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Marlene Mei-yu Liu for the Master of Science in
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(Signature)
E. K. Vaughan

Twelve chemicals (Busan 72, Chloropicrin, Dacthal, Dexon, Duter, EP 161, Lanstan, Methyl bromide, Phaltan, Vapam, Vidden D, Vorlex) were tested to determine their effect on populations of certain important soil-borne microorganisms including the onion pink root fungus *Pyrenochaeta terrestris*. The soil used was from a field in Malheur County, Oregon that was known to be heavily infested with *P. terrestris*. Fumigants were added to the soil in glass jars which were immediately sealed with plastic electrician's tape. Fungicides and the herbicide were added to soil in polyethylene bags and were mixed very thoroughly with the soil. These experiments were done entirely in the laboratories and greenhouse at the Oregon State University Campus in Corvallis.

The fumigants (Chloropicrin, EP 161, Lanstan, Methyl bromide, Vapam, Vidden D, Vorlex) were more effective than the

fungicides (Busan 72, Dexon, Duter, Phaltan) in reducing the number of viable propagules of all of the fungi studied. In these tests the herbicide Dacthal was relatively ineffective against any of the microorganisms.

EP 161, Methyl bromide and Vorlex gave best control of Pythium spp. (mostly P. ultimum) and the rate of recovery in soils treated with these fumigants were slow. The fungicide Dexon usually reported to be highly toxic to P. ultimum did not control this fungus in these tests.

Chloropicrin, Methyl bromide, Vapam and Vorlex were most effective against Fusarium spp. (mostly F. roseum and F. oxysporum).

Chloropicrin permanently inactivated most of the actinomycetes and recovery of this group of microorganisms was very slow in soils treated with either Chloropicrin or Methyl bromide. In soils treated with Vapam or Vorlex, on the other hand, populations of actinomycetes became much greater than in the untreated soil.

The heavily sporulating, carbohydrates reducing fungi were almost completely eliminated by Chloropicrin, Methyl bromide and Vorlex. EP 161, and Vapam were almost as effective but Lanstan and Vidden D were ineffective. Penicillium spp. were encountered with greatest frequency, following by Mortierella, Mucor, Alternaria, Rhizopus, Trichoderma, Aspergillus, Cephalosporium, Stephyllum, Epicoccum, Chaetomium, Sclerotinia and Monilia in that order.

EP 161, Methyl bromide and Vapam were most effective against Pyrenochaeta terrestris and the rate of recovery in soils treated with these materials was very slow. Chloropicrin, Vapam and Vorlex were almost as effective, while Lanstan and Vidden D were relatively ineffective.

The Influence of Soil Fumigants and Soil Fungicides on Some Important Soil-Borne Plant Pathogens

by

Marlene Mei-yu Liu

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Professor of Botany and Plant Pathology

in charge of major

Redacted for Privacy

Head of Department of Botany and Plant Pathology

Redacted for Privacy

Dean of Graduate School

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INTRODUCTION

People have long known that soil-borne pathogens cause severe diseases in crops and are of great economic importance. Many substances have been developed and tested for control of such soil borne fungus diseases as damping-off of seedlings caused by *Pythium* spp., pink root of onion caused by *Pyrenochaeta terrestris*, wilt of vegetable crops caused by *Fusarium oxysporum* f. *specialis*. Many of the chemicals proved ineffective and the specificity of others restricts their effectiveness and utilization. In Eastern Oregon which is one of the major crop production areas of the state, fungus diseases are a constant and severe problem and there is an acute need for finding chemicals that will control these pathogens.

In this experiment, soil from Malheur County, Oregon which was known to be heavily infested with *Pyrenochaeta terrestris* was treated with the fumigants Chloropicrin, EP 161, Lanstan, Methyl bromide, Vapam, Vidden D, Vorlex, the fungicides Busan 72, Dexon, Duter and Phaltan, and the herbicide Dacthal, to determine their effect on population of this fungus and certain other troublesome soil-borne fungi.

