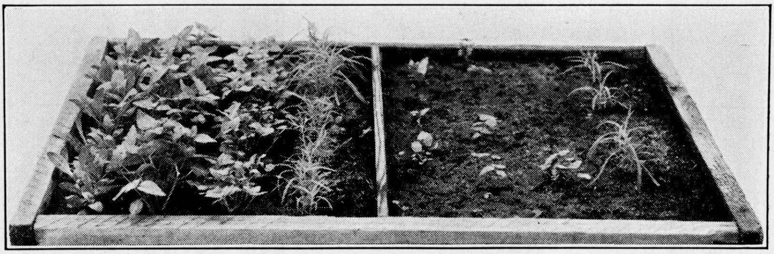

Fig. 1.—Soil in the left side of flat treated with formaldehyde dust. Right half, untreated. An equal number of seeds planted in each case

Stands of Delphinium, Gaillardia, carrot, corn, endive, and parsnip were but little, if any, better in the treated soil; whereas, Campanula, petunia, lettuce, and turnip were (and frequently are) injured by the addition of formaldehyde dust to the soil. Seeds of the latter group, including Campanula, petunia, Anchusa, lettuce, and most of the crucifers, should not be planted until about 24 hours after the soil has been treated. Seeds of certain hybrid varieties of plants are known to be inherently weak. Old seeds are also often of low vitality. Whenever it is known that the seed is weak, it is safest to delay planting for 24 hours after treating the soil with formaldehyde dust as suggested above.

STANDARD ROW TREATMENT

The method of thoroughly mixing or incorporating the formaldehyde dust with the soil mass as recommended for flat or bed treatment is hardly practical for large areas in the field, either from the standpoint of labor or cost. Because of this, tests were made to determine the practicability of placing a small quantity of dust in the seed row with the seed at the time of planting. The incorporation of formaldehyde dust with the soil surrounding the seed serves partially to sterilize a sufficient volume of soil so that the seed may germinate and the seedling emerge in comparative freedom from disease attack. It is also probable that some of the injury due to seed-borne diseases is checked, particularly if the causal organism is carried on the outside of the seed. The possibility of materially reducing losses which may occur from any damping-off which may take place from 1 to 2 weeks after seedling emergence is not very great. Since the volume of dust required to treat an acre is necessarily many times that of the seed used in planting an equal area, it is impractical to mix the dust and the seed together; instead, the dust must be fed into the seed row with the seed from a separate hopper and feed spout.

If a seed drill of the usual type is used, a special attachment must be provided for applying the dust in the proper manner and in the correct amount. Such a device is now available on the market. Preliminary tests were made with it in an effort to determine what amount of formaldehyde dust gave the best balance between the toxicity of the formaldehyde to the germinating seed, on the one hand, and the lack of fungicidal efficiency, on the other. It was found that the application of such a quantity of dust that the amount of formaldehyde per linear foot was approximately equal to that applied when treating for onion smut with a 1-128 dilution of formaldehyde in water gave the best results for most types of vegetables. This is roughly equivalent to 1 ounce of a 6% dust to each 30 feet of seed row. This is a comparatively small volume, even of a material as low in weight per unit of volume as infusorial earth or finely ground charcoal, to distribute evenly over a distance of 30 feet.

A wide variety of vegetables has been treated with formaldehyde dust by placing the material in the row with the seeds at the time of planting. These experiments have been carried on both in the greenhouse and in the field. Formaldehyde is much more likely to injure the seed when placed in the row in this manner than when it is mixed with the soil. For this reason, it is impractical to use the dust with species particularly susceptible to formaldehyde or in soils where organisms capable of causing a reduction in stand are not known to be present. Although a formaldehyde dust containing 6 per cent of formaldehyde by weight has been accepted as a standard product for mass treatment of the soil, there is abundant evidence to indicate that a weaker dust is more desirable for row treatment because of the reduction in toxicity to the seeds with which it is in contact and the increased ease of obtaining an even application.

Those vegetables with which difficulty in getting good stands is seldom experienced are not usually benefited by treatment and they may even be injured. Others which frequently come up poorly or damp-off badly after emergence are helped, and, even though some injury to germination may result from the formaldehyde, this is often completely hidden by the increased stand resulting from disease control.

Numerous experiments have been performed to determine the effect of placing a 6% formaldehyde dust in the row with the seeds at planting. The usual application was at the rate of 1 pound of dust to about 480 feet (1 ounce to 30 feet) of row. In the list given below the response to treatment with formaldehyde on a charcoal carrier is shown for various vegetables grown in greenhouse benches. Spinach, the one most benefited by treatment, is given first, and the others follow in decreasing order. The values given are the average of from three to eight trials and are the stands obtained when that of the untreated rows was taken as 100:

Spinach	422	Onion	117	Carrot	104
Beet	151	Watermelon	117	Corn	103
Bean	145	Muskmelon	115	Cabbage	94
Pea	140	Pepper	112	Radish	76
Cucumber	140	Parsnip	108	Turnip	54
Tomato	131	Endive	106	Lettuce	45

These results indicate that spinach, beet, bean, pea, cucumber, and tomato should be materially benefited by treatment, that the aid to onion, watermelon, muskmelon, pepper, parsnip, endive, carrot, and corn will be questionable, and that cabbage, radish, turnip, and lettuce will be detrimentally affected.

Experiments later conducted in the field largely confirmed the above data. Seeds of a number of the more common vegetables were planted out-of-doors in muck and in loam soils late in May, 1932. Three materials were used on each species—namely, the standard 1-128 liquid formaldehyde treatment, a 4½% formaldehyde dust with powdered charcoal as the carrier, and another dust of the same strength with equal parts of charcoal, muck, and kaolin as the carrier. The results are shown in Table 3, in which the relative stands obtained with the different treatments are stated as percentages of those occurring in the untreated checks.

TABLE 3.—Comparative Stands of Vegetables after Row Treatment with Formaldehyde Preparations. Planted in Muck and in Loam Soils.

(Values on basis of stand in untreated rows=100)

Vegetable	Muck			Loam		
	Liquid 1-128	Charcoal 4½ per cent	Charcoal-muck-kaolin 4½ per cent	Liquid 1-128	Charcoal 4½ per cent	Charcoal-muck-kaolin 4½ per cent
Spinach	530	410	485	304	280	348
Beet	254	238	282	112	180	132
Muskmelon	200	193	190	96	112	108
Pea	118	104	126	106	117	97
Bean	104	107	101	110	122	106
Carrot	122	102	100	......	......	......
Corn	90	104	75	106	105	104
Endive	96	80	83	57	104	86
Cucumber	......	......	......	94	93	97
Cabbage	76	84	28	20	96	40
Radish	26	89	20	9	73	36
Lettuce	92	50	75	4	36	36
Turnip	16	65	30	......	......	......

The improvement in stand, due to treatment, as observed about 3 weeks after emergence was very marked in these experiments for spinach and beets, and the peas and beans were noticeably benefited. The cruciferous plants, such as cabbage, radish, and turnip, were all injured. The stand of lettuce was greatly reduced in nearly every test made during the course of this work. The liquid treatment proved to be nearly as efficient as the dusts in most cases, especially in the muck soil. But with those species which are injured by the use of formaldehyde, the liquid treatment frequently reduced the stand to a greater extent than either of the dusts. The dust made up with powdered charcoal as a carrier was somewhat less toxic than that prepared with the charcoal-muck-kaolin mixture and was just as effective in disease control. However, it did not flow as freely as the latter and was thus more difficult to apply.

The response of spinach to treatment with formaldehyde was very marked in many instances and some increase in stand has always been obtained; whereas, in many cases, the untreated rows showed severe reductions in plant number. Stands are frequently trebled or quadrupled in the field by row treatment and may be increased 500 to 2000 per cent in heavily disease-infested soils in the greenhouse.

When spinach and beets were planted in muck fields in mid-July, the stands were increased 375 and 200 per cent, respectively, by row treatment. A row treatment made with a 4½% formaldehyde-charcoal dust, on spinach planted in a loam soil in mid-September, increased the stand over untreated rows by 232 per cent. Large increases in stand have also been obtained by row treatments with beets, cucumbers, and tomatoes, particularly when seeds of these species were planted in soils highly infested with disease-causing organisms. It would only be in such soils that any material benefit could be expected from the treatment of such crops as parsnip, endive, carrot, and corn.

