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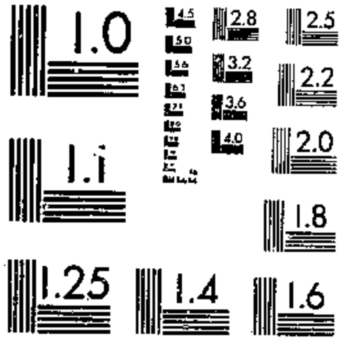

MICROCOPY RESOLUTION TEST CHART
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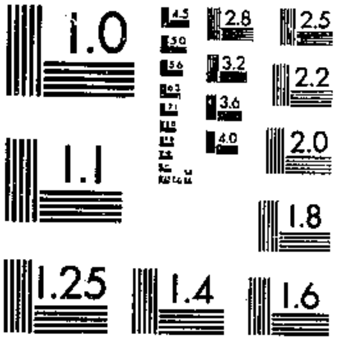

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

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Gas Treatment for the Control of Blue Mold Disease of Tobacco[1]

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INTRODUCTION

Blue mold (*Peronospora tabacina* Adam) now occurs in almost all of the tobacco-producing areas of the United States. The disease is primarily a plant-bed problem excepting in the small sections producing shade-grown cigar wrapper where it occasions some field loss.

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[4] The writers are under obligation to many of their associates for valuable suggestions and aid during the conduct of these experiments and in particular to Mr. E. G. Moss, Tobacco Station, Oxford, N. C., and to the Barrett Company, New York City, also to the Mine Safety Appliance Co., Pittsburgh, Pa., for the loan of special equipment in connection with the benzol experiments.

Most severe blue mold damage has occurred in Georgia. There 80 percent of the plants were killed in 1937, 25 in 1938, and 50 in 1939. The disease occurs regularly each year in practically all plant beds in the area from Florida to Maryland, inclusive. It is also common in Tennessee, Kentucky, Ohio, Pennsylvania, Connecticut, and Massachusetts. However, it should be noted that blue mold frequently occurs without causing serious damage, and many beds suffer a light attack, which merely delays transplanting a few days, after which the plants recover promptly and completely. On the whole it has now become quite clear that blue mold, although serious and costly, is not nearly so destructive in this country as in South Australia.

Since the crops of individual growers have a good chance to escape severe damage, even in an area such as Georgia, the natural tendency is for the grower merely to sow more beds rather than to undertake control measures that are comparatively laborious and costly. This is obviously why growers in the major producing areas have never become interested in the benzol gas treatment, despite the fact that this treatment, as reported originally by Angell et al. (*5*)[5] and confirmed by many workers since then, is both safe and highly effective.

The aggregate losses caused by blue mold, however, are large. Throughout the entire flue-cured belt the growers now plant double the plant-bed area that was considered adequate prior to the appearance of blue mold, and this alone means an increased expense of about $5,000,000. Therefore, there is a very definite need for a blue mold control measure that is simple and inexpensive enough to be generally accepted and used by the growers.

Clayton et al. (*8*) have previously reported the development and testing of the copper oxide-cottonseed oil spray mixture, and this treatment is being extensively and satisfactorily used. It is inexpensive and has an excellent physiological effect on plants that are to be transplanted. Disadvantages of this treatment are: (1) Applications must be made twice weekly, starting in advance of the disease; and (2) the treatment does not completely eliminate blue mold, it merely reduces the amount of disease to such a degree that it causes little or no damage. In contrast, gas treatment has the advantage that it need not be started until after the disease is actually present in the bed.

With these problems in mind the writers, as one phase of blue mold control investigation, have conducted an intensive study of gas treatments beginning in the fall of 1935 and continuing to date. Only one preliminary note, recording the development of paradichlorobenzene gas treatment (*3*) has been published, because there appeared little reason to present results of this study until substantial progress had been made. As the benzol method is definitely safe and effective, the progress sought was greater simplicity and cheapness.

METHODS OF STUDY

Blue mold develops readily in the greenhouse, and optimum conditions for the disease can be maintained during the period November 1 to March 1. Under suitable greenhouse conditions 80 to 100 percent of the untreated plants are regularly killed, hence greenhouse condi-

[5] Italic numbers in parentheses refer to Literature Cited, p. 37.

tions average more severe than those encountered in out-of-door plant beds. It has been possible, consequently, to obtain a vast amount of useful information from greenhouse experiments, checked of course with suitable subsequent plant-bed experiments. For greenhouse work, plants were grown in pots and thinned to uniform stands, about 44 per 6-inch pot and 14 per 4-inch pot. For out-of-door work, the writers have been fortunate in having an abundance of plant beds available, and plots have ranged in size from as little as 2 square yards to entire beds of more than 100 square yards.

The following have been used to measure the effectiveness of the various treatments: Counts of leaves showing the characteristic fungus spores and sporophores; counts of diseased leaves graded as to proportion of total area killed; counts of number of plants killed; and records of time of transplanting and number of plants set.

EXPERIMENTS WITH BENZOL

The original Australian recommendation was that a benzol evaporating surface of one seventy-second of the bed area be maintained. No account was taken directly of the amount of benzol used. In 1938 Clayton and Gaines (*7*) suggested that 1 fluid ounce of benzol be used per square yard per night (about 3 quarts per 100 square yards), with an evaporating surface of one one-hundredth of the bed area. McLean et al. (*13*) suggested that for greater safety a mixture of benzol and lubricating oil might be used in the proportion of 1 to 5. Gumaer (*10*), using wick evaporators, obtained satisfactory control with as little as 1 quart of benzol per 100 square yards. These and other results naturally raised the question as to what were the relative fungicidal and phytocidal levels with the benzol treatment.

To obtain information on this subject enclosures of glass and wood approximately 1 yard square were constructed. Benzol concentrations were regulated as follows: Air was piped from an air compressor into the top of a chamber which was provided with five outlets uniformly distributed around the bottom. The air from each outlet passed through a glass tube to a can and thence to one enclosed unit. In the bottom of each can was a benzol surface. These surfaces varied in size, and hence the uniform air streams going to the plant units took up different quantities of benzol vapor. To increase or decrease the concentration it was merely necessary to insert in the can a dish with a larger or smaller surface. Benzol concentrations within the plant units were measured with a Zeiss interferometer.

The air supply was regulated by two valves; one of these was adjusted and then left unchanged, the other was turned completely off each morning and completely on each night. Weighings showed that vaporization during successive nights was very uniform and direct measurements of benzol vapor in the plant units confirmed this. The concentration in each unit started at zero at 4:30 p. m. and mounted steadily until the units were opened at 8 a. m. Thus, the average concentration for the entire treatment period would be about one-half the maximum figure given in table 1, column 3. Referring to table 1, column 2, it may be seen that the maximum concentration measured was about one-third the amount that would have been present had all the vaporized benzol been retained in the plant case. Night temperatures were 60° to 65° F., and day temperatures rose to a maximum between 70° and 80°. Humidity records showed that saturated air conditions prevailed from about 5 p. m. to 8 a. m.

TABLE 1.—*The amount of benzol vaporized and the maximum concentrations reached in the treatment chambers*

Total benzol vaporized per night (cubic centimeters)	Calculated maximum concentration possible	Measured maximum concentration	Relation of measured (m) to calculated (c) maxima (m/c)	Total benzol vaporized per night (cubic centimeters)	Calculated maximum concentration possible	Measured maximum concentration	Relation of measured (m) to calculated (c) maxima (m/c)
	Percent	*Percent*	*Percent*		*Percent*	*Percent*	*Percent*
0.69	0.06	0.018	30.0	16.1	1.40	0.51	36.4
2.33	.20	.049	24.5	22.5	1.96	.65	33.1
3.5	.30	.097	32.3	26.5	2.30	.83	36.1
5.75	.50	.16	33.3	36.0	3.13	1.16	37.1
9.1	.79	.27	34.2				

The results from five separate experiments are combined in table 2. As the records of the untreated checks show, conditions were extremely favorable for blue mold development. Previous experiments have shown that a treatment that gives partial control under such severe disease conditions may be expected to give better, and perhaps even complete, control where conditions prevail that are less favorable to the disease. It was evident that even the lowest concentration of benzol, maximum 0.018, was strongly fungicidal, because the incubation period was increased from the 6- to 7-day interval with the untreated checks, to 12 to 13 days, and because the number of plants killed was reduced in most experiments.

TABLE 2.—*Fungicidal and phytocidal ranges of benzol-vapor concentrations*

Maximum measured concentrations (percent)	Blue mold incubation period	Plants killed by disease	Growth retardation caused by treatment
	Days	*Percent*	
Untreated checks	6 to 7	80 to 100	None.
0.018	12 to 13	50 to 100	Do.
0.049	16 to 21	0 to 20	Do.
0.097		0	Do.
0.16		0	Do.
0.27		0	Do.
0.51		0	Slight growth retardation in 2 experiments.
0.65		0	Slight retardation of growth.
0.83		0	Moderate retardation of growth.
1.16		0	Severe retardation of growth.

With a benzol maximum of 0.049 the incubation period was about three times longer than usual, 16 to 21 days as compared to 6 to 7 days, and plant mortality was reduced to a maximum of 20 percent. With a benzol maximum of 0.097 occasional yellowed areas were observed but no active disease. It was not until a maximum of 0.51 percent of benzol was reached that measurable toxic effects to the plant were observed. At this point there was a slight but distinct growth retardation. Growth retardation became pronounced with a benzol maximum of 0.83 percent and very pronounced at 1.16 percent.

Higher rates were not used in the present experiments, but Pinckard et al. (*14*) report that leaf necrosis occurs with 2 percent of benzol if the leaves are wet, and with 3 percent if the leaves are dry. In this case the concentrations were uniform for exposures of 12 to 19 hours. The same investigators report that—

Concentrations of benzol vapor in air of approximately 0.5 percent by volume or greater were lethal to sporangia of the tobacco-downy-mildew fungus. Repeated exposure of infected seedlings to less than 0.5 percent by volume of benzol inhibited sporulation.

Although this last statement would appear to be somewhat indefinite, it seems that in the present experiments fungicidal effects were obtained at very much lower benzol levels than were used by these workers. Thus, the average concentration of the writers' minimum treatment was approximately one-half of 0.018 or 0.009 for the all-night period, and even this retarded disease development. However, these differences do not appear to be of great importance since duration and frequency of exposures would have much effect on the values arrived at.

The important conclusions to be drawn from these experiments are:

(1) Benzol treatments rising to a maximum concentration of 0.1 percent gave complete disease control, and treatments eight times this strong were required before distinct plant injury occurred, and even this was only a moderate retardation of growth.

(2) There was no sharp break between effective and ineffective benzol concentrations. Even the weakest treatment used had distinct value, and under many actual plant-bed conditions would probably have given adequate disease control.

When benzol concentrations in plant beds were checked with the Mine Safety Appliance Co. instrument, readings were taken in plant beds that showed maxima of 0.5 and 0.6 percent. However, in many beds when entirely adequate disease control was being obtained, the maximum readings fell between 0.1 and 0.2 percent.

Gumaer (*10*) reports that in Connecticut blue mold developed to some extent when maximum readings did not rise above 0.03 percent; but that disease development was checked completely by 2 nights' treatment with concentrations about 0.05 percent throughout the night. This latter treatment would correspond closely with that reported in table 2 where from 0 to 0.097 percent was used, and it is interesting to note that this was the minimum completely effective concentration used in the greenhouse experiments (table 2). Wolf et al. (*18*) state that—

fungistatic action is secured when benzol-vapor concentrations in the atmosphere range from 0.025 to 0.10 percent by volume during the nightly periods of treatment. Minimal volume percentage concentrations of benzol vapor for fungicidal action within seed beds are approximated within the range 0.40 to 0.50.

To check on the amount of benzol required to control blue mold in the plant bed, many tests have been conducted each year with different rates. The results of these tests showed that ½ ounce per square yard of bed (about 1½ quarts per 100 square yards) gave distinct but not perfect control. Twice this amount, 3 quarts per 100 square yards, gave complete disease control without injury. Doubling the rate again sometimes resulted in retardation of plant growth. However, the optimum rate of benzol is dependent on other factors, such as frequency of application, type of cover, etc., and some of these factors will be discussed in the following paragraphs.