LITERATURE REVIEW

Selective toxicity of chemicals to soil fungi and soil-borne plant pathogens has been noted by many workers and reviewed by Kreutzer (33). The reports on results obtained with any fumigant or fungicide also are contradictory. Much more work will have to be done if we are ever to be able to determine the material that will give the best control of a specific organism under specific conditions.

Soil Fumigants

Chloropicrin. Various workers have reported effective control of *Pythium* (18, 69, 70, 71), *Pyrenochaeta* (26), *Fusarium* (4, 18, 19, 41, 84) and other plant pathogenic fungi (1, 13, 18, 29, 37, 66, 68, 72, 78, 84) with Chloropicrin. On the other hand, Rackham *et al*. (62) could detect no difference in severity of root rot of bean (*Fusarium solani* f. *phaseoli*) in Chloropicrin-treated and non-treated soil. Vaughan *et al*. (78) reported that fumigation with Chloropicrin eliminated almost all fungi and actinomycetes. Certain fungi, particularly *Trichoderma* spp. rapidly recolonized the fumigated soil. Some disadvantages of its use in the field are its mammalian toxicity (53, 58, 82), the relatively long waiting period between fumigation and planting (58, 69), and the need for some sort of sealing of the soil to prevent too rapid lose of the fumes (37, 58).

Methyl bromide. Methyl bromide has been reported to be highly effective for the control of Fusarium (18, 49, 50, 54, 59), Pythium (16, 18, 32, 50, 54, 59) and many other fungi (13, 16, 18, 29, 36, 40, 43, 49, 50, 54, 59), but McClellan et al. (40) reported that it was not effective against Fusarium oxysporum. Vaughan et al. (78) reported that Mehtyl bromide killed most fungi but did not materially alter the population of actinomycetes. Recolonization of fumigated soil by fungi was slow, with species of Penicillium predominating. Use of Methyl bromide for soil fumigation is limited by its high cost, the need for a surface seal (49) and the exceedingly high toxicity to humans (58).

Vidden D. Vidden D was first reported as an effective soil fumigant by Carter (8) who used it on pineapple soils infested with nematodes and Pythium spp. He found Vidden D more insecticidal than fungicidal in action as was also reported by Parris (58) and Good (20). Wilhelm (70) reported Pythium ultimum population in D-D (which is identical with Vidden D) treated soil was not different from that of untreated soil. McClellen et al. (40, 41) also reported that D-D was ineffective against Fusarium spp. But Altman et al. (2), Good (20), Morgan (48) and a report from Georgia (76) stated that D-D treatment had some effectiveness in controlling Fusarium oxysporum. Also Zentmger and Kendrick (84) reported that D-D treatment was very effective against Fusarium solani f. phaseoli,

Phytophthora cinnamoni and some other fungi.

Vapam. Vapam has been tested by many people. According to Corden et al. (12) and Cifferri (11), Fusarium oxysporum initially decreased but was re-established in soil one week following Vapam treatment. Cetas and Whidden (10) and Domsch (18) reported Vapam showed promise for control of Fusarium spp. Vapam also is reported effective against Pyrenochaeta terrestris (26, 35, 37, 74), Pythium spp. (13, 16, 18, 34, 35, 47) and many other fungi (16, 18, 21, 27, 34, 35, 36, 46, 47, 52, 66, 67, 71, 77, 79, 80, 82, 83). Vapam is relatively safe from the standpoint of phytotoxicity. Its chief disadvantage is its high cost.

EP 161. According to information furnished by the manufacturer, EP 161 is a soil fumigant possessing broad activity against nematodes, soil insects, fungi and weed seed (34, 63). Skotland (66) reported that EP 161 gave partial control of Verticillium wilt of eggplants and cantaloups and materially increased yields. Latham and Linn (35) found that EP 161 killed Pyrenochaeta terrestris, Pythium debaryanum, Sclerotium, Diplodia and Rhizoctonia.

Vorlex. Vorlex is a mixture of volatile chemicals which has been reported to be effective against most soil pests (21). Young (81) reported Vorlex gave some control of Fusarium wilt of tomato. Lathan and Linn (35) found that Vorlex killed Pyrenochaeta terrestris and Pythium debaryanum, and Vorlex has also been reported to be

effective against some other fungi (22, 26). Sleeth (67) on the other hand reported that Vorlex did not show good fungus disease control and was phytotoxic. Its chief disadvantage is its high cost.