FORMALDEHYDE CONTENT OF DUST AND RATE OF APPLICATION

As previously mentioned, formaldehyde dust is usually prepared with a formaldehyde content of 6 per cent. The addition of 15 per cent by weight of formalin to a carrier of average adsorptive capacity gives a rather damp mixture—moist enough so that it does not "flow" freely from a container. The application of so small a quantity as 1 ounce of this material to 30 feet of row, which provides as much formaldehyde as is necessary, is a mechanical operation requiring some care in order that an even distribution of material may be obtained. Also, tests in the field and in the greenhouse have shown that the use of a 6% dust in the seed row at this rate is toxic to some kinds of seeds. Some of these species might, however, be benefited by the use of the dust if the proper balance between absence of formaldehyde toxicity and presence of fungicidal action could be ascertained for a particular kind of seed. Since it is not practical to distribute less than the above-mentioned quantity of a 6% dust, it was decided to try dusts carrying a lower quantity of formaldehyde. Similarly, different dilutions of the liquid treatment were included in the experiments.

In one experiment a greenhouse bench was filled with a muck soil known to contain many damping-off organisms. The species of seeds planted included several known to be formaldehyde-sensitive, as well as others which are quite resistant to injury. The formalin-water solutions were used at the rate of 1 gallon to 200 feet of row. The different formaldehyde dusts (charcoal carrier) were used at the rate of 1 ounce on 30 feet of row. The seeds were covered with soil immediately after the treatments were applied. A near duplicate of this experiment was performed about 2 weeks later. The percentages of germination for spinach and stocks, selected from the plants in the first experiment, are shown in the left-hand portion of Table 4, and those for spinach and lettuce, selected for the second experiment, in the right-hand portion of the same table.

In the first experiment the emergence of both spinach and stocks was increased by the formaldehyde treatments. This was also true for spinach in the second experiment, but lettuce was reduced by each of them. Spinach, which is very susceptible to damping-off and quite resistant to the toxic effect of formaldehyde, showed the largest percentage of emergence with the heaviest formaldehyde applications; whereas the stand became poorer and poorer as the amount of formaldehyde decreased. This is illustrated in Figure 2 (A).

Beginning at the left, the first row was not treated (the check of the left-hand portion of Table 4). In order, from the left, the other rows were treated as follows: 1-150, 1-100 dilutions of formalin in water, 6, 4½, 3, and 1½% formaldehyde dusts. The stand may be seen to be thickest in the rows treated with the 1-100 liquid and the 6% dust treatments. Stocks, which belong to the Cruciferae, were benefited by all of the treatments, but the percentage of emergence was best with the weak applications of formaldehyde, some injury to the seeds having occurred from the formaldehyde in the strong treatments. The condition of these plants is shown in Figure 2 (B) in which the order of the treatments, beginning on the left, are the same as those given in the right-hand portion of Table 4.

TABLE 4.—Influence of Formaldehyde Content of Treatment (Liquid and Dust) on Disease Control and Formaldehyde Toxicity

Percentage of emergence

Treatment	Spinach	Stock	Treatment	Spinach	Lettuce
Check	6	27	Check	24	96
Liquid 1-150	62	53	Liquid 1-150	45	82
Liquid 1-100	79	36	Liquid 1-125	55	60
Dust 6%	80	38	Liquid 1-100	58	41
Dust 4½%	68	48	Dust 6%	59	40
Dust 3%	49	54	Dust 4½%	38	61
Dust 1½%	35	52	Dust 3%	36	70

These results indicate that, in the case of formaldehyde-resistant species such as spinach, plenty of formaldehyde to insure good control of damping-off may be used. For seeds such as stocks, which are moderately sensitive to injury by formaldehyde, weak dusts (or liquid treatments) which will give a balance between the fungicidal efficiency and the toxicity of the formaldehyde to the seedlings should be used. It seems likely that, in the absence of severe damping-off, lettuce and plants of similar sensitivity should not be treated at all. Similar conclusions must be arrived at from a consideration of results obtained in field trials as illustrated in the data of Table 3 and from that of other data given throughout this bulletin.

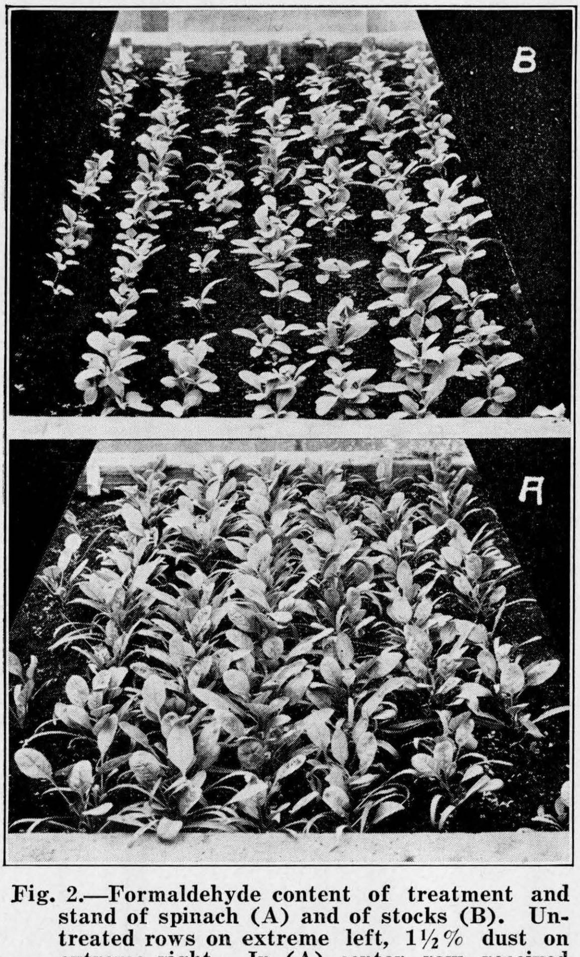

Fig. 2.—Formaldehyde content of treatment and stand of spinach (A) and of stocks (B). Untreated rows on extreme left, 1½% dust on extreme right. In (A) center row received the 6% dust. In (B) third row from right received the 6% dust. See text for further explanation.

As previously mentioned, the use of 8 ounces of a 6% dust per bushel of soil is commonly recommended for the control of damping-off, but for special purposes, such as the reduction of the nematode population, this may be doubled or even trebled to advantage. It has been found that the use of less than 8 ounces of dust per bushel of soil does not usually give control. This is especially true for plants like Celosia, Clarkia, sweet William, and spinach, which come up very poorly in untreated soils. For instance, when 10 species of ornamentals were used, treating the soil with 4 ounces of dust increased the stand 300 per cent over that in the checks; whereas the use of 8 ounces increased the stand 400 per cent. In other experiments designed to show the effect of various amounts of dust ranging from 4 to 32 ounces per bushel of soil, 4 ounces again proved to be less effective in increasing the stand than 8 ounces when five species of vegetables were used. The percentage of emergence was not significantly increased by the use of amounts of dust greater than 8 ounces per bushel of soil.

INFLUENCE OF SOIL-MOISTURE CONTENT AT THE TIME OF PLANTING ON THE EFFECTIVENESS OF FORMALDEHYDE TREATMENTS

An apparent relation between the moisture content of soils treated with formaldehyde dust and the amount of injury to the germinating seeds was observed in several instances during the progress of this investigation. Also, a similar relation had been noted for a number of years in using formaldehyde dust in the row as a treatment for onion smut. During the past 5 years a number of formaldehyde dust formulae have been compared with the standard liquid treatment (1 gallon of a 1 to 128 formalin-water mixture to 200 feet of row) for the control of onion smut (14). Some of these dusts have proved to be as good as the liquid, except in those years when the soil was especially dry at the time of planting. In these instances seed germination was reduced by the toxic effect of the formaldehyde. In years when the soil-moisture content was high at planting time, the dust treatments gave better smut control than the liquid. The influence of soil moisture in diluting the formaldehyde solution and thus decreasing its fungicidal efficiency has been recognized by various investigators for many years; because of this action, a stronger solution has been recommended for use in very wet soils.

Comparisons have been made between the liquid and dust treatments in greenhouse benches filled with muck soil having a heavy infestation of onion smut spores. Three beds were planted in each test, the soil in one was dry, in another it was near the optimum moisture content, and in the third it was much wetter than the optimum, or approximately 100, 140, and 180 per cent of water on the basis of dry weight, respectively. Known numbers of seeds were planted with each treatment. A 6% formaldehyde dust with infusorial earth as a carrier was used at the rate of 1 ounce per 30 feet of row (approximately 90 pounds per acre) on one-third of each bed, and on another third a 1-128 dilution of formaldehyde in water was applied at a rate equivalent to 1 gallon on 200 feet of row. The remaining third of each bed was left untreated. The results are summarized in Table 5.