Methods for Vaporizing Benzol

In Australia open pans have been used to provide evaporating surfaces, usually one seventy-second of the bed area. In this country a variety of modifications have been tried. Thus Gumaer (*10*) described a wick system of vaporization, which very ingeniously maintained a constant rate of vaporization regardless of temperature. Other wick-type vaporizers also have been developed.

The open-pan method is cumbersome, as the pans must be filled individually and are easily overturned. The wick-evaporator system overcomes these disadvantages, but the wick evaporators are relatively expensive and growers might experience difficulty in keeping them operating properly. The writers have used various simple types of evaporators, such as tin cans with cloth wicks and open troughs filled with sawdust. In most of these tests the benzol rate was 3 quarts per 100 square yards of bed and good disease control was obtained in all tests, although benzol-vapor measurements showed that with the sawdust trough type of evaporator there was a tendency for most of the benzol to be vaporized early in the evening, whereas with the wick-type evaporators more uniform concentrations were maintained. The general conclusion was that considering simplicity and cost, the pan method of vaporization was the most satisfactory.

Distribution of Evaporators and Evaporating Areas

Many experiments have been conducted with different distances between pan evaporators. In general, it has been found that the greatest distance between pans should not be more than 8 to 10 feet, although with very tight beds this distance has been increased successfully to as much as 12 feet.

Various evaporating areas, $\frac{1}{25}$, $\frac{1}{50}$, $\frac{1}{75}$, $\frac{1}{100}$, $\frac{1}{125}$, $\frac{1}{150}$, and $\frac{1}{200}$, of the bed area have been used during the present experiments. A rate of $\frac{1}{100}$ of the bed area was selected as best, as this makes it possible to use inexpensive piepans and have a distance of not more than about 8 feet between pans. Also, 3 quarts of benzol per 100 square yards can be vaporized readily using this pan spacing, and, by means to be described later (p. 8), it is easily possible to vaporize even larger quantities of benzol without increasing the number of pans.

Type of Cloth Covers

Ordinary tobacco cloth with thread counts from 18 to 36, both single and double thicknesses, muslin having thread counts ranging from 40 to 72, and special waterproof cloth were all used as covers during these experiments. The results show that there is no sharp breaking point, but merely a gradual increase in the effectiveness of treatment as the tightness of the cover increases. With single weights of ordinary tobacco cloth and benzol at the rate of 3 quarts per 100 square yards, the disease control was slight. Even with a 36 to 40 cloth there was adequate protection for only a small area immediately around the evaporators. With thread counts between

40 and 46 the degree of control obtained approached what might be termed "commercial control," i. e., abundant infection but generally very little actual damage. With thread counts above 50 adequate control has been obtained regularly, but still each increase in the tightness of the cloth had a measurable effect; thus 68 x 72 was more effective than 64 x 64, and the latter in turn more effective than 56 x 56.

Glass sash were also used and, if tight, they held in the benzol vapors more effectively than any cloth. However, the usual glass sash are so leaky that they are not satisfactory.

The desirability of using covers that allow rain penetration has been recognized, and a 68 x 72 muslin will shed most of the rain after it is wet. However, with the development of interval treatment in place of nightly treatment this disadvantage from tight covers has been lessened. The advantage of heavy over light covers, and of wet over dry covers, has been effectively shown by Gumaer (*10*) and Wolf et al. (*18*), and the disease control results and benzol measurements of the writers' experiments support fully their conclusion; namely, that the heavier the cover the better the benzol vapor retention and also that wet covers retain the vapor far better than dry.

Bed Construction in Relation to Benzol-Vapor Treatment

Growers throughout the Southeastern States, where blue mold is a serious problem, rarely make beds that are less than 3 yards wide, and usually they are 5 to 10 yards wide. The side walls are generally constructed of logs. The writers have built beds of many types, but have found (*9*), as has been generally recognized, that benzol treatment cannot be used conveniently in wide beds, because of the difficulty in reaching the pans, and that it is not desirable to have the side walls less than 8 to 10 inches high, because of the danger of the pans being overturned by sagging cloth.

Internal Treatment with Benzol

Interval treatment in the judgment of the writers offers the only important way in which the labor and expense of the benzol gas treatment can be materially reduced. The original Australian (*5*) recommendation involved treatment each night. However, Allan et al. (*2*) recently reported that treatment on alternate nights has given satisfactory blue mold control at a number of locations over a 2-year period. In this country Kincaid and Tisdale (*11*) suggest treatment for 3 or 4 nights, and then no further treatments until the disease again becomes active. Anderson (*3*) states that when the treatment is just started it is advisable to continue for 2 or 3 nights in succession, if the mildew has been noted in the beds. If the disease is not present, every second or third night is sufficient. Wolf et al. (*18*) report that 100 cc. of benzol per square yard (about 10 quarts per 100 square yards) for 2 nights completely checked the disease and 250 cc. (about 26 quarts per 100 square yards) for 1 night was effective, and although a moist cover was used with the latter rate, no plant injury resulted.

In the present experiments benzol treatments were used for 2, 4, 6, and 7 nights per week, and at various rates. In repeated tests, using 64 x 64 covers, benzol at the rate of 3 quarts per 100 square yards twice a week greatly reduced the amount of mold, whereas 5 quarts per 100 square yards either eliminated or greatly reduced infection. Rates of treatment exceeding 5 quarts were found unsafe, as plant injury resulted in some tests. A practical problem in using the higher rates was how to vaporize the full amount, particularly during cool nights. This can be accomplished by increasing the evaporating surface ratio to one-fiftieth of the bed area, but the larger number of pans would be objectionable. A much more satisfactory solution was to use the regular one-hundredth ratio and to place in each pan a piece of muslin with a small stone tied in the center to serve as a weight (fig. 1). The muslin, functioning as a wick, made it possible to vaporize the larger amounts of benzol.

With the arrangement illustrated, it was possible to vaporize 5 quarts of benzol per 100 square yards even on cool nights. Treatment at this rate twice weekly gave excellent control of blue mold. Furthermore, this method of treatment is quite safe, as no plant injury resulted. Although a variety of other methods of benzol treatment were tried out, they proved either too expensive to install or too cumbersome to be considered practical.

Conclusions Regarding Benzol Treatments

Large-scale repeated tests have demonstrated that most growers consider any form of benzol treatment as entirely too cumbersome. Also, tank-car distribution would be required to provide benzol at moderate costs. On the other hand, material such as paradichlorobenzene is readily available, because it can be economically sold in small quantities.

It is concluded, however, that effective and safe benzol treatment can be obtained with treatments two times a week using: (1) Benzol at the rate of 5 quarts per 100 square yards of bed; (2) an evaporating-pan surface of one one-hundredth of the bed area with the aid of cloth wicks and with pans 8 to 10 feet apart; and (3) a muslin cover, 60 to 65 thread count, weighing about 4½ ounces per square yard.

Injury from Benzol Treatment

Immediate plant injury from benzol treatment can only result from extreme neglect, as the margin of safety is very great. However, toxic soil aftereffects have been observed for 2 years at the Arlington Experiment Farm, Arlington, Va. Beds that were used for gas-treatment experiments in the spring were planted to tobacco again in the late summer, and the plants in the gassed areas made only a stunted growth. However, these ill effects disappeared by the following spring, and plant growth was normal again. These toxic effects are a matter of some concern, and the question of possible cumulative toxic effects from benzol treatment when used at permanent plant-bed locations must be considered. So far the evidence is that toxic aftereffects are not usual, and even when they occur they do not persist from one season to the next.

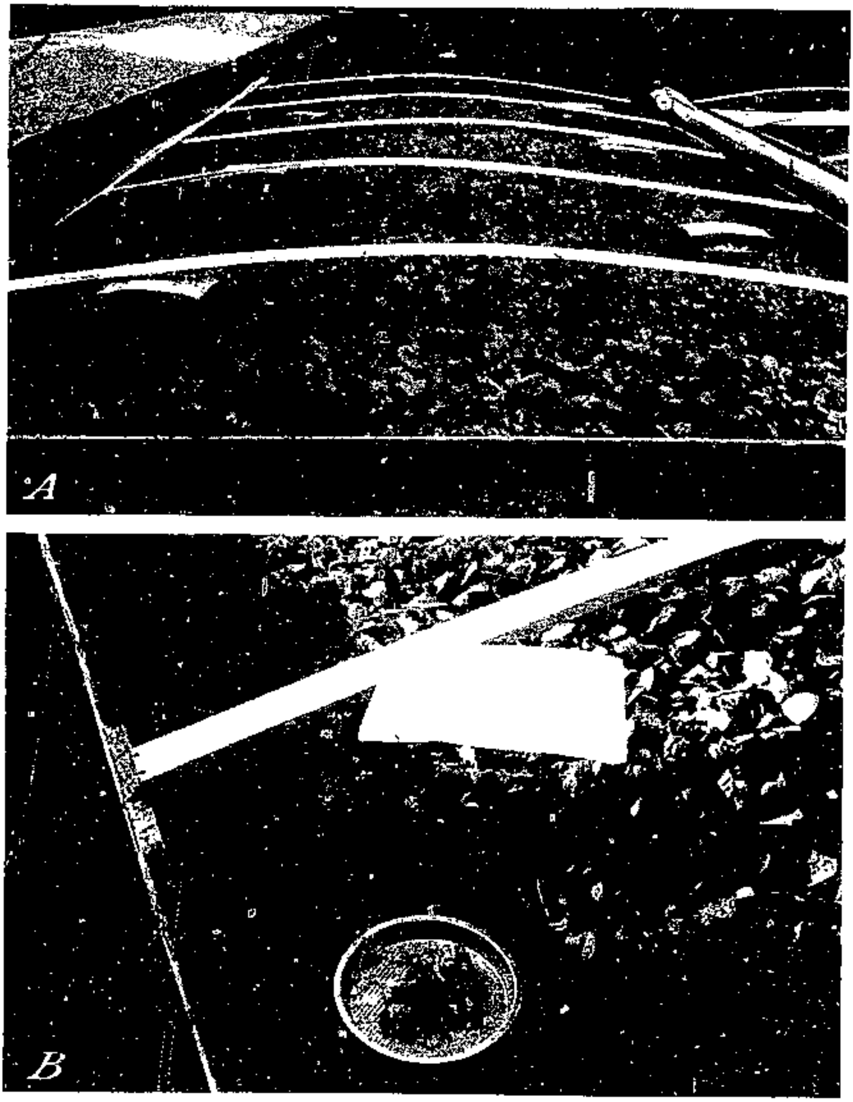

FIGURE 1.—Plant-bed treatment with benzol: *A*, The 3-yard-wide bed has slat supports for the heavy muslin cover which is rolled up on the right. *B*, Details of the pan arrangement. Note the tin cover used to keep out rain and the piece of muslin weighted with a stone. The purpose of this muslin in the pan is to increase vaporization and hence reduce the number of pans required.

BLUE MOLD CONTROL USING VAPOR TREATMENTS OTHER THAN BENZOL

XYLOL

In their original report Angell et al. (5) stated that toluol was almost as effective as benzol. Xylol was also mentioned. Later (7) they reported tests with various commercial petroleum fractions, and Allan, Hill, and Angell (*1* and *5*), reporting on tests with different vapors, concluded that "only benzol gave complete protection from the disease, and that only toluol and X3 solvent were likely to be of value as substitutes." They also state that "the degree of control obtained with hydrocarbons depends upon their content of aromatics of low boiling point. Aromatics higher in the series than toluene are not likely to be of practical value." In this country McLean et al. (*13*) reported that monochlorobenzene was both effective and safe. Beginning in the fall of 1935 the writers conducted tests with a variety of materials, searching for one that would be simpler and cheaper to use than benzol. With the discovery that paradichlorobenzene was effective for control (*6*) it appeared that this objective had been achieved, in large part at least.

In addition, however, experiments were conducted with a variety of other chemicals with a view both to finding effective vapors and to measuring their efficiency in terms of benzol, on a quantitative basis. In the Australian work, dosage was reported in terms of evaporating surface, and little definite information was given as to the amounts actually vaporized, although it was pointed out that the rate of vaporization would depend on the boiling point of the material, the surface exposed, and the temperature. The writers early became interested in xylol, because of its apparent efficiency in disease control and also because there were indications that it had a more favorable effect on the plants than did benzol.