Lanstan. Lanstan is said to be effective against *Pythium* (23, 25, 35, 79), *Fusarium* (23, 78) and *Pyrenochaeta* (35). But when applied with PCNB (Pentachloronitrobenzene), it no longer reduced *Pythium* and *Fusarium* spp. on cotton seedlings (83). Lanstan also has been reported to be effective against some other fungi (14, 25, 35, 38, 79). Watson (79) however reported that in Lanstan-treated soil, the population of actinomycetes, *Trichoderma* and *Penicillium* increased. In one case (39), Lanstan was reported to be unstable and to become inactive if stored for any length of time.

Fungicides

Phaltan. Cetas (9) reported that Phaltan applied to soil gave satisfactory control of damping-off of spinach caused by a *Fusarium*-*Pythium*-*Rhizoctonia* complex. Control of *Rhizoctonia solani* by Phaltan was reported also by Crossan (15) and Owen (57). Tammen *et al.* reported Phaltan at 40 ppm limited colonization by *Pythium*, but the degree of reduction was not statistically significant (73). Phaltan was also effective against some other fungi as reported by May and Palmer (44). Halisky and Satour found Phaltan ineffective against *Rhizopus* (24), and Bird and Andres (6) reported that when

applied with Captan, Phaltan did not reduce Pythium and Fusarium infection in cotton.

Dexon. Dexon is reported highly effective against Phycomycetous pathogens of seedlings and roots, including Pythium, Phytophthora, etc. (17, 31, 55, 60, 66). According to Tammen et al. (73), Dexon most satisfactorily meets the requirements of a fungicide to limit colonization of steam treated soil by Pythium--not only does this chemical retain its initial level of activity over an extended period of time, but its expressed activity remained at a high level independent of the environment. Tammen also reported that Dexon is not phytotoxic to plants. On the other hand, Vaartaja et al. (77) reported control of damping-off by Dexon was not consistent.

Duter. The few reports in the literature concerning Duter are all concerned with foliage diseases. Horn (28) found that Duter not only gave poor control in cucumber anthracnose caused by Colletotrichum but also was phytotoxic. In Oklahoma, Duter is reported to be an excellent fungicide for control of Pecan scab and powdery mildew (5).

Herbicides

Dacthal. Various universities in the United States have reported reduced incidence of disease in crops when Dacthal is used as a weed killer. In Colorado, Altman et al. (3) found that Dacthal

applied in onion fields not only gave good weed control, but also reduced *Fusarium* infection in the bulbs. In Arizona, researchers reported that there was no grass and no damping-off of cotton in Dacthal-treated soil.

MATERIALS AND METHODS

Soil for the tests was collected in January 1968 from an Eastern Oregon field which previously had been planted to onions and was known to be heavily infested with Pyrenochaeta terrestris. This was a loam soil consisting of silt, 42 percent; sand, 29 percent; and clay, 29 percent, with a pH of 7.1, Ion Exchange capacity of 20.8 (K = 2.4; Ca = 15.8; Mg = 7.2 milliequivalent per 100 gram soil) and a water holding capacity of 135.

Soil that was to be fumigated was crushed and sieved through a #28 sieve to eliminate most of the large aggregates. 2268 grams (five pounds) of soil (air-dry weight) was placed in each glass jar, and 230 ml of distilled water was added to bring the moisture content to about field capacity.

Fungicide- or herbicide-treated soils and the controls were screened through a #16 sieve. Two and one-half pounds of soil was placed in each plastic bag and 115 ml distilled water was added to bring the moisture content to about field capacity.