TABLE 5.—Influence of Soil-moisture Content at Time of Planting on Effectiveness of Formaldehyde Dust and Liquid Treaments in Controlling Onion Smut

Treatment	Dry			Optimum			Wet		
	Germination	Smut	Damping-off	Germination	Smut	Damping-off	Germination	Smut	Damping-off
	Pct.	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
Check	69	86	25	66	87	38	71	90	48
1-128 liquid	75	39	0	78	38	1+	76	54	2+
6% dust	37	30	0	58	14	1—	73	16	1—

Germination in the rows receiving the liquid treatment was better than in the untreated rows at each soil-moisture content. As the moisture content of the soil increased, the germination in rows treated with the dust also increased, being very low in the dry soil and above the check in the wet soil. The dust treatment gave better smut control than the liquid at all three soil-moisture contents. Damping-off of the seedlings, which was severe in the untreated rows, was almost entirely controlled by each treatment. These results help to explain those obtained in field trials where dust compared unfavorably with the liquid treatment in dry springs and favorably in wet ones.

In an effort to determine more exactly the influence, at the time of planting, of the soil-moisture factor on formaldehyde injury, the experiment described below was repeated several times. Three soils with quite different water-holding capacities were used, sand with 20 per cent on the basis of dry weight, compost with 60 per cent, and muck with about 200 per cent. The checks, or untreated portions, were prepared from the dry soil. Besides air-dry lots, the sand was used at moisture contents of 4, 8, 12, and 16 per cent; the compost at 10, 20, 30, and 40 per cent; and the muck at 40, 80, 120, and 160 per cent. The mixtures at the highest moisture content mentioned in each case were about as wet as could be conveniently handled. The soils, with the exception of the check portions, were treated in the air-dry condition with a 6% formaldehyde-charcoal dust at the rate of 16 ounces per bushel and then were made up to the various water contents stated above. This heavy treatment was used to insure formaldehyde injury under conditions favorable to it. The prepared soils (treated and untreated) were placed in 4-inch pots and planted with various vegetables, some of which were known to be very sensitive to formaldehyde injury and others which were not particularly susceptible. The pots were then sunk in moist gravel up to their rims and the whole group then covered with saturated blotting paper. At the end of 48 hours the paper was removed and the pots all watered thoroughly. It was found necessary nearly to immerse the pots containing the dry check and dry, treated muck soil in water for several hours to promote wetting. Two weeks later the seedlings were examined and counted.

Germination was checked to the greatest extent in most instances at the medium moisture contents, especially with species rather susceptible to formaldehyde, such as lettuce, cabbage, and onion. Injury was not as great in the treated, air-dry soil, as is illustrated in Figure 3, probably because much of the formaldehyde had escaped before water was added 48 hours after treatment and planting and in the meantime the scarcity of soil moisture had retarded the inception of the physiological activities incident to seed germination. On the other hand, the population of damping-off organisms in the soil had apparently been considerably decreased, since the number of good plants was higher in most instances than in the pots of untreated soil. The number of good plants obtained in the treated soils at high moisture contents was also larger than in those at medium moisture contents. This is possibly due to the fact that the formaldehyde which was added to the soil in the treatment was diluted to a much greater extent by the water present in the soil and thus less of it was absorbed by the seed in the process of germination. At the medium moisture contents the formaldehyde was not greatly diluted, but there was plenty of water available to the seed so that absorption took place freely and germination occurred quickly and before much of the formaldehyde had escaped from the soil. The fact that stunting, which took place in some species, occurred only at these medium soil-moisture contents also indicates that formaldehyde is more toxic to seeds in this range than in dry or wet soils. These differences in the percentage of germination could not be attributed to the variations in soil-moisture content alone, since, in a series of treated checks held at the moisture contents listed above, seed germination was better in each soil type in the intermediate soil-moisture range.

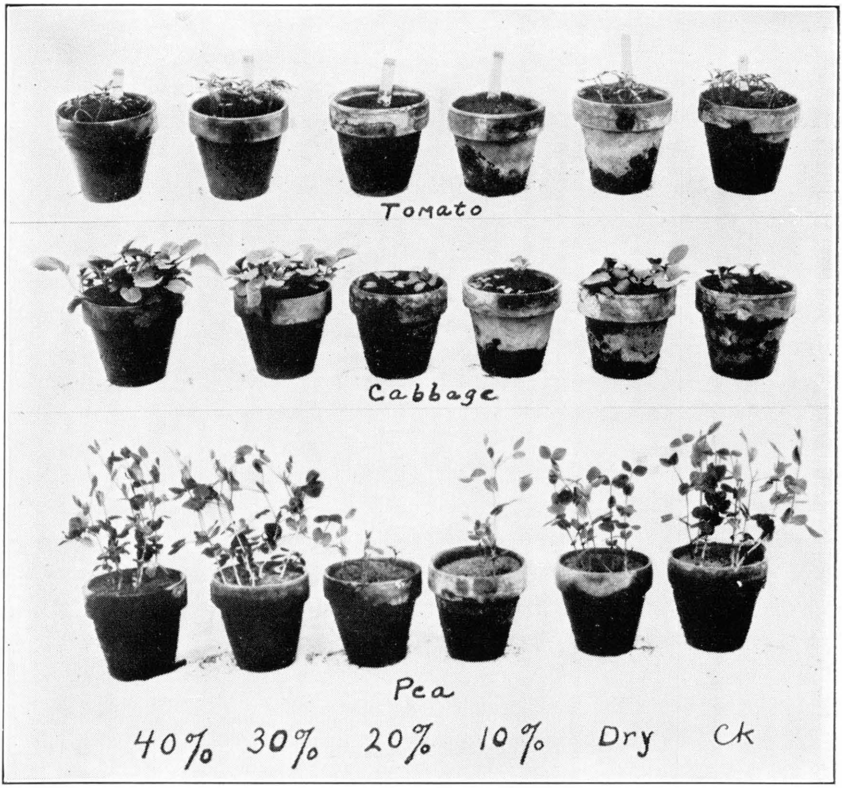

Fig. 3.—Influence of soil-moisture content at time of planting on toxicity of formaldehyde to germinating seeds

These results indicate that, when seeds are planted in soils treated with formaldehyde dust, the soil should be well soaked with water immediately after planting. Although it is probable that no injury would occur if seeds were planted in an extremely dry soil which had been treated and was not watered until 48 hours after treating and planting, it would seldom be either desirable or practical to do this.

RELATION OF SOIL TYPE TO FUNGICIDAL EFFICIENCY AND TOXICITY OF FORMALDEHYDE TREATMENTS

The influence of soil treatment with formaldehyde dust on the stand of seedlings which is obtained has been found to vary somewhat with soil type. It would be expected that soils with large surface areas (made up of finely divided particles) and those high in organic matter, such as muck, could be treated with larger amounts of dust before the formaldehyde became toxic to the seeds and seedlings than could soils like coarse sands. Also, it would seem likely that larger quantities of formaldehyde should be added to soils of the former types to give comparable control of soil-borne diseases, due to the greater absorptive powers of these soils. The chemical composition of the soil probably plays some part too, as well as its degree of acidity. Soils high in available calcium neutralize the toxic effect of any added formaldehyde since the calcium combines chemically with the formaldehyde. Another cause of variation in effect with different soil types is connected with the fact that certain organisms may grow much more vigorously in one kind of soil than in another, and thus it would be more difficult to eliminate them from the ones in which they grow best. For instance, *Pythium* spp. grow much better in loose media which furnish an environment high in oxygen. Another factor which must always be considered in connection with the apparent variations which occur in fungicidal effectiveness of the formaldehyde dust treatment is the fact that some lots of soil are much more highly contaminated with disease-producing organisms than are other lots of the same type of soil.

In an effort to determine something of the influence of the type of soil in which the seeds are planted on the effectiveness of a given amount of formaldehyde dust in checking damping-off and on the degree of its toxicity to the seedlings, a number of experiments was performed. In one experiment, treated and untreated portions of the following soils and soil mixtures were planted to seeds of stocks—sand, sand-peat moss in equal volume, sand-compost in the same manner, sand-compost-peat moss (one part of each), compost-peat moss, and compost. All of the pots were thoroughly watered immediately after planting.

The percentage of germination in the treated portions of the various soils used was similar in all instances, indicating a more or less complete control of the damping-off organisms regardless of soil type. Germination in the untreated portions was much poorer in any mixture containing compost, probably due to the compost being more highly infested with disease-causing organisms than either the sand or peat moss. Thus, of course, the response to treatment was greatest in the compost and the mixtures containing it. There was some evidence of formaldehyde toxicity in the treated sand. Damping-off was most severe in the sand-compost mixture, possibly due to the fact that here there was high infestation with damping-off organisms combined with a loose soil condition (high soil-air content) favorable for their development.

In another experiment to determine the influence of soil type on the degree of formaldehyde toxicity with a minimum of emphasis on disease control, portions of sand, compost, and muck were treated with quantities of a 6% formaldehyde dust ranging from 4 to 32 ounces per bushel. Lettuce was used because of its sensitiveness to the toxic factor of formaldehyde. The results are shown in Table 6.