In 1937 and 1938 at Tifton, Ga., and at Arlington Farm, Va., xylol at rates from 21 to 33 fluid ounces per 100 square yards and benzol at rates from 64 to 100 fluid ounces per 100 square yards of bed gave excellent disease control with no plant injury. A variety of muslin and glass covers were used. These results suggested that xylol, volume for volume, was almost three times as effective as benzol. A greenhouse experiment was conducted to test this, using benzol at rates of 10, 20, and 30 cc. per square yard and xylol at one-third these rates. The results are given in table 3.

TABLE 3.—*Comparative blue mold control efficiency of xylol and benzol*

Gas and treatment rate per square yard (cubic centimeters)	Leaf disease development after 30 days [1] in—									
	Plot 1		Plot 2		Plot 3		Plot 4		Total	
	Infected	Dead	Infected	Dead	Infected	Dead	Infected	Dead	Infected	Dead
Benzol:	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*
30	0	0	0	0	0	0	0	0	0	0
20		2	0	0	0	0	1	0	3	0
10	17	12	20	17	17	13	13	5	67	47
Xylol:										
10	0	0	0	0	0	0	0	0	0	0
6⅔	14	0	1	0	2	0	9	4	26	13
3⅓	18	10	19	15	18	14	20	14	75	53

[1] All check plants dead after 18 days.

These results indicate that xylol was more than two but less than three times as effective as benzol. Also it was noted here, as had been observed elsewhere, that the xylol-treated plants were a little more vigorous than those benzol-treated. Thus, on the basis of efficiency and cost, these results indicate that xylol is fully as satisfactory for mold control as benzol. However, it is understood that, although the artificial-gas industry is producing an excess of benzol, the available supply of xylol is limited. Therefore, any new large-scale use might result in increased prices.

Ethane Group

A study of the ethane group as vapor fungicides has yielded much of interest. The dichloroethane, despite the fact that it has been found to be an effective substitute for paradichlorobenzene (*16*) in peach-borer control, has shown little fungicidal value against blue mold. The beta-trichloroethane and the pentachloroethane, however, have proved distinctly fungicidal, whereas the crystaline hexachloroethane was ineffective.

Both the trichloroethane and pentachloroethane have high boiling points, and poor results have been obtained in some of the writers' plant-bed tests with these materials under cool conditions. With adequate vaporization 6 fluid ounces of pentachloroethane has given as good control as 100 fluid ounces of benzol, which makes this material the most potent of all, or about 17 times as effective as benzol, volume for volume. Pentachloroethane, however, has one serious defect. Plants treated with this vapor show no injury until they are exposed to an exceptionally bright warm day and then the leaves suffer from sudden and excessive wilting and finally burn severely. In the absence of bright sun the plants grow normally, but obviously this limits the practical possibilities of pentachloroethane. Beta-trichloroethane is not so effective fungicidally as the pentachloroethane, but plant-bed experiments indicated that it was about five times as effective as benzol, volume for volume. No trouble with excessive wilting was encountered with this gas, and also the toxic soil conditions that sometimes persist after benzol treatment were not observed after treatments.

The results of a representative greenhouse test showing the comparative effectiveness of benzol, beta-trichloroethane and pentachloroethane are given in table 4.

Table 4.—*Comparative blue mold control efficiency of benzol, beta-trichloroethane, and pentachloroethane*

Gas and treatment rate per square yard (cubic centimeters)	Leaves severely diseased in—				
	Plot 1	Plot 2	Plot 3	Plot 4	Total
	Number	*Number*	*Number*	*Number*	*Number*
Benzol:					
10	91	70	65	56	282
15	68	50	28	21	167
30	45	20	0	0	65
Beta-trichloroethane:					
2	56	91	58	51	256
3	64	48	20	15	147
6	29	29	1	1	60
Pentachloroethane:					
2	41	37	1	0	79
3	8	23	0	0	31
6	3	6	0	0	9
Checks	85	83	87	97	352

Pentachloroethane proved the most effective and satisfactory of all treatments for use in the greenhouse. At Arlington Farm, it was necessary to use three sections of a greenhouse 25 by 100 feet for other tobacco work while one section was used for blue mold investigations. The use of benzol was impractical because of fire hazard, and it was found very difficult to maintain effective concentrations of xylol. The volume of pentachloroethane required was so small, 100 to 200 cc. per 25- by 25-foot greenhouse unit, that it was possible to vaporize it in a shallow pan over an alcohol lamp. Usually adequate control was obtained by treatments two times a week.

INTERVAL TREATMENT WITH BETA-TRICHLOROETHANE.—Limited tests indicate that 2 or 3 nights' treatment with 15 to 20 cc. of beta-trichloroethane per square yard (1½ to 2 quarts per 100 square yards) will check mold development completely and is safe to use. Beta-trichloroethane has a high boiling point, and hence if pan evaporations are used, a piece of cloth must be placed in each pan to serve as a wick and facilitate evaporation. In 1938 a beta-trichloroethane dust was made, using a very absorbent carrier. This dust scattered on boards gave successful control. Therefore, it might be possible to use high-boiling-point liquids that are very potent fungicidally in the form of dusts.

OTHER GASES

In addition to xylol and the ethanes, limited tests have indicated that paraldehyde, which is a benzene compound and not an aldehyde, is effective against blue mold when used at the same rate as xylol. Many materials, such as formaldehyde, chloropicrin, napthalene, analine, and the cyclohexanes, have been tried and show little or no value.

BLUE MOLD CONTROL WITH PARADICHLOROBENZENE

Although the writers were first to obtain successful control of blue mold with paradichlorobenzene (*6*), they were not the first to conduct tests with this material. McLean, Wolf, Darkis, and Gross (*13*) reported paradichlorobenzene as one of a group of materials tested in 1937 which showed no fungicidal value, and the writers were advised by Dr. Angell[6] that paradichlorobenzene was one of the many materials used in their experiments and that it proved ineffective. However, the writers' early experience with this material indicated that it had distinct possibilities from a practical viewpoint. But it was apparent that (1) paradichlorobenzene was less safe than benzol, because the margin between concentrations effective in disease control and concentrations causing plant injury was less and (2) the vaporization problem with paradichlorobenzene presented many complications. Therefore, to provide an adequate basis for successful use of paradichlorobenzene under practical conditions it was decided that a very thorough study of the factors involved should be made.

[6] Correspondence in files of the Division of Tobacco Investigations.

With benzol the vaporization rate depends primarily on temperature and vaporization surface, and this latter remains constant throughout the night. Some of the complexities introduced by paradichlorobenzene are: The size of the crystals (evaporation surface), which changes as vaporization proceeds; the distribution of the crystals on a given surface; and the nature of the surface on which the crystals rest. In addition, the usual problems of fungicidal and phytocidal dosage, spacing of treatments, and type of cover are also present.

In presenting experimental results, some of the vaporization problems peculiar to paradichlorobenzene will be considered first, for, as will be shown later (p. 21), proper vaporization is the secret to success with this material.

Vaporization in Relation to Size of the Paradichlorobenzene Particles

Commercial concerns sell different grades of paradichlorobenzene. and the grades are based on particle size. The average particle size of grades used in the present experiments is shown in table 5.

Table 5.—*Particle size of different grades of paradichlorobenzene used in the experiments*

Commercial grade No.[1]	Average diameter	Average number of particles per 7 gm.[2] lot	Commercial grade No.[1]	Average diameter	Average number of particles per 7 gm.[2] lot
	Mm.	*Number*		*Mm.*	*Number*
1	11.93		6	1.96	489
3	4.64		9	.93	5,252
4	.86	238	11	.50	15,400

[1] Materials purchased from the Solvay Sales Corporation, New York, N. Y.
[2] About ¼ ounce.

The surface, of course, increases as particle size diminishes and theoretically the smaller the particle the more rapid the vaporization. In the following test 14-gm. lots were distributed as evenly as possible over areas 22 by 3 inches. Temperatures with different determinations ranged from 51° to 61° F. Exposures were for the period 4:30 p. m. to 8 a. m.

Table 6.—*Vaporization of paradichlorobenzene as affected by particle size*

Commercial grade No.	Average diameter of particle	Vaporization per night								
		1st	2d	3d	4th	5th	6th	7th	8th	Total
	Mm.	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*
4	2.80	3.5	2.5	4.7	3.8	3.6	4.2	2.8	4.1	29.2
6	1.96	6.2	4.1	7.9	7.2	5.2	6.5	5.8	7.9	50.8
9	.93	9.2	8.0	10.1	10.9	10.7	10.7	9.7	10.0	79.3
11	.50	8.5	7.9	11.5	11.1	11.2	11.0	9.1	11.1	81.4

The vaporization with grade No. 6 was about 74 percent greater than with No. 4, and with No. 9 about 56 percent greater than with No. 6. However, the difference between No. 9 and No. 11 is not appreciable and, furthermore, a pulverized grade (diameter of particles about 0.33 mm.) was used, and vaporization was quite uneven. The difficulty with grades such as No. 11, or finer, is that the particles tend to aggregate and hence are not easy to distribute properly. Therefore, as the result of repeated tests it is concluded that it is not practical to use smaller size particles than No. 9.

Vaporization as Affected by Surface Area over Which the Crystals Are Distributed

Vaporization of paradichlorobenzene is affected not only by the size of the crystals but also by the size of the area on which these are distributed. In the early experiments relatively light treatments, 1½ pounds per 100 square yards of bed, were used at frequent intervals. This amount was distributed on board shelves equaling about one-eighteenth of the total bed area, and good vaporization was secured. In order to determine whether, if disease conditions were severe, it might not be advisable to increase the dosage to 3 or 4 pounds, a new experiment was undertaken in which board evaporating surfaces and No. 9 crystals were used. First 1½-, 3-, and 4½-pound rates were used, all on the same size evaporating surface (one-eighteenth of the bed area). Then the same rates of application were repeated, but as the dosage increased the distribution surface was also increased as follows: First, 1/18; then, 1/9; finally, 1/6 the bed area.

The results are given in table 7 and show quite clearly that merely increasing the amount of paradichlorobenzene did not appreciably increase the amount vaporized. On the other hand, if as the rate was increased from 1½ to 3 and 4½ pounds the distribution area was increased from 1/18 the bed area to 1/9 and 1/6, the amount vaporized increased almost proportionally.

Table 7.—*Vaporization as related to the amount of paradichlorobenzene used and the size of the area over which the crystals are distributed*

Paradichlorobenzene per 100 square yards (lbs.)	Size of distribution area[1]	Vaporization											
		First night						Second night					
		Plot 1	Plot 2	Plot 3	Plot 4	Mean		Plot 1	Plot 2	Plot 3	Plot 4	Mean	
		Grams	*Grams*	*Grams*	*Grams*	*Grams*	*Percent*	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*	*Percent*
1½	1/18	5.3	4.5	5.0	5.0	4.95	70.7	6.5	6.3	6.2	6.0	6.25	89.3
3	1/18	5.5	5.8	5.6	5.6	5.63	40.2	8.3	8.3	6.8	7.1	7.63	54.5
4½	1/18	5.9	5.8	5.7	5.7	5.78	27.5	8.3	8.4	8.3	8.3	8.33	39.7
1½	1/18	4.8	5.6	4.8	5.0	5.05	72.1	6.1	7.6	7.0	7.1	6.95	99.3
3	1/9	9.2	10.4	9.8	9.7	9.78	69.9	12.2	14.0	13.0	13.3	13.13	93.8
4½	1/6	13.8	14.0	14.2	14.1	14.02	66.8	17.9	19.2	20.2	19.9	19.30	91.9

[1] Fractional part of total bed area.

Vaporization in Relation to the Nature of Distribution Surface

In addition to the area of the surface over which the paradichlorobenzene is scattered, the nature of this surface has an important bearing on the rate of vaporization. In the present experiments solid surfaces, board or metal, and open surfaces, either tobacco cloth or wire mesh, were used. For the most part, however, board rather than metal surfaces were used because of lesser cost, and cloth rather than wire, because the cloth is more readily available, costs less, and does not permit small particles of paradichlorobenzene to fall through so readily onto the plants below. Many comparisons have been made between the different materials, and table 8 gives the results of a representative test. In this experiment the treatment was 10.5 gm. per night per 1 square yard unit, and the temperature was 67° to 71° F. The cover was double 28 x 32 tobacco cloth.