TABLE 6.—Influence of Soil Type on Toxicity to Lettuce of Increasingly Large Amounts of Formaldehyde Dust

Ounces per bushel of 6% dust (mass treatment)	Percentage of germination		
	Sand	Compost	Muck
Check	60	40	42
4	66	54	64
8	52	44	68
12	40	24	62
16	24	26	72
20	16	16	56
24	12	10	64
28	6	4	50
32	0	0	54

The treatment of 4 ounces of dust per bushel increased the percentage of emergence over that in flats of untreated soil in each soil type. At the 8-ounce treatment injury was evident in the sand, and at the 12-ounce the injury was severe in both sand and compost; whereas in muck there was no indication of injury until more than 16 ounces of dust per bushel of soil were used. With a treatment of 32 ounces there was no germination in sand or compost, but the percentage of emergence was still greater in the muck than it was in the check in that soil. The ability of muck soils to minimize injury from the toxic factor of formaldehyde is well illustrated in these data and has been shown in many other instances in this investigation.

It will be shown later that the degree of toxicity of a given amount of formaldehyde to germinating seeds varies with the different carriers on which the formaldehyde is adsorbed. Likewise, formaldehyde incorporated into the row with the seed is toxic to different degrees in different types of soil.

In an effort to determine some of the variations in degree of toxicity to seedlings of formaldehyde placed in the seed row, several vegetables were planted in sand, compost, and muck soils, and there treated with a wide variety of formaldehyde dusts. The data given in Table 7 show the results obtained with charcoal and muck carriers only bearing 6 per cent of formaldehyde, used at the rate of 1 ounce to each 30 feet of row, and represent the average of several trials. The sand was inoculated with damping-off organisms by mixing a quantity of infested muck soil with it.

TABLE 7.—Variation in Response of Several Vegetables to Row Treatment with Two Different Dusts When Seeds were Planted in Different Soil Types

Number of good seedlings from 100 seeds

Vegetable	Sand			Compost			Muck		
	Check	Charcoal	Muck	Check	Charcoal	Muck	Check	Charcoal	Muck
Spinach	4	52	48	23	57	48	8	58	61
Onion	33	33	31	38	44	34	54	56	44
Cabbage	58	25	18	45	47	32	67	71	50
Lettuce	46	14	12	38	19	12	55	29	26

These data indicate that, in general, (disregarding variations in stand due to disease-producing organisms) the toxicity of formaldehyde decreases as the organic content and the particle fineness of the soil increase; this is in agreement with the results obtained in mass treatment of the soil as shown in Table 6. Also, that formaldehyde adsorbed on finely divided charcoal is less toxic than that on finely ground muck soil. The increases in stand which may result from treating spinach are again emphasized, and the extreme susceptibility of lettuce to the toxic factor of formaldehyde is also further demonstrated. The use of dusts weaker in formaldehyde than the usual 6 per cent product is suggested for very sandy soils, especially with seeds of medium or high sensitivity to formadehyde.

THE USE OF FORMALDEHYDE DUST IN THE HILL TO IMPROVE STAND OF CUCURBITS

Difficulty is often experienced in getting good stands of cucumbers and other cucurbits even under the best of cultural conditions. In many instances during the progress of the work reported here only 5 to 50 per cent of the cucumber seeds sown in the compost came up, if no soil treatment was used. Mass treatment with a 6% formaldehyde dust at the rate of 8 ounces per bushel resulted in the attainment of nearly 100 per cent emergence.

Experiments were then carried out to determine whether it was possible to increase emergence by placing a quantity of dust in the hill with seeds at planting.

Fifty hills each of cucumbers, muskmelons, and squashes were planted in a silt-loam soil early in June. Two grams (a tablespoon level full) of a 4½% formaldehyde dust (charcoal carrier) were added (spread thinly) to each of 25 hills of each species, and the remaining hills were left untreated. The results are shown in Table 8.

TABLE 8.—Influence on Stand of Placing Formaldehyde Dust in the Hill with Cucurbit Seeds

Plant	Percentage of germination	
	No treatment	Treated
Cucumber	78	86
Muskmelon	76	75
Squash	82	94

These data do not show any great increase in stand due to the use of formaldehyde dust in the hills, and it is unlikely that any would ever occur when good seeds are planted in soils comparatively free from organisms capable of attacking germinating seeds and seedlings. However, if the cucurbitaceous seeds are to be planted in soil in which difficulty has previously been experienced in obtaining a good stand, the use of a level tablespoonful of a 4½% dust in each hill should be worth while.

COMPARISON OF LIQUID AND DUST TREATMENTS

The treatment of soil, flats, pots, and the structural parts of beds, bins, benches, walks, etc., with a solution of formaldehyde in water for the elimination of the causal organisms of plant diseases has been recommended for many years. It is often resorted to in sterilizing soil in benches and ground beds for the control of such soil-borne organisms as are capable of attacking seedlings. Although the method is fairly effective it has certain disadvantages. The formaldehyde gas which is later given off may be injurious to other plants growing in the greenhouse and it is also very disagreeable to anyone who has to be in the house. Soil heavily drenched with water must be allowed to stand for some time (the period varying with the soil type) before it can be worked or planted. This time factor may also be important if it is necessary to get the seedlings started as soon as possible after the beds are prepared.

Mass treatment of the soil with formaldehyde dust makes it unnecessary to add any water to the soil until after the seeds are planted, and no time need be allowed between treating and planting, except in the case of certain very susceptible species which have already been mentioned.

In order to determine the practicability of using a weak formaldehyde drench after the seeds had been placed in the soil and to compare this treatment with that of mixing formaldehyde dust with the soil before planting, the following experiment was performed: A soil mixture of one part of sand to one of compost was prepared, and eight flats were filled with it. The soil in one flat was treated with a 6% formaldehyde-charcoal dust at the rate of 8 ounces per bushel. One of the untreated flats and the one containing the soil which had been treated with dust were watered thoroughly. One of each of the other six flats was drenched with one of the following dilutions of commercial formaldehyde in water (0.1, 0.25, 0.50, 0.75, 1.0, and 2.0%) until the solution ran out at the bottom of the flats. After 2 weeks the seedlings were counted and their average height determined for each flat. The data are shown in Table 9.

TABLE 9.—Comparison of Formaldehyde Drench and Dust Treatments of Soil for Growing Tomato Seedlings. Soil Mixture ½ Sand and ½ Compost

Treatment	Good seedlings	Damped-off	Av. height of plants 2 weeks after planting
	Per cent	*Per cent*	*Inches*
Check	77	13	3.2
6% dust at 8 oz. per bushel	95	1	3.5
0.1% HCOH sol.	96	2	3.4
0.25% HCOH sol.	96	1	3.0
0.50% HCOH sol.	89	9	2.8
0.75% HCOH sol.	99	0	2.6
1.0% HCOH sol.	95	1	2.2
2.0% HCOH sol.	87	0	1.8

All of the liquid treatments gave good control of damping-off except that of 0.50%, and it is likely that secondary contamination from an outside source occurred in this instance. However, all of them except the 0.1% solution caused some stunting of the seedlings. The dust treatment also gave good control of damping-off, and the seedlings were actually larger than those in the check flat, as were those in the flat drenched with the 0.1% solution. These data indicate that care must be used not to get the formaldehyde solution which is to be used for drenching too strong and that the 0.1% solution should give satisfactory results with tomatoes.

Another experiment was performed in an effort to determine the relative effectiveness in controlling damping-off of a number of different formaldehyde treatments and in what way their toxicity to a number of different vegetable seedlings (spinach, tomato, pepper, cabbage, and cucumber) varied in different soil types (sand, compost, and muck). The following formaldehyde treatments were used: a 1-200 formalin-water drench, a 6% dust used for mass treatment at the rate of 8 ounces per bushel of soil, a 1-128 formalin-water solution added to the seed row at the rate of 1 gallon on 200 feet of row, and 6% formaldehyde dusts (charcoal and muck carriers) in the seed row at the rate of 1 ounce to 30 linear feet. The results are given in Table 10 as percentages of the seeds sown which developed into good seedlings.