As may easily be seen (table 8), the vaporization from the solid board surface was only five-ninths that from either the wire screen or the tobacco cloth, the figures for these latter two running close together.

TABLE 8.—*Vaporization in relation to type of surface on which the paradichlorobenzene is distributed*

Type of surface	Vaporization per night						Total	Mean
	1st	2d	3d	4th	5th	6th		
	Grams	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*	*Percent*
Tobacco cloth (28 x 32)	9.1	9.0	10.5	10.5	8.9	9.3	57.3	90.9
Wire screen (40 mesh)	9.0	9.0	10.5	10.5	9.3	9.5	57.8	91.7
Board	5.0	5.0	6.2	6.3	4.0	4.1	30.6	48.6

VAPORIZATION AS AFFECTED BY THE INTERACTION OF SIZE OF CRYSTALS AND TEMPERATURE

The rate of vaporization of paradichlorobenzene is dependent on temperature. Thus, Roark and Nelson (*15*) have presented data showing that if, at a temperature of 36° F., vaporization is represented by the figure 1, at 50° F. the vaporization value will be approximately 2, and at 60° F. it will rise to 4. All of these temperatures may be encountered in plant beds during the course of treatments for blue mold, hence it is apparent that, with equal amounts of paradichlorobenzene used, the rate at which it vaporizes may vary widely depending on temperature. It has already been shown (p. 13) that the rate of vaporization is affected by the grade and, hence, the size of particles and the evaporating surface. Therefore, it would appear that by varying the grade the effects of temperature changes might either be accentuated or reduced.

Table 9 gives results from a series of out-of-door plant-bed plots. These plots were each 4 square yards, and the paradichlorobenzene was scattered on 28 x 32 tobacco cloth that covered the entire bed area. Treatments were in duplicate, but, owing to time limitation, the paradichlorobenzene remaining was collected from only one plot each morning (8 a. m.). The results from nine sets of weighings are arranged on the basis of average temperature and provide a range from left to right of 43.5° to 69.8° F.

TABLE 9.—*Relation of the size of paradichlorobenzene particles and of temperature to the amount vaporized*

Commercial grade No.	Cover	Rate per 100 square yards [1]	Amount vaporized per night [2]									Range of vaporization values
			1st	2d	3d	4th	5th	6th	7th	8th	9th	
		Lbs.	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
4	Wet	2	*15.9*	*22.8*	*34.3*	*37.5*	*27.8*	49.0	55.2	46.4	48.4	15.9–55.2
	Dry	2½	*22.8*	*30.0*	*38.3*	54.6	52.0	73.5	91.1	82.8	92.7	22.8–92.7
	Dry	4	*22.1*	*27.0*	*33.9*	53.0	50.4	70.4	88.1	76.9	85.2	22.1–88.1
6	Wet	2	*15.0*	*20.8*	*42.1*	*40.9*	*35.5*	58.6	68.9	51.0	57.2	15.0–68.9
	Dry	2½	*33.8*	*35.8*	48.2	74.8	68.5	86.3	*97.5*	*94.5*	*97.0*	33.8–97.5
	Dry	4	*29.1*	*31.4*	*40.3*	69.8	64.3	83.5	*96.9*	92.6	*96.5*	29.1–96.9
9	Wet	2	*32.4*	*39.3*	59.7	75.4	69.5	89.0	90.3	73.8	76.1	32.4–90.3
	Dry	2½	62.5	70.0	79.9	*99.2*	*97.9*	*100.0*	*100.0*	*100.0*	*100.0*	62.5–100
	Dry	4	51.8	54.6	60.3	*98.0*	*94.5*	*100.0*	*100.0*	*100.0*	*100.0*	51.8–100
			°F.	*°F.*	*°F.*	*°F.*	*°F.*	*°F.*	*°F.*	*°F.*	*°F.*	*°F.*
Average temperature			43.5	47.1	54.2	55.5	55.5	64.3	66.8	68.9	69.8	43.5–69.8
Minimum temperature			39.0	43.7	53.5	54.0	47.0	60.0	64.0	63.5	65.5	39.0–65.5

[1] Paradichlorobenzene distributed over entire bed surface on 28 x 32 tobacco cloth, cover 62 x 64 muslin.
[2] Italic figures represent vaporization values either too low to be effective or too high to be safe.

Paradichlorobenzene not vaporized when the beds are opened in the morning is lost, and any treatment that allows most of the material to remain unvaporized on the cotton is obviously inefficient. On the other hand, as will be shown later (p. —), vaporization that approaches 100 percent is likely to proceed too rapidly for plant safety. Taking as the limits 45 and 93 percent, out of 81 values 40 showed either less than 45-percent or more than 93-percent vaporization. However, it is quite apparent also that if the smaller No. 9 grade was used on cool nights, when the minimum dropped to 39° and 43.7° F., for example, and the larger size, No. 6 or No. 4, was used on warmer nights, the danger of either too slow or too rapid vaporization could be reduced.

The results given in table 9 are but a small fraction of the records of this particular experiment. With respect to disease control these records show that all nine treatments gave adequate blue mold control as measured (1) by plant survival, (2) by weight of plant produced, and (3) by counts of infected leaves. The check plots were severely damaged, defoliation being general, and in many plots the stand was reduced over 75 percent. To give these data in detail, however, would involve much space, so they will be omitted with the above brief summary and attention given to the plant injury encountered. This injury was very pronounced following treatment on the warm nights with paradichlorobenzene No. 9. Vaporization figures were usually 95 to 100 percent on these nights and it seemed likely that injury was due to the too rapid vaporization early in the evening. To obtain information on this point paradichlorobenzene was applied at the rate of 2½ pounds per 100 square yards on the 28 x 32 tobacco cloth, using removable trays. The amount vaporized was determined for each third of the night, 5 p. m. to 10 p. m., 10 p. m. to 3 a. m., and 3 a. m. to 8 a. m. Vaporization values are given in table 10 for one cool night (minimum below 45° F.), two nights of medium temperature (minimum between 45° and 60°), and one warm night (minimum above 60°).

TABLE 10.—*Quantities of paradichlorobenzene vaporized during different parts of the night as related to temperature*

FIRST TREATMENT, MINIMUM 39° F.

Commercial grade No.	Vaporization period	Average temperature	Vaporization on— Plot 1	Plot 2	Plot 3	Average	
		° F.	Grams	Grams	Grams	Grams	Percent
4	5 p. m. to 10 p. m.	49.3	[1] 1.25	1.12	1.07	1.15	16.1
	10 p. m. to 3 a. m.	44.7	.58	.67	.61	.62	8.7
	3 a. m. to 8 a. m.	39.7	.67	.83	.77	.70	10.6
6	5 p. m. to 10 p. m.	49.3	1.66	1.65	1.65	1.65	23.2
	10 p. m. to 3 a. m.	44.7	.87	.72	.68	.76	10.6
	3 a. m. to 8 a. m.	39.7	1.31	1.24	1.07	1.21	16.9
9	5 p. m. to 10 p. m.	49.3	3.93	3.78	3.54	3.75	52.5
	10 p. m. to 3 a. m.	44.7	1.12	1.25	1.30	1.25	17.5
	3 a. m. to 8 a. m.	39.7	1.20	1.05	1.16	1.14	15.9
	SECOND TREATMENT, MINIMUM 49° F.						
4	5 p. m. to 10 p. m.	58.2	1.84	1.78	1.71	1.78	24.9
	10 p. m. to 3 a. m.	52.3	.89	.68	.79	.79	11.0
	3 a. m. to 8 a. m.	49.5	1.02	1.21	1.12	1.12	15.6
6	5 p. m. to 10 p. m.	58.2	2.75	2.38	2.22	2.45	34.3
	10 p. m. to 3 a. m.	52.3	1.07	1.05	1.26	1.13	15.8
	3 a. m. to 8 a. m.	49.5	1.04	.97	1.20	1.07	15.0
9	5 p. m. to 10 p. m.	58.2	5.22	5.27	5.04	5.18	72.5
	10 p. m. to 3 a. m.	52.3	1.04	1.20	1.40	1.21	17.0
	3 a. m. to 8 a. m.	49.5	.51	.49	.41	.47	6.6
	THIRD TREATMENT, MINIMUM 51° F.						
4	5 p. m. to 10 p. m.	53.1	1.53	1.29	1.43	1.42	19.8
	10 p. m. to 3 a. m.	52.6	.88	1.00	1.35	1.08	15.1
	3 a. m. to 8 a. m.	52.4	1.31	1.18	.92	1.14	15.9
6	5 p. m. to 10 p. m.	53.1	2.28	1.61	1.68	1.99	27.9
	10 p. m. to 3 a. m.	52.6	.92	1.12	1.56	1.20	16.8
	3 a. m. to 8 a. m.	52.4	1.72	1.80	1.19	1.57	22.0
9	5 p. m. to 10 p. m.	53.1	4.55	4.37	4.53	4.48	62.8
	10 p. m. to 3 a. m.	52.6	2.82	2.01	1.84	2.23	31.3
	3 a. m. to 8 a. m.	52.4	.56	.47	.60	.54	7.6
	FOURTH TREATMENT, MINIMUM 65.5° F.						
4	5 p. m. to 10 p. m.	73.6	4.12	3.59	3.63	3.78	52.9
	10 p. m. to 3 a. m.	67.4	1.34	1.58	1.84	1.59	22.2
	3 a. m. to 8 a. m.	66.8	1.12	1.31	1.03	1.15	16.2
6	5 p. m. to 10 p. m.	73.6	5.25	4.62	4.73	4.87	68.2
	10 p. m. to 3 a. m.	67.4	1.38	1.98	1.91	1.77	24.7
	3 a. m. to 8 a. m.	66.8	.43	.45	.22	.37	5.1
9	5 p. m. to 10 p. m.	73.6	7.13	7.03	6.92	7.03	98.4
	10 p. m. to 3 a. m.	67.4	.01	.11	.22	.11	1.6
	3 a. m. to 8 a. m.	66.8	0	0	0	0	0

[1] Rate of application 2½ pounds per 100 square yards.

The results in table 10 show very clearly that in all cases maximum vaporization with paradichlorobenzene occurred during the first one-third of the night. This is natural, since at this time temperatures are highest and the maximum surface is exposed. With the first treatment recorded in table 10 (minimum 39°F.) the ease with which the No. 9 crystals vaporized was clearly an advantage, and it is obvious that the use of the No. 4 was very wasteful, as about two-thirds of the amount applied remained unvaporized when the beds were opened in the morning. With the fourth treatment the situation is very different; No. 9 vaporized almost completely by 10 p. m. and caused severe plant injury (fig. 2). No. 4 gave good disease

FIGURE 2.—Influence of the size of the paradichlorobenzene crystals on the rate of vaporization: *A*, Untreated check; *B*, treated with No. 6 crystals; *C*, treated with No. 9 crystals. Both *B* and *C* were treated at the rate of 2½ pounds per 100 square yards of bed. The No. 6 crystals controlled the disease without plant injury, whereas the No. 9 caused severe burning.

control without injury. Note how closely vaporization values for No. 4 at the high temperature in the fourth treatment compare with the vaporization of No. 9 at the low temperature of the first treatment.

These results raised a question as to the disease-control effectiveness of treatment during the early and late part of the night. It has been shown that one effect of benzol vapor is to inhibit germination of spores and spores are formed during the early hours of the morning about 4 to 6 a. m. Consequently, it seemed possible that exposure of plants to paradichlorobenzene vapors during the early part of the night would be much less effective than exposure later.

To settle this question the following experiment was conducted in the greenhouse. Three lots of plants were placed in each of 14 separate enclosed units. Four units were not treated. The remaining 10 units were divided into 2 series of 5 units each. Series A received the No. 9 grade of paradichlorobenzene at the rate of 4 pounds per 100 square yards on a twice-weekly schedule and series B the same treatment with No. 6 grade.