TABLE 10.—Comparison of Relative Effectiveness in Disease Control and Degree of Toxicity of Various Forms of Formaldehyde Soil Treatments

Treatment	Spinach	Tomato	Pepper	Cabbage	Cucumber
		Sand			
Check	22	42	20	22	44
Liquid drench	34	76	60	12	88*
Dust (mass treatment)	40	56	56	64	100
Liquid in row	38	52	30	70	68
Charcoal dust in row	36	74	84	56	64
Muck dust in row	60	62	44	8	72*
		Compost			
Check	36	50	60	44	16
Liquid drench	66	38*	56	56	100*
Dust (mass treatment)	40	64	60	88	84
Liquid in row	48	82	74	60	72
Charcoal dust in row	48	76	86	46	80
Muck dust in row	36	70*	36*	24	52*
		Muck			
Check	32	76	64	80	92
Liquid drench	28	80	40	20	92
Dust (mass treatment)	42	80	80	92	96
Liquid in row	60	84	72	94	96
Charcoal dust in row	46	86	58	76	84
Muck dust in row	44	78	36	30	88

*Seedlings stunted.

These data indicate that stunting may occur in some instances with the use of the formaldehyde drench and the muck carrier dust, especially in compost and with certain species. In the case of species particularly susceptible to the toxic effects of formaldehyde, such as cabbage in this instance, the injury is much greater with the drench method than when dust carrying an equivalent amount of formaldehyde is mixed with the soil. In several instances the stand of seedlings was just as good with the drench method as with any of the others. It should be noted that this was also true for the treatment in which the liquid was placed in the row with the seed. On the average the losses due to formaldehyde toxicity were greatest in the sand and least in the muck, and this was found to be true in a number of other experiments reported later in this paper. There was some damping-off in the check flats, especially in the spinach and tomato seedlings, and almost none in any of the treated plots. The results obtained in the experiments described above suggest that the formaldehyde-drench method may be resorted to if the materials necessary for other treatments are not available but that care must be used to keep the solution used weak in formaldehyde and to avoid its use on formaldehyde-sensitive plants.

A number of experiments were performed to determine the relative efficiency of different strengths of formaldehyde-water dilutions and formaldehyde-carrier dusts on disease control and the relative toxicity of the various treatments to the seeds when the materials were placed in the row with the seeds. The results indicated that comparable amounts of formaldehyde were equally effective in fungicidal action regardless of whether they were applied to the row as water dilutions or adsorbed on dust-like carriers. Also, the degree of toxicity to the seeds in the treated row was similar but perhaps somewhat greater for the liquid treatment in the case of extremely sensitive species. Thus, the advisability of using either one form of treatment or the other will be regulated by the equipment available and possibly, to some extent, by the moisture content of the soil at the time of planting, as was discussed in a previous section of this paper dealing with the influence of soil moisture on formaldehyde toxicity.

COMBINATION OF MASS AND ROW TREATMENTS IN RESTRICTED AREAS OUTDOORS

Even though mass treatment with formaldehyde dust of the soil in a field would seldom, if ever, be practical because of the labor and cost involved, it is possible that restricted areas could be treated thus. For instance, it may be desirable to plant a small area to some special crop like sweet peas, and the soil in which these are to be grown may be so infested with disease-causing organisms that it would be impossible to do so without first sterilizing the soil in some manner. In this case formaldehyde dust may be spaded, or otherwise mixed, into a strip of soil of the desired width and depth before the seed is sown.

An experiment was designed to test the practicability of such strip treatments. A ground bed (in a greenhouse) in which sweet peas were known to germinate poorly and then damp-off badly after emergence was selected for treatment. In one instance a 6% formaldehyde dust was mixed with the soil in strips 6 inches wide and 6 inches deep at the rate of 1½ ounces per linear foot (8 ounces per cubic foot of soil). Seeds were planted in rows in these strips as well as in an adjacent untreated area. The whole bed was then watered heavily. Three weeks later 78 per cent of the seeds planted in the treated strips had developed into good plants; whereas only 37 per cent of those in the untreated area had emerged as seedlings, and 27 per cent of these damped-off later. There was no damping-off in the treated rows. In another similar experiment, started about 1 month later, in which the treated strips were 12 inches wide, 49 per cent of the seeds planted in untreated soil produced good plants; whereas 72 per cent of those in the treated strips had come up and grown. The appearance, 1 month after planting, of the plants in the treated (left) and untreated (right) areas is shown in Figure 4.

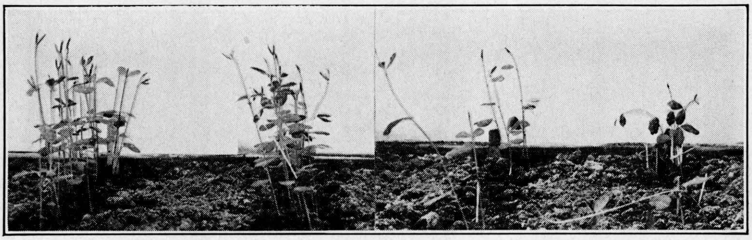

Fig. 4.—Two rows of sweet peas, on the left, were planted in soil treated with formaldehyde dust. Soil on the right was left untreated

These results indicated that mass treatment of strips of soil in which seeds are to be planted is a satisfactory method of insuring a good stand of seedlings in areas where the soil is highly contaminated with organisms injurious to seed germination and seedling growth.

PLACING GLASS OVER TREATED SOIL

It is sometimes desirable to place a pane of glass over flats or pots in which seeds are planted until the seedlings emerge. This practice prevents the soil from drying out and usually the seedlings come up more quickly than they would otherwise. Several tests were made to find out if a pane of glass could be placed over flats or pots containing soil treated with formaldehyde dust without injuring the seedlings. In no case was there any indication that the glass covering held the formaldehyde gas in to the extent that the seedlings were injured.

TRANSPLANTING

It is usually desirable to remove small seedlings from the crowded conditions of the seed flat or bed to small pots, beds, or other flats, and there to let them grow under more favorable conditions of spacing and light until top and root growth are sufficient for final transplanting. Many seedlings are still susceptible to the attack of damping-off organisms after this first transplanting, and, for this reason, it may be desirable to sterilize the soil into which they are to be placed in some manner. If formaldehyde dust is used, a certain amount of time must be allowed for the formaldehyde to escape from the soil before the transplants are placed in it; otherwise injury will result.

The minimum duration of this interval between treatment and transplanting necessary to avoid formaldehyde injury is regulated by numerous factors, some of the more influential of which are the temperature, water content, organic-matter content, and physical characteristics of the soil used. The particle area (degree of fineness) and chemical make-up (mineral or organic) of the soil are important because of their influence on its adsorbing and water-holding capacities.

The influence of soil type on the toxicity of formaldehyde to the germinating seedling was discussed in previous sections of this paper dealing with mass and row treatments. It is, perhaps, even more influential in connection with transplanting since the transplant is very sensitive to any formaldehyde which may be present at the time it is placed in the soil; whereas dry seeds placed in the soil are allowed a few hours of grace before the processes of germination have progressed far enough to make them sensitive to a degree comparable with that of the seedling, and during this interval much of the formaldehyde has escaped. Some of these inter-relations of soil factors and the degree of injury following treatment with formaldehyde dust have been investigated and the results are discussed in the following pages.

Three soils which varied widely in their adsorbing capacity, water-holding power, and organic content—namely, sand, silt-loam compost, and muck—were selected for treatment in one experiment. These soils were made up to medium moisture contents (sand 10, compost 30, muck 120 per cent on basis of dry weight) and treated with a 6% formaldehyde dust at the rate of 8 ounces per bushel. Celery and tomato seedlings were transplanted into flats (4 inches deep and 1 foot square) filled with these soils which had been treated at intervals of 0, 6, 12, 18, 24, 48, and 72 hours previously. This procedure permitted the use of seedlings of the same age and size, subjected to one set of conditions after transplanting. Within a few hours after the plants had been placed in the treated soils, those in the sand treated less than 48 hours previously were badly wilted and at the end of 1 day many of them at the 0-, 6-, and 12-hour intervals were dead. In the compost many of them soon wilted at the 0-, 6-, and 12-hour intervals, but most of these later recovered, even at the 0-hour period. But little visible injury occurred in the muck even though there was some drooping of the tomatoes at the 0- and 6-hour intervals. Of the 20 plants originally transplanted, the numbers of each kind alive in each flat at the end of 1 week are shown in Table 11.

TABLE 11.—Relation of Soil Type to Time Which Must Elapse After Treatment With a 6% Formaldehyde Dust at the Rate of 8 Ounces per Bushel Before Seedlings May Be Safely Transplanted Into It

20 plants set; number alive shown

Time elapsing (hours) between treatment and setting	Sand		Compost		Muck	
	Celery	Tomatoes	Celery	Tomatoes	Celery	Tomatoes
No treatment	19	20	20	19	20	19
0	0	0	17*	6*	15*	19*
6	1*	0	14†	11*	17†	20†
12	2*	0	15†	10†	19	20
18	20†	13†	18	19	18	20
24	20	19	18	19	19	20
48	20	19	17	19	19	20
72	20	20	19	19	20	19

*Stunting.
†Slight stunting.

As indicated in the table, many of the plants which survived the initial injury due to the formaldehyde were stunted. The data of Table 11 indicate that at least 24, 18, and 12 hours *must* elapse after treatment of sand, compost, and muck, respectively, before freedom from formaldehyde injury may be assured, and the increase of these periods to 48 or even 72 hours is known to be highly desirable if injury is to be avoided under all environmental conditions (13, 15). In this experiment the sand with a low water and organic matter content and a low adsorbing capacity allowed the greatest formaldehyde injury at the short time intervals after treatment; whereas the muck, which had a high adsorbing capacity and possessed a high organic matter content and water-holding capacity, allowed much less. The compost, which was intermediate between the other two soils in these factors, was also intermediate in the degree of formaldehyde injury which occurred in it. It is believed that one of the very important factors which influenced the injury occurring in these three soils was the degree of dilution of the formaldehyde by the water in the soils, since much greater dilution took place in the muck than in the sand, and this more dilute solution was much less toxic to the seedlings placed in the muck.

In another experiment designed to show the relation of soil type to formaldehyde injury to plants placed in the treated soil, sand, compost, and muck at medium moisture contents were treated with a 6% formaldehyde dust at the rate of 24 ounces to the bushel. The soil was then placed in flats and allowed to stand in a warm room for 36 hours. At the end of this period stocks, pepper, celery, cabbage, and tomato seedlings were transplanted into the treated soil. At this time other flats containing untreated soil were set with the same species. Measurements made 10 days later again showed formaldehyde to be more toxic to transplants in coarse, mineral soils, such as sands, than in finer ones, such as silt loam or a highly organic soil like muck. All species except celery were stunted in sand by the treatment. Only stocks showed poorer growth than the check in treated compost, and only pepper in muck. It was interesting to note the marked increase in growth of celery, cabbage, and tomato, due to the treatment of muck. Root growth was much better in the treated flats in these instances, indicating that certain organisms injurious to the roots of these plants were killed or inhibited by the treatment with formaldehyde.

The temperature and moisture content at which a soil is held during the interval between treatment with formaldehyde dust and placing the seedlings in it are important factors in determining the rate at which the formaldehyde will escape and, consequently, on the amount of injury which will occur due to its presence. In an effort to determine something of the significance of these soil factors in relation to formaldehyde injury, compost at two different moisture contents (1 and 24 per cent on the basis of dry weight) were treated with 8 ounces of a 6% formaldehyde dust per bushel of soil and placed in flats. Flats of treated soil at each moisture content, together with check flats of untreated soil at the same moisture contents, were held for a period of 48 hours at temperatures varying between 30 and 40° F. A similar series of flats was held at temperatures varying between 65 and 75 degrees F. At the end of this period the flats were returned to the greenhouse and were planted to tomato seedlings, and the soil in each was heavily watered immediately. The condition of these plants a few days later is shown in Figure 5.

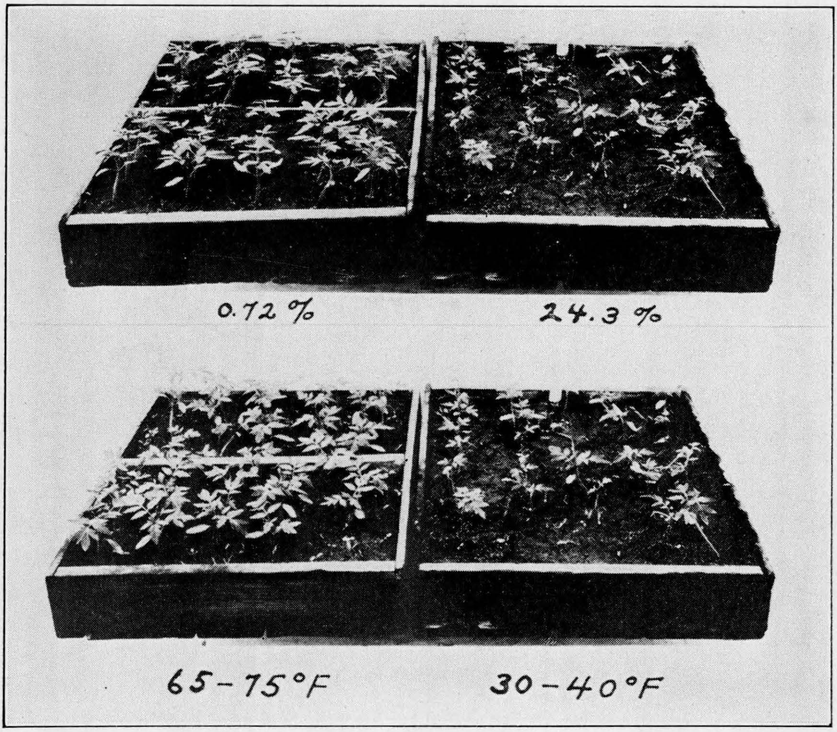

Fig. 5.—Influence of soil moisture (top) and soil temperature (bottom) on rate of formaldehyde escape from treated soil. Tomato plants as indicators

As may be seen in the figure, the injury to transplanted seedlings was much less in the dry and warm soils than in the wet and cold ones. In another experiment, similar to the one described above, except that the interval between treating and planting was 24 hours rather than 48, the difference in the amount of injury which occurred in dry and wet soils was not very noticeable, but more injury did occur in cold than in warm soils. In general, it may be assumed that formaldehyde escapes from dry, warm soils more quickly than from cold, wet ones.

That the decrease in injury with elapse of time is due more largely to the escape of the formaldehyde from the soil than to its adsorption by, and chemical change within, the soil was indicated by the results of the following experiment. Four bushels of compost of medium moisture content were treated with a 6% formaldehyde dust at the rate of 8 ounces per bushel. One bushel of this treated soil was sealed tightly in a metal can, the other 3 bushels were placed in a pile on the floor of the greenhouse. At the end of 48 hours this pile was shoveled over thoroughly. Seventy-two hours after treatment sufficient soil to fill a flat was removed from the metal can and from the pile on the floor. These flats were set with tomato seedlings at once and watered immediately afterward. No drooping (the first visible symptom of formaldehyde injury to transplants) was observed in the soil which was taken from the pile on the floor; whereas it was severe in that taken from the metal can. This drooping was just as severe in soil removed from the can at the end of 4 and 5 days, indicating that formaldehyde toxicity in treated soil does not decrease very rapidly when diffusion of the gas into the surrounding air is checked.

The experiments mentioned above, together with numerous others, have repeatedly shown that at least 72 hours must elapse between the time of treating soil with formaldehyde dust, at even as low a rate as 8 ounces per bushel, and transplanting seedlings into it, if injury is to be avoided under all the different air and soil conditions which may be encountered.

TREATING SAND IN THE CUTTING BENCH WITH FORMALDEHYDE DUST

It is usually unadvisable to use the same sand in a cutting bench for more than one season, unless it is sterilized by some means. Fungi, such as *Botrytis* sp., *Rhizoctonia solani*, and *Pythium debaryanum*, are often so numerous in cutting-bench sand after it has been used for a season that a large percentage of the cuttings damp-off. It was found that treating sand with 3 ounces of a 6% dust to the cubic foot killed these organisms.

From the results of several experiments, it was concluded that cuttings may be set in sand 48 hours after it has been treated with a 6% formaldehyde-charcoal dust at the rate of 3 ounces per cubic foot, if the sand is thoroughly stirred at the end of the first 24 hours following treatment.

RELATION OF ADSORBENTS TO FORMALDEHYDE TOXICITY

During the progress of experimentation with formaldehyde dust for the control of onion smut, it was frequently noticed that variations in the percentage of emergence of onion seedlings occurred which could only be accounted for by the fact that the formaldehyde was applied to the seed row on different carriers, the dusts being of equal formaldehyde content and applied at the same rates. Similar variations were noticed early in the course of the present investigation.

In an effort to ascertain more definitely on what carriers or combination of carriers formaldehyde was least toxic, a number of materials was selected which would absorb about 15 per cent of their own weight of moisture without becoming too sticky for use. Various formaldehyde dusts were prepared, using these carriers alone or in definite combinations, and these dusts were then used for soil treatment. Finely divided charcoal was mixed in equal parts (by weight) with muck, kaolin, infusorial earth, and lime. Charcoal, lime, muck, kaolin, and infusorial earth were each used alone as adsorbents. Muck was used in equal parts with kaolin and with infusorial earth, and a half and half mixture of kaolin and infusorial earth was included. In one experiment each of these dusts was mixed with lots of sand, of compost, and of muck (each at a medium moisture content) at the rate of 24 ounces per bushel. Seeds of onion, cabbage, and lettuce were sown in these treated lots of soil and the seedlings counted about 10 days later. With the exception of the dusts containing lime, the variations in percentage of emergence with the different carriers were of little significance. The treatments containing muck resulted in slightly lower average seedling number than those containing charcoal; this was in agreement with observations made in other experiments.