There were 3 lots of plants in each of the 10 treated units. Treatment of lots 1 and 3 was started at 4:30 p. m. Lots 1 were removed at 12:15 a. m. and lots 2 put in their place. In this manner all lots 1 were treated for 7¾ hours during the first half of the night. Lots 2 were treated for the same period but during the second half of the night, and lots 3 were treated all night for a total of 15½ hours. The figures in the third column of table 11 show the percentage of paradichlorobenzene vaporized during the different treatment periods.

TABLE 11.—*Comparative blue mold control efficiency of half-night and all-night treatments with paradichlorobenzene*

Series, commercial grade No., and treatment period	Lot No.	Vaporization [1]	Diseased leaves [2] on— December 18, Plot 1	Dec. 18, Plot 2	Dec. 18, Plot 3	Dec. 18, Plot 4	Dec. 18, Plot 5	Dec. 18, Mean	December 21, Plot 1	Dec. 21, Plot 2	Dec. 21, Plot 3	Dec. 21, Plot 4	Dec. 21, Plot 5	Dec. 21, Mean	December 27, Plot 1	Dec. 27, Plot 2	Dec. 27, Plot 3	Dec. 27, Plot 4	Dec. 27, Plot 5	Dec. 27, Mean	Plants [3] killed, Plot 1	Plants killed, Plot 2	Plants killed, Plot 3	Plants killed, Plot 4	Plants killed, Plot 5	Plants killed, Mean
		Pct.	*No.*	*No.*	*No.*	*No.*	*No.*		*No.*	*No.*	*No.*	*No.*	*No.*		*No.*	*No.*	*No.*	*No.*	*No.*		*No.*	*No.*	*No.*	*No.*	*No.*	
Series A, using No. 9:																										
4:30 p. m. to 12:15 a. m.	1	44.28	4	3	2	5	1	3.0	24	38	19	25	12	23.6	35	74	26	45	15	39.0	15	17	17	9	10	13.6
12:15 a. m. to 8 a. m.	2	35.82	6	5	10	8	12	8.2	31	43	40	38	40	38.4	81	85	96	98	90	90.0	25	32	25	28	25	27.0
4:30 p. m. to 8 a. m.	3	80.10	0	0	1	1	1	.6	5	3	0	4	0	2.4	3	0	2	4	0	1.8	2	3	1	0	0	1.2
Untreated check			135	135					135	135					135	135					45	45				
Series B, using No. 6:																										
4:30 p. m. to 12:15 a. m.	1	39.56	23	25	10	13	7	17.4	38	34	26	10	12	25.8	69	61	55	57	69	62.2	22	16	18	16	21	18.6
12:15 a. m. to 8 a. m.	2	32.20	37	34	34	27	36	33.6	59	55	61	44	62	56.2	96	99	104	105	109	102.6	22	27	26	36	24	27.0
4:30 p. m. to 8 a. m.	3	71.76	0	0	0	1	2	.6	7	6	4	2	6	5.0	60	20	21	4	23	25.6	7	6	2	3	4	4.4
Untreated check			135	135					135	135					135	135					45	45				

[1] The mean in each case of 30 separate determinations.
[2] Total leaves exposed, 135 per plot.
[3] Total plants exposed, 45 per plot.

Although somewhat more paradichlorobenzene vaporized during the first half of the night as compared to the second half, the difference is much less than is usually found in out-of-door beds. Furthermore, it is to be noted that, whereas the lots of plants treated from 4:30 p. m. to 12:15 a. m. started with zero concentration, the lots treated from 12:15 a. m. to 8 a. m. had the carry-over of vapors from the first half of the night. The arrangement, therefore, was favorable to the 12:15 a. m. to 8 a. m. treatment.

These results bring out two points of great interest. Both half-night treatments were much inferior to the all-night treatment; and treatment from 4:30 p. m. to 12:15 a. m. gave better disease control than treatment from 12:15 a. m. to 8 a. m. It would appear that, although the organism sporulates in the early hours of the morning, this has no particular significance with respect to gas-treatment control, and that treatment over a long period is most desirable. In this latter connection it should be noted that in the previous table when the small-sized crystals, No. 9, were used at high temperature, the result was a high vaporization rate which used up the entire dose during the first third of the night. This very short treatment was quite ineffective in disease control and also was associated with severe plant injury. It is apparent, therefore, from the standpoints of effectiveness and safety that the paradichlorobenzene treatment should be so conducted as to distribute vaporization throughout the night.

Vaporization as Affected by Different Methods of Distributing the Paradichlorobenzene

In the original announcement of successful control of blue mold by paradichlorobenzene treatment (*6*), reference was made to the distribution of the crystals on board shelves attached to the sides of the beds. Later Anderson (*3*) recommended wire baskets.

In subsequent experiments the writers have tried tobacco cloth as strips stretched at intervals across the beds and as a covering for the entire bed. The latter method has been generally regarded as being probably the most practical.

To obtain more definite information on the distribution method and to take into consideration the effects of temperature and size of crystal, the following experiment was conducted. All treatments in this experiment were at the rate of 2½ pounds per 100 square yards of bed area. In table 12 the distribution method is listed in the first column, the size of the distribution area in relation to total bed area in the second, the grade of crystals in the third, and vaporization figures are shown in the remaining columns.

TABLE 12.—*Vaporization of paradichlorobenzene as affected by method of distribution, size of crystals, and temperature*

Paradichlorobenzene distribution on—	Size of distribution area[1]	Size of particles (grade)	Vaporization																				Range of vaporization values per night
			First night				Second night				Third night				Fourth night				Fifth night				
			Plot[2] 1	Plot[2] 2	Average		Plot[2] 1	Plot[2] 2	Average		Plot[2] 1	Plot[2] 2	Average		Plot[2] 1	Plot[2] 2	Average		Plot[2] 1	Plot[2] 2	Average		
			Gm.	*Gm.*	*Gm.*	*Pct.*	*Gm.*	*Gm.*	*Gm.*	*Pct.*	*Gm.*	*Gm.*	*Gm.*	*Pct.*	*Gm.*	*Gm.*	*Gm.*	*Pct.*	*Gm.*	*Gm.*	*Gm.*	*Pct.*	*Pct.*
Tobacco cloth (entire cover)	1/1	No. 4	2.40	2.50	2.45	34.3	2.78	2.36	2.57	36.0	4.08	3.76	3.92	54.9	5.14	5.01	5.08	71.1	6.47	6.50	6.49	90.9	34.3–90.9
Tobacco cloth (strips)	1/6	No. 4	1.95	2.02	1.99	27.9	2.04	2.13	2.07	29.0	3.14	3.42	3.28	45.9	4.23	4.11	4.17	58.4	6.18	6.03	6.11	85.6	27.9–85.6
Board shelves	1/18	No. 4	1.20	1.24	1.22	17.1	1.28	1.25	1.27	17.8	1.44	2.03	1.74	24.4	2.22	2.52	2.37	33.2	4.64	5.15	4.90	68.6	17.1–68.6
Wire baskets	1/122	No. 4	.55	.64	.60	8.4	.82	.76	.79	11.1	.94	1.04	.99	13.9	1.23	1.36	1.30	18.2	3.39	3.28	3.34	50.6	8.4–50.6
Tobacco cloth (entire cover)	1/1	No. 6	3.38	3.66	3.52	49.3	4.55	4.18	4.37	61.2	5.53	5.92	5.73	80.3	6.54	6.54	6.54	91.6	7.08	7.06	7.07	99.0	49.3–99.0
Tobacco cloth (strips)	1/6	No. 6	2.58	2.81	2.70	37.8	2.80	3.43	3.12	43.7	4.44	4.90	4.67	65.4	5.05	5.54	5.29	74.2	6.74	6.68	5.71	94.0	37.8–94.0
Board shelves	1/18	No. 6	1.06	1.40	1.23	17.2	1.46	1.43	1.45	20.2	2.09	2.28	2.19	30.7	2.50	2.80	2.65	37.1	5.28	5.70	5.49	76.9	17.2–76.9
Wire baskets	1/122	No. 6	.64	.80	.72	10.1	1.09	1.09	1.09	15.3	1.59	1.55	1.57	22.0	1.64	1.48	1.56	21.8	3.22	3.20	3.21	45.0	10.1–45.0
Tobacco cloth (entire cover)	1/1	No. 9	6.30	6.60	6.45	90.3	6.78	6.38	6.58	92.2	7.12	7.13	7.13	99.8	7.12	7.14	7.13	99.9	7.14	7.14	7.14	100.0	90.3–100.0
Tobacco cloth (strips)	1/6	No. 9	3.58	3.36	3.47	48.6	4.84	4.63	4.74	66.4	6.43	6.30	6.37	89.2	6.91	6.62	6.77	94.8	7.07	7.10	7.09	99.3	48.6–99.3
Board shelves	1/18	No. 9	1.48	1.49	1.49	20.8	1.94	1.75	1.85	25.9	2.38	2.83	2.61	36.6	3.23	3.44	3.34	46.8	6.23	6.26	6.25	87.5	20.8–87.5
						°F.				*°F.*				*°F.*				*°F.*				*°F.*	*°F.*
Average night temperature						38.5				47.1				55.5				59.5				68.9	38.5–68.9
Minimum night temperature						34.5				43.0				54.0				56.0				63.5	34.5–63.5

[1] Fractional part of total bed area.
[2] 7.14 gm. per plot applied.

The values obtained with grade No. 6 (table 12) indicate that at the lowest temperature 49.3 percent of the crystals actually vaporized for tobacco cloth (entire cover) and 10.1 percent for wire baskets. This means that with 2½ pounds applied the actual treatment dosage was in the one instance 1.2 pounds and in the other 0.25 pound, or that the two treatments were in no respect comparable.

On the basis of the previous estimates (p. 16) that vaporization rates below 45 percent are ineffective and above 93 percent are likely to cause plant injury, it is apparent that many of the treatments listed in table 12 were either ineffective or dangerous. In 26 of a total of 55 treatments there recorded less than 45 percent of the paradichlorobenzene was vaporized; in 7, more than 93 percent was vaporized; and in only 22 did vaporization values fall between 45 and 93 percent. Again it is apparent that at low temperatures, minimum below 45° F., No. 9 distributed over the entire tobacco cloth was most effective. Other effective treatments at low temperatures were No. 6 over the entire tobacco cloth and No. 9 on cloth strips.

At medium temperatures, minimum 45° to 60° F., Nos. 6 and 4 on tobacco cloth or cloth strips, and No. 9 on boards all gave favorable vaporizations. At high temperatures, minimum 61° and above, Nos. 6 and 4 on cloth strips or boards or wire baskets, No. 4 on tobacco cloth, and No. 9 on boards all gave favorable vaporization.

One fact deserves special mention, and that is the safety of treatment using either boards or wire baskets. Table 12 shows with these methods a maximum vaporization with No. 9 of 87.5 percent at the high temperatures, which is still well within the safety margin. Injury has been rarely encountered in numerous tests where these methods of vaporization were used. They are, however, quite ineffective at low temperatures, and very wasteful unless, as Anderson has suggested (*3*), the baskets can be removed in the morning and replaced in the evening. The use of the tobacco cloth either covering the entire bed or as strips, therefore, is definitely more effective and simpler, but also less safe.

Height of Vaporizing Surface on the Plant Bed

As a matter of precaution, during the course of the present experiments with different types of surfaces on which the paradichlorobenzene was distributed, the effect of height of the vaporization surface in the bed was tested. Side boards when used were located near the soil surface, just under the muslin, and halfway between. These differences had no effect. However, when the crystals are scattered over a cloth covering the entire bed surface the situation is different. In the spring of 1939 experiments were conducted in which the tobacco cloth was stretched just under the muslin about 13 inches above the soil; down 3 to 4 inches from the muslin, and down 6 to 8 inches, just touching tips of the plants (table 13).

TABLE 13.—*The effect of height in plant bed of tobacco cloth on which paradichlorobenzene is distributed on the mold control and plant injury by treatment*

Rate of treatment per 100 square yards of dry or wet muslin (pounds)	Location of tobacco cloth	Diseased leaves: Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Plot 6	Total	Mean	Plant injury[1]: Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Plot 6	Mean
		No.	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*
2¼ pounds and dry muslin.	Immediately under muslin.	7	14	12	6	0	4	43	7.2	1	1	1	1	1	1	1
	Down 3 to 4 inches.	5	7	14	18	4	1	49	8.2	1.5	1.5	1	1.5	1	1	1.25
	Down 6 to 8 inches.	6	26	31	29	0	2	94	15.7	1.5	2	2	1.5	1.5	1.5	1.67
3 pounds and dry muslin.	Immediately under muslin.	10	7	22	0	0	0	39	6.5	1	1	1	1	1	1	1
	Down 3 to 4 inches.	0	0	2	0	0	0	2	.3	2.1	2.1	2.1	3	3	2.3	2.43
	Down 6 to 8 inches.	6	16	25	8	0	0	57	9.5	2.3	2.3	2.3	3.3	2.8	2.5	2.6
4 pounds and dry muslin.	Immediately under muslin.	3	3	9	0	0	0	15	2.5	1	1	1	1	1	1	1
	Down 3 to 4 inches.	0	0	1	0	0	0	1	.2	2.5	3	2.9	4	4.5	4.5	3.57
	Down 6 to 8 inches.	2	6	10	11	0	0	29	4.8	3	3.5	3.7	4	4	3.8	3.67
2¼ pounds and wet muslin.	Immediately under muslin.	0	0	0	0	0	0	0	0	2.2	2.7	2.7	1.5	1.5	1.5	2.02
	Down 3 to 4 inches.	0	0	0	0	0	0	0	0	4.5	5	5	5	5	4.5	4.83
	Down 6 to 8 inches.	0	0	0	0	0	0	0	0	4.5	5	5	4.9	4.9	4.4	4.78
Check		62	72	70	131	47	87	460	78.2							
Check		71	61	84	126	46	86	474	79.0							

[1] Injury ratings—1=no injury; 2=slight injury; 3=moderate injury; 4=severe injury; 5=very severe injury.

The results in table 13 are of distinct practical interest. In this experiment it was possible to use paradichlorobenzene at the rates of 2¼, 3, and 4 pounds per 100 square yards provided the tobacco cloth holding the crystals was stretched immediately below the muslin. If, however, the cloth was dropped down 3 to 4 inches or 6 to 8 inches below the muslin, the lowest rate of 2¼ pounds was still safe, but 3- and 4-pound rates were progressively more injurious.

Temperature conditions during this experiment were moderate to high (night minimum in the range 50° to 65° F.), and the severe injury with the 2¼-pound rate and wet muslin occurred particularly on warm nights. Here again the increased safety from locating the tobacco cloth high is apparent. Surprisingly it did not make much difference in the amount of injury whether the tobacco cloth was dropped down only 3 to 4 inches or 6 to 8 inches. As to disease control, the 2¼-pound rate under dry muslin allowed considerable disease development, though defoliation was insignificant as compared with the checks. At 3- and 4-pound rates most effective disease control was obtained with the paradichlorobenzene scattered on tobacco cloth located 3 to 4 inches below the muslin. On the whole, however, the height of the tobacco cloth did not have a great deal to do with the fungicidal effectiveness of the treatments. It is not meant to imply that the treatments tested in table 13 have frequently caused as much injury as was encountered in this experiment because, with lower temperatures, injury has never been such an important factor.

The height of the surface on which the paradichlorobenzene crystals are distributed is an important phytocidal factor when tobacco cloth covering the entire bed is used. When boards or baskets are used to hold the crystals, they car be placed immediately above the plants or just below the muslin without any effect on injury. It seems apparent that when the crystals are distributed on the tobacco cloth close to the plants the quick build-up of toxic concentrations immediately around the plants is favored. Figure 3 illustrates the bad effect of having the tobacco cloth too close to the plants.

FIGURE 3.—Paradichlorobenzene treatment in relation to the height of the surface on which the crystals are distributed: *A*, Plants treated with the crystals scattered on tobacco cloth 12 to 13 inches above the ground; *B* and *C*, plants treated with the cloth 9 to 10 inches and 5 to 7 inches above the ground, respectively. All treatments were at the rate of 4 pounds per 100 square yards of bed. Note that injury resulted when the crystals were close to the plants, *B* and *C*, but not when they were well above the plants, *A*.

Retention of Paradichlorobenzene Vapors in Beds by Various Types of Covers

In addition to factors that determine the amount of paradichlorobenzene vaporized, treatment effect is determined to a considerable degree by the type of cover used to enclose the bed. The previous discussion has been concerned primarily with factors that influence the rate of vaporization. The ability of different types of bed covers to retain the vapors can also be measured in terms of disease control and plant injury (table 14).

TABLE 14.—*Blue mold control and plant injury in relation to the amount of paradichlorobenzene used and the type of cover*

Cover	Paradichlorobenzene rate per 100 square yards	Size of distribution area [1]	Average vaporization	Disease injury: Infected leaves [2]: Plot 1	Disease injury: Infected leaves [2]: Plot 2	Disease injury: Plants killed [3]: Plot 1	Disease injury: Plants killed [3]: Plot 2	Treatment injury: Stunting of plants	Treatment injury: Burning of leaves	Treatment injury: Plants killed
	Pounds		*Percent*	*Number*	*Number*	*Number*	*Number*	*Degree*	*Degree*	*Percent*
Thin muslin, 36 x 40.	1½	1/18	75.1	141	142	27	53	None	None	0
	3	1/9	70.0	13	34	0	0	do	do	0
	4½	1/6	66.7	0	0	0	0	do	do	0
Thick muslin, 62 x 64.	1½	1/18	52.8	27	43	0	0	do	do	0
	3	1/9	52.1	0	0	0	0	do	do	0
	4½	1/6	50.4	0	0	0	0	Slight	do	0
Glass	¾	1/18	48.0	0	0	0	0	None	do	0
	1½	1/18	44.3	0	0	0	0	Moderate	do	0
	3	1/9	35.7	0	0	0	0	Severe	Severe	70
	4½	1/6	26.7							100
Check				240	240	76	80			
Do				240	240	80	80			

[1] Fractional part of total bed area.
[2] Total leaves exposed 240 per plot.
[3] Total plants exposed 80 per plot.

In this experiment three types of bed covers were used—thin muslin 36 x 40, tight muslin 62 x 64, and glass. It will be noted (table 14, column 4) that much more of the paradichlorobenzene vaporized under the thin muslin than under the 62 x 64 cloth and more under the 62 x 64 cloth than under glass. This is a general and consistent effect, namely, that the tighter the cover the lower the percentage of vaporization. However, considering the amount of paradichlorobenzene vaporized as related to the disease-control and plant-injury records, it will be observed that none of the treatments under 36 x 40 muslin caused injury and that only when paradichlorobenzene was applied at the rate of 4½ pounds per 100 square yards, with 3 pounds actually vaporized, was the disease control complete. Under 62 x 64 cloth, half this amount, vaporization at the rate of 1½ pounds per 100 square yards gave complete control; and under glass, vaporization at the rate of 1/5 pound per 100 square yards did the same. Under glass, vaporization at the rate of 1.2 pounds per 100 square yards killed every plant. Obviously there would be little point to considering effective dosage without considering type of cover (fig. 4), since in this experiment the effective dosage in terms of paradichlorobenzene actually vaporized ranged from 1/5 to 3 pounds per 100 square yards of bed.

In both 1938 and 1939 numerous experiments were conducted in out-of-door plant beds using (1) grades of tobacco cloth ranging from 24 x 26 to 32 x 36 and weighing from 1 to 1.5 ounces per square yard; (2) muslins ranging from 36 x 40 to 68 x 72 and weighing from 3.25 to 5 ounces per square yard; (3) light canvas; and (4) glass sash. The results from these tests need not be presented in detail but may be summarized briefly as follows: Tobacco cloths, either single or double, in out-of-door beds do not hold the paradichlorobenzene vapors sufficiently well to give adequate, or even measureable, disease control in most instances, although in occasional well-

FIGURE 4.—Paradichlorobenzene treatment in relation to type of cover: *A*, Glass cover; vapor concentration was so excessive as to retard growth. *B*, Heavy muslin (62 x 64) cover; disease controlled without plant injury. *C*, Thin muslin (36 x 40) cover; vapor retention inadequate to give complete disease control. All plants, except untreated check *D*, were treated at the rate of 2 pounds per 100 square yards of bed.

sheltered outside locations control was obtained. Light muslins with thread count around 40 to 46, averaging 3.2 to 3.5 ounces per square yard, often give fair control, but they are not to be recommended for most effective treatment. A muslin 62 x 64, averaging 4.5 ounces per square yard, has been used extensively in these experiments and is not considered too heavy. If the muslin is to be moved and used on several beds, it is subjected to severe strains and must be strong. Muslins 56 x 60 and 50 x 56, averaging 4 ounces per square yard, have given satisfactory results, though not quite equal to those from the 62 x 64 muslin. The 68 x 70 muslin, running 5 ounces per square yard to the pound, was superior in gas retention to the lighter weights but was so tight as to be practically impervious to water as soon as it became wet; consequently, the 62 x 64 was preferred. Light canvas was too heavy and stiff. Glass sash have been reported to give poor results, but doubtless because they were old and leaky. The glass sash used by the writers were new and tight and gave excellent results. However, their very complete retention of the gas made it easy for plant injury to occur, if, for example, the sash were closed a little early on a warm evening. The cost, plus the danger of injury, makes sash impractical in most areas.

Continuous Day and Night Treatments

In the early days of the benzol treatment in Australia the beds were apparently closed most of the time, and it was not until later that the practice was adopted of opening the beds during the day and vaporizing the gas only at night. Since paradichlorobenzene has been under consideration, several continuous treatments have been recommended. One by McGee (*12*) advocated 3 to 5 pounds per 100 square yards of bed and 1 to 3 treatments a week. This treatment was to be carried out under ordinary cotton plant-bed covers, either single or double. Although it had been established that with the usual nightly treatment satisfactory control could not be obtained in out-of-door beds under double cotton, the possibility that, by using large quantities of paradichlorobenzene and continuous vaporization, adequate disease control might be attained still remained to be investigated.

The question of vaporization during day and night periods is first considered. Paradichlorobenzene No. 1, largest size crystals, and No. 6 were used in preliminary experiments at the rate of 6 pounds per 100 square yards. It was found that with the No. 1 vaporization was too slow. With the No. 6 the vaporization of the 28-gm. dose in the closed units required 72 hours. If the bed was kept constantly closed, about 53 percent of the vaporization occurred during the period from 8 a. m. to 4:30 p. m. and 47 percent during the remaining 16 hours. If, however, the bed remained open during the day, practically all the paradichlorobenzene was lost during the daytime period. Therefore, since it was established that a one-dose treatment could be carried out and that about half the paradichlorobenzene would be vaporized in the closed bed during the daytime, 8 a. m. to 4 p. m. period, it became of interest to know what would be the disease-control value of this daytime treatment. Several experiments were conducted to settle this question, and the data given in table 15 are from a representative test.

TABLE 15.—*Comparative blue mold control efficiency of day and night treatments with paradichlorobenzene*

Paradichlorobenzene per 100 square yards (lbs.)	Treatment period	Diseased leaves					Plants killed				
		Series A [1]		Series B [2]		Mean	Series A [1]		Series B [2]		Mean
		Plot 1	Plot 2	Plot 1	Plot 2		Plot 1	Plot 2	Plot 1	Plot 2	
		No.	*No.*	*No.*	*No.*		*No.*	*No.*	*No.*	*No.*	
1½	4:30 p. m. to 8 a. m., 15½-hour night	0	0	20	0	5	0	0	2	0	0.5
1½	8 a. m. to 4:30 p. m., 8½-hour day	34	36	266	24	90.5	0	0	40	8	12.0
3	24 hours, day and night	6	3	41	4	13.5	0	0	22	0	5.5
Check		238	240	280	249	251.5	68	72	75	54	67.3

[1] Total plants per plot exposed 80; total leaves 240.
[2] Total plants per plot exposed 100; total leaves 300.

A study of the disease counts in table 15 shows that blue mold control was perfect in all but one of the four plots receiving the regular nightly treatments. The same treatments during the daytime gave very poor control, and the combination of day and night treatment failed to give as good control as night treatment. In general these and other similar results have failed to indicate any real value from daytime treatment.