The dusts listed above were used on the same seeds (onion, lettuce, and cabbage) and in the same soils in row treatments at the rate of 1 ounce on 30 feet of row. Injury due to the toxic factor of the formaldehyde was much more noticeable with this form of treatment than in the previous case where the dust was mixed with the soil. The three species used were all quite sensitive to formaldehyde injury; because of this all of the treatments showed a lower percentage of emergence than the checks, which was not true of the mass form of treatment. Those dusts of which muck was a part were again more toxic than those which contained charcoal or infusorial earth. Injury was rather severe also where kaolin was a carrier. These results substantiate the conclusion arrived at earlier in this bulletin to the effect that formaldehyde adsorbed on carriers of low weight per unit of natural volume is less toxic than that adsorbed on those of high weight. The dusts made up with lime as a carrier were less toxic than many of the others, which is the opposite of the situation with mass treatment. This was probably due to the fact that the lime partially neutralized the toxic effect of the formaldehyde added to it and that the quantity of lime itself was small compared to that of the soil mass which surrounded it in the row form of treatment. This same relation between degree of toxicity and volume-weight ratio held in regard to the soil to which the formaldehyde was added. The percentage of emergence was lowest with both forms of treatment in the sand (heavy) and highest in the muck (light).

In another test the series of dusts used in the above experiments was added to sand, compost, and muck at the rate of 24 ounces per bushel. The treated soils were then placed in flats 4 inches deep; after 24 hours plants of celery, cabbage, pepper, tomato, and stocks were transplanted into them. The plots were then watered heavily and after 2 weeks the height of the plants was determined. The variations in growth which occurred in the different soil types, treated with different dusts, were not significantly uniform with the exception again of those containing lime. The effect of the lime treatment was very noticeable in the sand where many of the plants died and those which survived were badly stunted. Many of the plants in the sand and compost wilted temporarily, due to the effect on the roots of the formaldehyde remaining in the soil. Recovery occurred within a day or two, and in the compost the plants went on growing more rapidly than in the check flats. Most of those planted in treated sand were not as large at the end of the experiment as the check plants and the average was slightly smaller. The plants in the treated flats of muck were also larger than the checks, indicating that the formaldehyde had inhibited certain organisms which hindered plant growth, directly or indirectly, in the compost and in the muck when untreated. The lime treatment hindered growth in all three soils.

It was suspected that the explanation of the variation of the different dusts in their toxicity to germinating seeds and to seedlings was that the carriers, or adsorbents, varied in their ability to retain the formaldehyde. In other words, when certain adsorbents were used the formaldehyde escaped before germination had advanced far enough for injury to occur; whereas with certain other adsorbents it was held so securely that enough remained in the soil when germination occurred to cause injury. A set of experiments was performed to determine the relative rates at which formaldehyde escapes from dusts prepared by using various carriers.

A small quantity of each of the dusts containing 6 per cent of formaldehyde (Page 32) was placed on a square of cheese cloth supported on a wire screen. The screens were then put on a revolving table and rotated so that conditions for the evolution of the formaldehyde gas would be uniform for all the dusts. After various intervals of time small samples were removed from each dust and placed in test tubes. About 10 cc. of distilled water were added to each tube, and after violent shaking the contents were filtered into other test tubes. A quantity of Schiff's reagent, approximately equal to that of the filtrate, was added to each tube. The presence or absence and the relative amount of formaldehyde in the dust sample were indicated by the presence or absence and the intensity of the rose color which developed after adding the reagent. The dusts prepared with the different carriers gave negative tests for formaldehyde in the following order: lime, lime-charcoal, kaolin-infusorial earth, infusorial earth, kaolin, charcoal-infusorial earth, charcoal, and charcoal-kaolin. The dusts prepared with muck-charcoal, muck-infusorial earth, muck, and muck-kaolin gave positive tests for formaldehyde after 90 hours, when the experiment was discontinued. The muck-charcoal combination, however, gave a much fainter test than the other three dusts which contained muck.

It is known that formaldehyde and certain alkaline materials enter into chemical combination, and this very likely explains why the dusts prepared by using lime or part lime as the carrier were the first to give negative tests for formaldehyde. The fact that a lime-formaldehyde dust confined in a tight container soon loses the characteristic formaldehyde odor further indicates a chemical reaction. It has been shown in the present investigation that formaldehyde dusts in which lime is the whole, or part, carrier may be extremely toxic, especially when these are used for mass treatment of soils in which seeds are to be planted or seedlings transplanted.

Dusts which contain muck as the carrier retain the formaldehyde much longer than the other dusts listed above. In several instances during the course of the investigation, a direct comparison of the toxicity of dusts prepared with muck and with charcoal as carriers was made. For mass treatment of soil in which seeds were planted immediately, there seemed to be little difference between these two or any of the other carriers tried, with the exception of lime. When used in the row with the seed, however, the dusts prepared by adsorbing formaldehyde on ground muck were much more toxic than when charcoal was the adsorbent. For example, in Table 10 the average percentage of seedling emergence for seeds of five species of vegetables in three different soils, when charcoal dust was used in the row, was 67 per cent; whereas for muck dust it was about 50 per cent.

STERILIZING EFFECT OF FORMALDEHYDE DUST IN SOIL

Eight measured quantities of soil were placed in wide-mouth bottles, which were then plugged with cotton and autoclaved for 2 hours on 3 successive days at 15 pounds pressure. The following fungi were used to inoculate the sterilized soil in the bottles: *Fusarium* sp. (isolated from celery), *Rhizoctonia solani*, *Pythium debaryanum*, and *Sclerotium delphinii* Welch. Two bottles of soil were used for each organism. After 1 week isolations were made from the soil in each bottle, and it was found that in every case the fungus had grown well through the soil. A 6% formaldehyde-charcoal dust was then mixed with the soil in each bottle at the rate of 8 ounces of dust per bushel of soil. After 24 hours had elapsed another set of isolations was made, and no growth was obtained from the Fusarium-, Sclerotium-, or Pythium-infested soils. In the case of the Rhizoctonia-infested soil, sclerotia had formed around the sides of the bottle; when these were plated out they were found to be still alive, although the mycelium in the soil where no sclerotia occurred was dead.

In a second similar experiment in which Fusarium produced a fungous mat over the surface of the soil, this fungus was not entirely eliminated by treating the soil with formaldehyde dust. Other experiments were performed by making isolations from compost which had been treated with dust at the rate of 8 ounces per bushel. In no case was the soil completely sterilized. Soil bacteria and certain fungi always survived the treatment.

In still another experiment soil was obtained which was known to contain the tomato wilt organism, *Fusarium lycopersici* Sacc. Three portions of this soil were treated with 6% formaldehyde dust at the rate of 8, 12, and 16 ounces per bushel and placed in flats. A fourth flat was filled with untreated soil. After sufficient time had elapsed to allow the formaldehyde to get out of the soil, 24 tomato seedlings were set in each flat. At the end of 6 weeks, eight of the plants in the untreated soil were affected with wilt ; whereas all of the plants were healthy in each of the flats where the soil had been treated.

Evidently, treating soil at the rate of 8 ounces of a 6% formaldehyde dust is fairly effective in eliminating such organisms as

Fusarium, Pythium, and Sclerotium. The mycelium of Rhizoctonia is also killed, but the sclerotia are not. Also, it is very probable that sclerotia of *Sclerotium delphinii* would not be killed. Sclerotia had not formed in the experiment where this organism was used.

NEMATODE CONTROL

Although nematodes assume importance in the production of outdoor crops in Ohio only in special instances in isolated localities, they are almost universally present in greenhouses in this State and must be controlled there if crops are to be grown profitably. Sterilization of the soil with steam is the most efficient and thorough method of nematode eradication. However, this involves the use of special equipment, which is not always available. Thus, in cases where it is not practical to use steam, some other method must frequently be resorted to in an effort to reduce the nematode population. The use of formaldehyde dust for this purpose has been discussed by Tilford (13) and by Wilson (15).

The use of formaldehyde dust in nematode (*Caconema radicicola* [Greef] Cobb) control is not practical except in very restricted soil areas, such as small beds, benches, or pots. If possible, the soil to be treated should be screened to remove all large root galls and lumps of soil, since the formaldehyde cannot penetrate these sufficiently to kill any nematodes which may be present. Larger quantities of dust (at least 16 ounces per bushel of soil) must be used than when fungi only are to be killed in order to insure a thorough penetration of the soil by the formaldehyde. The dust should be carefully and thoroughly mixed with the soil. Moderate watering immediately following treatment is advisable, and then the soil should be allowed to stand for about 72 hours before plants or seeds are placed in it. The latter precaution to avoid formaldehyde injury is even more important here than in the case of applications for the control of fungi because of the larger amount of dust which has been added to the soil.

CONCLUSIONS

The organisms which cause damping-off of vegetable and flower seedlings belong principally to three genera of fungi; namely, Pythium, Rhizoctonia, and Fusarium. These fungi may attack all parts of the seedling and the seedling may become infected either before or after emergence. The conditions under which seedlings are commonly grown are favorable for the damping-off organisms. They occur almost universally in all soils and some form of treatment is usually necessary for their control.

Methods for the control of the damping-off organisms fall into two general groups—first, those which make use of high temperatures and, second, those which involve the use of lethally toxic chemical compounds. Formaldehyde, which is one of the most important of the latter group, has been used as a soil and seed disinfectant for many years. More recently formaldehyde has been used as a dust, prepared by adsorbing formalin on an inert carrier. This is then thoroughly mixed with the soil or placed in the row with the seed. The present bulletin includes a discussion of the various factors which must be considered in using formaldehyde dust as a soil disinfectant.

Mass treatment of soil at the standard rate (8 ounces of a 6% dust per bushel) has, with few exceptions, improved the stand of seedlings. Celosia, Clarkia, Gypsophila, Kochia, mignonette, Portulaca, pansy, Stevia, sweet William, and Salvia among the ornamentals and beet, cucumber, pea, spinach, and tomato among the vegetables respond especially well to treatment. Delphinium, Gaillardia, carrot, corn, endive, and parsnip are not usually benefited; whereas other plants, such as Campanula, petunia, lettuce, and turnip, are often injured by the addition of formaldehyde dust to the soil. Seeds of the latter group, together with most of the other crucifers, old seeds, and seeds which are known to be weak should not be planted until 24 hours after treatment.

It has been found that the use of 8 to 12 ounces of a 6% dust per bushel of soil (depending on the type of soil) is most efficient in controlling damping-off. A smaller amount of dust fails to give control and a larger amount involves unnecessary expense and may be injurious.

Failure to obtain good seed germination and satisfactory stands of certain vegetables in the field is often due, at least partially, to the attack of organisms causing seedling diseases. The introduction of a fungicidal material into the row with the seeds when they are planted should check some of the losses due to these diseases. Formaldehyde dust is more likely to injure germinating seeds when placed in the row than when mixed with the soil mass; for this reason its use is impractical with species especially susceptible to formaldehyde injury. Such vegetables as spinach, beet, bean, pea, cucumber, tomato, etc., are usually benefited by row treatment; whereas others, including cabbage, radish, turnip, other crucifers, and lettuce, are often injured.

If a 6% dust is used, it should not be used at a rate greater than 1 ounce to each 30 feet of seed row, since this rate insures the application of a sufficient quantity of formaldehyde for disease control and any more will be toxic to many kinds of seeds. A dust carrying 4½% of formaldehyde is usually more desirable for row treatment than a 6% dust, since it flows more freely and can be more evenly applied. If a 4½% dust is used on plants such as beet and spinach which are not particularly susceptible to formaldehyde injury, the rate of application should be increased to 1 ounce to 22½ feet of seed row. For plants rather sensitive to formaldehyde, such as the crucifers, the 4½% dust should be used at the rate of 1 ounce to 30 feet of row.

Formaldehyde injury to germinating seeds has been found to be most severe at medium soil-moisture contents. Watering thoroughly immediately after treating and planting largely eliminates this injury. Injury is most severe in coarse soils, such as sand, and least severe in those high in organic matter, such as muck.

The injury resulting from row treatment with formaldehyde dust has been found to vary with the type of soil in which the seeds are planted. In general, (disregarding variations in stand due to disease-producing organisms) the toxicity of formaldehyde decreases as the organic content and particle fineness of the soil increase.

Drenching the soil after planting with a dilute solution of formaldehyde is an effective treatment for controlling damping-off but is much more likely to injure and stunt the seedlings than the dust treatment. Drenching may also be objectionable because of the undesirable physical effect it has on certain soils.

Comparable amounts of formaldehyde are equally effective in fungicidal action, regardless of whether they are applied to the row as water dilutions or adsorbed on dust-like carriers. The liquid treatment is slightly more injurious to those species which are especially sensitive to formaldehyde; whereas the dust causes more injury than the liquid if the soil-moisture content is low at time of planting.

Due to the expense involved, it is impractical to use the mass treatment in large outdoor areas, but a combination of mass and row treatment may be used in special instances.

Glass may be placed over soil which has been treated with formaldehyde dust immediately after the seeds are planted without causing injury.

If seedlings are transplanted to soil which has been treated with formaldehyde dust, sufficient time must be allowed to elapse between treating and transplanting for the formaldehyde to escape, or injury will result. In general, this period should be about 72 hours, but it is modified to some extent by the temperature, moisture content, and type of soil used. Formaldehyde escapes more rapidly from warm, dry soils than from cold, wet ones. When transplants are placed in soil soon after it has been treated with formaldehyde dust, the injury decreases as the organic content and particle fineness of the soil increase.

It has been found that much of the injury to cuttings which results from the attack of damping-off organisms can be eliminated by treating the sand in the cutting bench at the rate of 3 ounces of a 6% formaldehyde dust per cubic foot. The sand should be thoroughly stirred at the end of the first 24 hours after treatment, and the cuttings may be set after 48 hours.

When seeds are planted or seedlings are transplanted into soils treated with formaldehyde dust, injury is more likely to occur if the formaldehyde is adsorbed on carriers of high weight per unit volume, such as muck and kaolin, than on carriers of low weight per unit volume, such as finely divided charcoal and infusorial earth. Tests have indicated that formaldehyde escapes more rapidly from carriers, such as infusorial earth and charcoal, than from kaolin and muck.

Treatment of the soil with a 6% formaldehyde dust at the rate of 8 ounces per bushel kills *Pythium debaryanum*, *Sclerotium delphinii*, *Fusarium lycopersici*, and the mycelium of *Rhizoctonia solani*. The sclerotia of Rhizoctonia are not killed.

The nematode population of a soil may be materially reduced by screening to remove large galls and then treating with formaldehyde dust at the rate of 16 ounces per bushel of soil.

LITERATURE CITED

1. Alexander, L. J., H. C. Young, and C. M. Kiger. 1931. The causes and control of damping-off of tomato seedlings. Ohio Agr. Exp. Sta. Bull. 496, 1-38.

2. Atkinson, G. F. 1895. Damping off. N. Y. (Cornell) Agr. Exp. Sta. Bull. 94, 231-272.

3. Doran, W. L. 1932. Acetic acid and pyroligneous acid in comparison with formaldehyde as soil disinfectants. Jour. Agr. Res. **44**: 571-578.

4. Hemmi, T. 1923. On the relation of temperature to the damping-off of garden-cress seedlings by *Pythium debaryanum* and *Corticium vagum*. Phytopath. **13**: 273-282.

5. Horsfall, J. G. 1930. Combatting damping-off of tomatoes by seed treatment. N. Y. (Geneva) Agr. Exp. Sta. Bull. 586, 1-22.

6. Johnson, J. 1914. The control of damping-off in plant beds. Wisc. Agr. Exp. Sta. Res. Bull. 31, 29-61.

7. May, C. 1930. Damping-off of coniferous seedlings. Ohio Agr. Exp. Sta. Ann. Rept., Bull. 446, 69-70.

8. Sayre, J. D. and R. C. Thomas. 1927. New dust treatments for oats smuts. Science n. s. **66**: 398.

9. ———— and ————. 1928. Formaldehyde and iodine dusts for the control of oat smut. Ohio Agr. Exp. Sta. Bimo. Bull. 130, 19-21.

10. Selby, A. D. 1900. Onion smut, preliminary experiments. Ohio Agr. Exp. Sta. Bull. 122, 71-84.

11. ————. 1906. Soil treatment of tobacco plant beds. Ohio Agr. Exp. Sta. Circ. 59, 1-3.

12. Tilford, P. E. 1931. Control of "damping-off" of flower seedlings. Ohio Agr. Exp. Sta. Bimo. Bull. 152, 167-175.

13. ————. 1932. Diseases of ornamental plants. Ohio Agr. Exp. Sta. Bull. 511, 1-82.

14. Wilson, J. D. 1930. Control of onion smut with formaldehyde dust. Ohio Agr. Exp. Sta. Ann. Rept., Bull. 446, 76-77.

15. ————. 1932. The use of formaldehyde dust in growing celery seedlings. Ohio Agr. Exp. Sta. Bimo. Bull. 159, 198-204.

This page intentionally blank.