Continuing the study of treatments involving vaporization of paradichlorobenzene continuously during the day and night, using coverings of double tobacco cloth, several experiments were conducted in the greenhouse in which various weights of crystals were placed in the units and the covers allowed to remain in place for 4 days and 5 nights. In each instance plants were inoculated in advance of treatment and in some cases the treatment for 4 days and 5 nights was repeated. Extensive data were taken, but only the conclusions will be presented. Paradichlorobenzene at the rate of 12 pounds per 100 square yards in the treatment continued for 4 days and 5 nights gave control; lesser amounts were inadequate. However, the prolonged shading made the plants very succulent and, when they were exposed to infection after the treatment was concluded, all were destroyed.

The possibilities of continuous treatment under double tobacco cloth were further investigated in out-of-door plant beds at Arlington Farm in 1938 and at Tifton, Ga., in 1939. In a few of these tests some degree of control was obtained, but in the majority of the experiments even large applications—for example, 12 pounds per 100 square yards twice a week—gave no control whatsoever. Whereas in the greenhouse it was possible to obtain control by this method, in the plant bed it usually failed completely. The reason for this difference appears to be that in well-protected locations the double tobacco cloth retains the vapors fairly well, but in the usual bed, exposure to air currents makes for very poor vapor retention. Certainly there appeared no reason to give further consideration to treatments using double tobacco cloth.

The writers have not conducted extensive tests with the night and day treatment using the heavy muslin covers, as recommended by Tisdale and Kincaid (*17*), for the reason that in several experiments muslin covers were left in place on cloudy, cool days and severe plant injury occurred. In each instance the sun came out for just a short time, but even this short interval was sufficient to produce damage, particularly under wet covers. It is believed that the margin of safety is too narrow with the paradichlorobenzene to justify the hazard of such daytime treatments.

Interval Treatment

In early experiments it was established that if paradichlorobenzene was used at the rate of 7 gm. per square yard (about 1½ pounds per 100 square yards), treatments two or three times a week did not give as good disease control as treatments five to seven times a week. However, if the rate was increased, intermittent treatments gave effective disease control (fig. 5). In the following experiment, paradichlorobenzene was used (1) nightly at the rate of 6 gm. per square yard; (2) every third night at the rate of 18 gm.; (3) every fourth night at the rate of 24 gm. under a dry cover; and (4) every third night at the rate of 9 gm. under a wet cover. A 62 x 64 muslin was employed in the tests. The 6-gm. nightly rate was a little less than the amount required for most effective control. The leaf-count means in table 16 are in each case the average for four plots. The differences in disease development in the different series are accounted for by the varied inoculation procedures. Series A was inoculated 80 hours prior to first treatment; Series B was inoculated 8 hours before treatment; and Series C was not inoculated but merely exposed to natural infection.

FIGURE 5.—Results of varying the interval between treatments with paradichlorobenzene: *A*, Treatments twice weekly; *B*, treatments once weekly; *C*, untreated check. All treatments made at the rate of 4 pounds per 100 square yards under dry 62 x 64 muslin. During periods when the disease is active, treatments at least twice weekly are required to give adequate control.

TABLE 16.—*Blue mold control efficiency of nightly treatments with paradichlorobenzene as compared with treatments each third and each fourth night using wet and dry muslin covers*

Treatment frequency	Cover	Rate per square yard	Vaporized	Diseased leaves: Series A	Diseased leaves: Series B	Diseased leaves: Series C	Injury from treatment
		Ounces	*Ounces*	*Number*	*Number*	*Number*	
Each night	Dry	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	None.
Each third night	do	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Do.
Each fourth night	do	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Slight.
Each third night	Wet	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Moderate injury.
Check				[illegible]	[illegible]	[illegible]	

These data bring out some interesting points. The treatment each third night was three times as strong as the treatment each night, and the figures show that disease control was superior. Treatment four times as strong, every fourth night, gave good disease control, but there was slight plant injury. With wet covers, the amount of paradichlorobenzene could be reduced one-half without sacrifice of disease control but with a distinct increase in plant injury.

Treatment at intervals gave good results provided the dosage was adequately increased. The next question considered was how widely apart could treatments be spaced. Repeated experiments, the details of which need not be given, showed that a single treatment was not sufficient effectively to check blue mold if conditions were favorable for the disease. In further experiments the value of 2- and 3-night treatments and the value of alternate versus consecutive night treatments was considered. Paradichlorobenzene was used at the rate of 4 pounds per 100 square yards with dry cover and half this rate with wet cover (table 17).

TABLE 17.—*Blue mold control efficiency of treatments with paradichlorobenzene at different intervals using wet and dry muslin covers*

Number and frequency of treatments	Cover	Diseased leaves												Plants killed			
		April 3[1]				April 6				April 12				April 21			
		Plot 1	Plot 2	Plot 3	Mean	Plot 1	Plot 2	Plot 3	Mean	Plot 1	Plot 2	Plot 3	Mean	Plot 1	Plot 2	Plot 3	Mean
		No.	*No.*	*No.*		*No.*	*No*	*No.*		*No.*	*No.*	*No.*		*No.*	*No.*	*No.*	
2 on consecutive nights.	Wet	0	0	4	1.3	35	42	26	34.3	130	127	124	127	27	24	21	24
2 on alternate nights	do	0	0	0	0	25	19	35	29.3	129	115	129	124.3	30	24	19	24.3
3 on consecutive nights.	do	0	0	0	0	1	9	7	5.7	117	104	116	112.3	29	23	24	25.3
2 on consecutive nights.	Dry	7	4	6	5.7	43	48	38	43.3	127	121	127	125	23	21	19	21.0
2 on alternate nights	do	3	2	4	3.0	15	21	19	18.3	118	121	121	120	29	23	23	25.0
Check		144	147	145	145.3	150	150	150	150	150	150	150	150	37	38	35	36.7

[1] 8 days after the first treatment.

The data in table 17 show that 8 days (April 3) after treatment all treatments had given successful disease control as indicated by comparison with the checks. The counts 3 days later show that the 3-night treatment had extra disease-control value as compared with the 2-night treatment, and the figures also indicate that two treatments on alternate nights were slightly more effective than the same number on consecutive nights. This series was not treated further, and, as conditions for disease development continued favorable, blue mold was active in all the treated plots. However, the leaf counts on April 12 are given, as well as the mortality records on April 21, to bring out a point frequently observed, namely, that even a limited amount of gas treatment, which temporarily checks the disease, has some permanent disease-control value. Note that the final counts both on leaf infection and on plant kill are lower in the treated than in the untreated check plots.

Finally, it seemed possible that if the disease was checked by two effective treatments the first week it might be possible to control it by less frequent treatments during the following weeks. Disease conditions were exceptionally severe throughout the following experiment and, hence, provided a very critical test. In each series two treatments were given on alternate nights, after which the schedule was as indicated in the first column of table 18.

TABLE 18.—*Blue mold control efficiency of treatments with paradichlorobenzene at more widely spaced intervals*

Frequency of treatment [1]	Diseased leaves [2]												Plants killed [3]			
	April 6				April 10				April 16				April 28			
	Plot 1	Plot 2	Plot 3	Mean	Plot 1	Plot 2	Plot 3	Mean	Plot 1	Plot 2	Plot 3	Mean	Plot 1	Plot 2	Plot 3	Mean
	No.	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*
Each second night	0	0	0	0.0	29	31	39	33.0	50	63	57	56.7	0	0	0	0.0
Each third night	0	0	0	.0	59	82	69	70.0	172	206	205	194.3	10	11	13	11.3
Each fourth night	0	0	0	.0	102	130	142	124.7	234	256	240	243.3	12	14	19	15.0
Each fifth night	0	0	0	.0	113	117	128	127.3	244	243	231	239.3	25	19	24	22.7
Each sixth night	15	21	13	16.3	275	272	254	267.0	301	270	239	270.0	25	29	30	28.0
Check	231	314	332	292.3	329	319	335	327.7	341	325	326	330.7	93	84	90	89.0

[1] All treatments at rate of 1½ pounds per 100 square yards under wet 62 x 64 muslin.
[2] Total leaves exposed, 350 per plot.
[3] Total plants exposed, 140 per plot.

Table 18 shows that under the very severe conditions of this experiment even alternate-night treatment did not eliminate the disease, although most of the infected leaves were only slightly to moderately damaged and no plants were killed. The results also show that under very severe conditions, such as obtained in this experiment, even treatment only every fifth or sixth night may distinctly reduce disease damage, as indicated particularly by the reduction in the number of plants killed from 89 to 15 and 22.7 per plot.

DISCUSSION

TYPE OF GAS

It has been found that the benzol gas treatment, developed in Australia, is very effective against blue mold. The margin of safety—that is, the difference between fungicidal and phytocidal vapor concentrations—is extremely wide. Furthermore, if benzol is used at the rate of 5 quarts per 100 square yards of bed area, two to three treatments a week will give excellent disease control. This amount of benzol can be readily vaporized with the aid of home-made cloth wicks (fig. 1, *B*). However, numerous large-scale tests made by growers have shown that for the most part they regard the treatment as too cumbersome and laborious. It is certainly true that, with the wide beds (3 yards or more) most growers prefer, it is difficult to fill the pans and to prevent them from being overturned once they are filled. Despite its effectiveness and safety, the benzol-gas treatment cannot be considered as a practical solution of the blue mold problem for the average grower.

Xylol, beta-trichloroethane, and pentachloroethane are very effective gas-treatment materials, and the latter has proved especially suitable for use in the greenhouse during the winter. These materials, however, are all liquids, and for practical use present the same problems as benzol.

Paradichlorobenzene is a solid and consequently can be marketed inexpensively in small amounts and is easily distributed in plant beds.

It is more liable to cause plant injury than benzol. However, because of its convenience, growers have shown much interest in this type of gas treatment. The experiments here reported indicate that an understanding of certain fundamentals will do much to insure success with paradichlorobenzene. One of the first problems in using paradichlorobenzene is how to distribute it in the bed most effectively. In the first plant-bed experiments at the Coastal Plain Experiment Station, Tifton, Ga., in 1938, the crystals were scattered on boards placed in the bed. The next tests were conducted at the Pee Dee Experiment Station, Florence, S. C., and the boards were attached to the sides of the beds as shelves. Meanwhile other experiments had shown (table 8) that vaporization was much more rapid if the

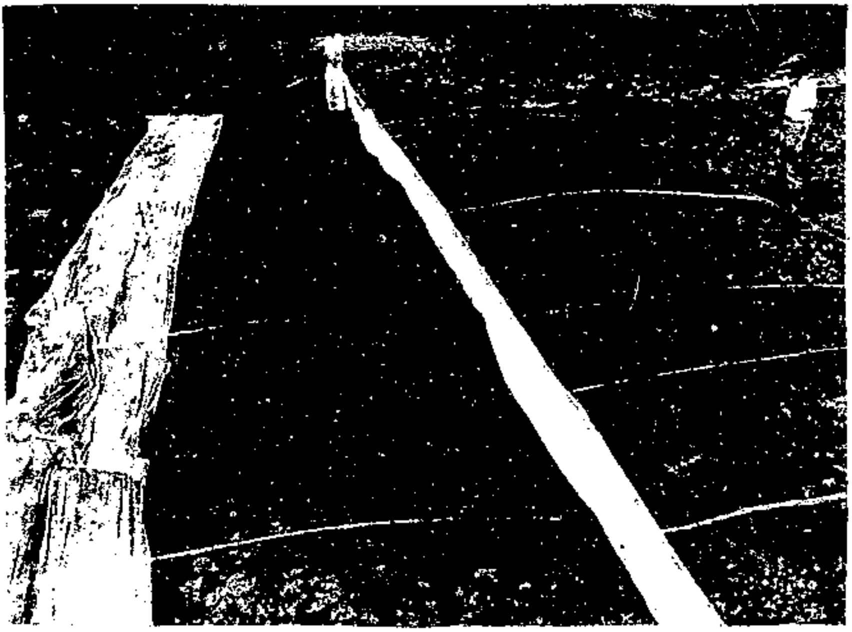

FIGURE 6.—Bed arranged for gas treatment with paradichlorobenzene. The bed is divided into two sections each 4 by 20 yards. The pole cross supports are 2 yards apart and the wire running lengthwise to each section is 15 inches above the ground. The top of the side-wall logs is about 7 inches from the ground surface. Note the tobacco cloth on the left on which the paradichlorobenzene is scattered, and the muslin in the center so it can be used to treat either bed section. A partition down the center is concealed by the muslin.

crystals were scattered over a porous surface, and so it seemed logical to make use of the tobacco cloth already present in the bed (fig. 6). In Connecticut where the growers use sash and have no tobacco cloth, the use of wire baskets attached to the sides of the beds was suggested. Table 12, however, indicates that with cool nights the paradichlorobenzene in such wire baskets vaporized only about one-fourth as rapidly as the same amount of paradichlorobenzene scattered over the tobacco cloth. This method, consequently, is at a great disadvantage in cool weather, but the authors found it very effective and safe when the night temperatures are 55° F. and above. As a substitute for the tobacco cloth covering the entire bed, strips of either tobacco cloth or thin cheesecloth, 1 yard wide, stretched across at the rate of one strip to each 18 feet of bed to give an evaporation area one-sixth the total bed area, have proved satisfactory (fig. 7). Reference to table 12 shows that under cool conditions the inexpensive cloth strips provide vaporization about three times as great as the wire baskets. In beds where the cloth-strip evaporators have been used, they remained in place throughout the treatment period, and the plants beneath were in no way retarded. However, the cloth strips should be 12 to 15 inches above the surface of the ground. In general, it has been found that a 24- to 26-thread-count tobacco cloth will hold the No. 6 crystals very well; but, if a smaller size crystal is used, cloth having a tighter weave is required.

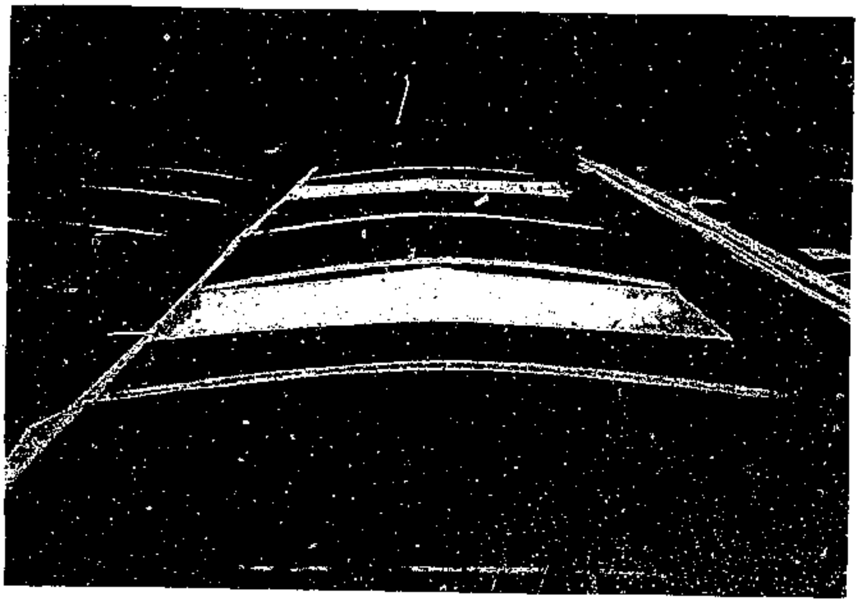

FIGURE 7.—Paradichlorobenzene crystals scattered on temporary strips of tobacco cloth, 3 feet wide, stretched across the bed every 18 feet. Adequate vaporization requires that the crystals be above the plants and well scattered.

TYPE OF COVER

Although the first problem is to vaporize the paradichlorobenzene, the second is to hold in the vapors. Tight sidewalls are one factor, but the greatest vapor loss occurs through the overhead cover. The writers used new and tight glass sash and found that they made very effective covers. However, few tobacco growers used sash, and where they do the sash are generally too old and leaky to be satisfactory. Extensive tests were made with tobacco cottons ranging from 18 to 36 threads per inch. These were used in both single and double thickness and both wet and dry. On the whole, such covers have given very ineffective disease control. Lightweight muslins 40 x 40 and 42 x 40, running 3.2 to 3.5 ounces per square yard, have given fair control in a number of tests, but results were not completely satisfactory. Muslins running 48 to 56 threads per inch have proved distinctly more effective. Finally, in 1939 and 1940, a 62 x 64 [7] muslin averaging 4½ ounces per square yard was made available in quantity by the Surplus Commodity Division of the Agricultural Adjustment Administration. This material was quite satisfactory and distinctly superior to lighter weight grades. Still tighter and heavier muslins, as, for example, a 68 x 72 product, weighing 5 ounces per square yard, have been used and found slightly more effective in retaining vapors than 62 x 64, but such grades become almost impervious to rain when wet and hence are not so satisfactory. In general, growers who have considered using paradichlorobenzene treatment have sought to save money by purchasing very lightweight grades of muslin. If costs are figured on a 3-year basis it will be found that such cheaper muslins do not reduce treatment costs because they soon wear out. Also the expenditure for paradichlorobenzene will be increased (see table 14).

Discussion of the muslin cover would not be complete without a consideration of the value of artificially wetting it. Soaking the muslin with water makes it practically impervious to gas. Covers not soaked by artificial wetting are often damp, but a damp cover is not gas-impervious to anything like the same degree as a wet cover. Therefore in referring to wet covers, covers that are water-soaked are meant. Under most conditions, the greatest vaporization of paradichlorobenzene occurs during the first third of the treatment period (table 10) the reason being that during this period the greatest paradichlorobenzene surface is exposed and the temperature average is highest. A cover that is not artificially wetted usually becomes soaked with dew about the end of this period, but prior to this time there is a considerable loss of vapor. Artificial wetting largely prevents this loss by insuring a practically impervious cover throughout the night. Numerous experiments have shown that with wet covers the amount of paradichlorobenzene required is only half as much as with dry covers. It would appear logical to recommend that the muslin be soaked with water at the start of each treatment. However, many tests have brought out two practical objections. First, it is often not convenient for growers to wet their covers, and further, they are likely to dampen rather than soak them and so not obtain the thorough sealing effect. Second, it has been found that by using water-soaked covers the danger of injury is greatly increased. Injury is most likely to occur on warm nights because of excessive vaporization of the paradichlorobenzene during the early evening. The use of wet covers under such conditions greatly increases the likelihood of injury. To meet this situation the grower desiring to use wet covers can either omit wetting on a warm night or else start the treatment very late, 7:30 or 8 p. m. It should be noted that new covers cannot be thoroughly wet until the sizing has been removed by washing with soap and water.

Size of Crystals and Quantity per Treatment

The different sizes of crystals used in these experiments are listed in table 5. Grades No. 3 and No. 4 proved very satisfactory on warm

[7] As determined from three separate samples analyzed by the Bureau of Standards.

nights and No. 9 on cool nights. Considering behavior under a wide range of temperature conditions, however, No. 6 is recommended. As to rate of treatment, with covers that were not artificially wet, good blue mold control was obtained with rates from 2 to 4 pounds per 100 square yards. Lesser amounts were ineffective on a twice weekly schedule and greater amounts injurious. With covers artificially wet, 1, 1½, and 2 pounds gave excellent disease control; 2½ pounds is definitely too much. Growers, however, have reported using 3 and 4 pounds under wet covers, but this is dangerous with a good grade of muslin cover and a well-constructed bed, providing the cover is thoroughly wet. In general, 2½ to 3 pounds with the cover dry or damp and 1½ pounds with the cover water-soaked are about the right amounts. It is interesting to note that 2 pounds per 100 square yards is the minimum that is reasonably effective with the dry cover and the maximum that can be used with comparative safety under a wet cover.

Duration of Treatment

With cool, cloudy days, treatment can be started as early as 4 p. m., and on bright warm days 7:30 p. m. is early enough. Usually treatments should start about sundown, and the beds should be opened about 8 a. m. Allowing covers to remain in place throughout cool, cloudy days has been tried and found to be dangerous because very little sunshine may cause severe plant injury. However, effective results do require as long a treatment period as is practical (table 11).

Number of Treatments

The gas treatment will check disease development even after the mold has made its appearance. However, it is not safe to delay treatment too long, particularly when one muslin is to be used on several beds. In general, it is advisable to begin as soon as the disease appears in the vicinity and to follow some regular schedule, because growers are too busy to keep disease developments under close observation, and these developments often occur with unexpected rapidity. The number of treatments required per week will vary somewhat with conditions and localities. When blue mold is active under very cool conditions, as is often the case in Georgia, three treatments a week are advisable; and in beds where considerable disease is present at the start, treatments on two and three consecutive nights are desirable. In most areas two treatments a week are adequate, and these should be so spaced as not to have more than a 4-day interval between treatments during periods when the disease is active. Treatments should continue as long as protection is required. In different sections and years the period during which protection has been required has varied from 2 to 8 weeks. In general, from 5 to 10 treatments have been sufficient.

SUMMARY

Controlled experiments showed that benzol-vapor concentrations reaching a maximum of 0.018 percent, over the period 4:30 p. m. to 8 a. m., distinctly retarded blue mold development, whereas 0.097 percent gave complete disease control. A concentration reaching

a maximum of 0.83 percent produced growth retardation. Hence, the phytocidal level was about eight times the fungicidal level.

In plant beds blue mold control was obtained with maximum measured benzol concentrations falling between 0.1 and 0.2 percent.

As the result of repeated tests it is concluded that effective blue mold control can be obtained with twice-weekly treatments using (1) benzol at the rate of 5 quarts per 100 square yards of bed; (2) an evaporating pan surface of one one-hundredth the bed area; with supplementary cloth wicks (fig. 1) and with pans 8 to 10 feet apart; (3) a muslin cover, 60- to 65-thread count, running about 4½ ounces per square yard.

Tests with other vapors have shown that xylol is about 2½ times as effective as benzol, beta-trichloroethane 5 times as effective, and pentachloroethane about 15 times as effective. Pentachloroethane has the serious disadvantage that the treated plants are likely to wilt severely when exposed to bright sun.

Paradichlorobenzene gave effective blue mold control and has certain practical advantages over benzol. It is much more convenient to use, but, because the margin of safety is less than with benzol, a thorough understanding of the limitations of paradichlorobenzene, particularly with respect to vaporization, is essential.

Several factors affect the vaporization of paradichlorobenzene. (1) Size of crystals. The vaporization rate increased as crystal size decreased until a diameter of about 0.93 mm. was reached. Still smaller particles were unsatisfactory because they tended to aggregate. (2) Surface over which the crystals are scattered. Vaporization was almost twice as rapid from an open surface of tobacco cloth or wire mesh as from a solid board surface. (3) Area over which the crystals are distributed. Using the same rate of treatment the vaporization rate under cool conditions was four to five times as great with crystals scattered over a cloth covering the entire bed as it was with crystals held in small wire baskets. (4) Temperature is an important factor, the effects of which can to some degree be compensated for by varying the size of crystals or the method in which they are distributed. Under very cool conditions the smallest crystals and the widest distribution (over tobacco cloth covering the entire bed) are desirable. Under warm conditions larger crystals and distribution on board shelves or in wire baskets will give good results. In general, from the viewpoint of disease control, a vaporization figure above 45 percent is desirable, whereas from the viewpoint of plant safety it is advisable not to have vaporization exceed 93 percent.

Measurements of paradichlorobenzene vaporization during different periods of the night showed that maximum values were usually obtained during the first third of the night. On warm nights, with a small-size grade of crystals, such as No. 9, practically all the paradichlorobenzene may evaporate during this period, and under such conditions plant injury is likely to result.

Most effective disease control is obtained by exposure to the vapors throughout the night. If, however, treatment is limited to half the night, then treatment during the first half is slightly superior to treatment during the second half. Daytime treatment gave ineffective disease control and frequently caused severe plant injury.

The danger of plant injury was greatly reduced by suspending the paradichlorobenzene well above the plant, i. e., 12 to 18 inches above the surface of the soil.

The amount of paradichlorobenzene required to control blue mold depends to a large extent on the tightness of the cover. With covers of varying tightness, from 1/5 pound to 3 pounds of vaporized paradichlorobenzene was required per 100 square yards of bed. Soaking the muslin cover with water reduces the paradichlorobenzene dosage required for disease control by about one-half but increases the danger of plant injury.

Two treatments per week were the minimum number that could be depended on to give adequate blue mold control. Treatments must be continued as long as blue mold protection is desired.

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