Chemicals used, and rate of application were as follows:

Name	Active Ingredient	Amount Per Acre	Actual Amount Added Per Jar or Bag	Type of Material
Chloropicrin	99% Trichloronitromethane	30 gal	0.2 ml	Fumigant
EP 161	20% Methyl isothiocyanate	30 gal	0.2 ml	Fumigant
Lanstan	1-chloro-2-nitropropane	30 gal	0.2 ml	Fumigant
Methyl bromide	99% compressed gas	30 gal	0.2 ml*	Fumigant
Vapam	32% Na N-methyl dithiocarbamate	30 gal	0.2 ml	Fumigant
Vidden D	Dichloropropene-Dichloropropane	30 gal	0.2 ml	Fumigant
Vorlex	80% chlorinated C_3-hydrocarbon and 20% Methylisocyanate	30 gal	0.2 ml	Fumigant
Busan 72	2-thiocyanomethylthiobenzo-thiazole 60%	15 lbs	0.012 ml	Fungicide
Dexon	P-dimethylamino benzene diazo-sodium sulfonate 70 W	15 lbs	0.0121 g	Fungicide
Duter	Triphenyltin hydroxide 47.5%	15 lbs	0.018 g	Fungicide
Phaltan	50% N-trichloromethyl thiophalimide	15 lbs	0.017 g	Fungicide
Dacthal	Dimethyl-tetrachlorotetra-phthalate 75%	15 lbs	0.014 g	Herbicide

*Because of its low boiling point the amount of Methyl bromide applied could not be accurately measured.

Application of Chemicals

Soil temperature at the time of treatment was 23° C and was maintained at about the same temperature during the fumigation period. Each treatment was replicated four times. All chemicals were applied February 29, 1968. As soon as the fumigants were added to the soil, each glass jar was capped and sealed with plstic electrical tape. Soil and fumigant were mixed by rotating the sealed jar. After 48 hours the tape was removed from each jar and the lid loosened to permit escape of the fumigant and aeration of the soil. Fungicides and a herbicide were added to the soil in polyethylene bags which were then tied securely and kneaded to mix the chemical and soil very thoroughly. After 48 hours the bags were untied but the tops left folded over to prevent recontamination.

Assay for Microorganisms

Selective media were used for each group of organisms and the same media were used throughout the experiment. Assays for the pink root organism started on March 22, for the other organisms on April 4. Four successive assays were made at approximately one month intervals.

Culture medium for *Pythium* spp. To determine population of *Pythium* spp., a soil particle method similar to that described by

Schmitthenner (64) was used. Four particles each approximately three mg in size were seeded on medium MRA-E5-S50 on each petri plate and the agar discs were inverted to avoid bacterial contamination. Medium MRA-E5-S50 has the following formula:

30 mg KH_2PO_4	30 mg K_2HPO_4
20 mg $MgSO_4 \cdot 7H_2O$	0.56 mg $CaCl_2$
2.88 mg $MnCl_2$	1.67 mg $ZnCl_2$
0.1 mg $FeCl_2$	11.60 mg EDTA
0.41 g Sucrose	0.12 g L-asparagine
0.04 mg thiamine hydrochloride	1 liter H_2O
20.0 g agar	Streptomycin 30 mg
	Endomycin 5 mg

The plates were poured two days before use. After four days incubation, each plate was checked under low power microscope and the number of agar discs on which Pythium had grown was recorded. The Pythium culture was then transferred to clean PDA slants for further identification (Middleton's key) (45).

Culture medium for Fusarium spp. (51).

15 g Difco peptone	20 g agar
1 g KH_2PO_4	0.05 g $MgSO_4 \cdot 7H_2O$
300 ppm streptomycin	1:1000 PCNB
1 liter H_2O	

This medium need not be autoclaved. Plates were poured four

days before use and contaminated plates were discarded.

One ml of a 1:100 soil suspension was added to each plate. After one-week incubation, the total number of Fusarium colonies was recorded and representative colonies were transferred to PDA slants to be identified to species level according to the classification of Toussoun and Nealson (75).

Culture medium for Actinomycetes. Jensen's agar medium (30) was used to grow actinomycetes. It contains:

15 g agar

0.2 g casein (dissolved in 10 ml 0.1 N NaOH)

0.5 g K_2HPO_4

$FeCl_3 \cdot 6H_2O$ Trace

1 liter H_2O

2 g dextrose

0.2 g $MgSO_4 \cdot 7H_2O$

The mixture was adjusted to pH 6.5-6.6 prior to autoclaving. One ml of a 1:10,000 soil suspension was added to each plate. After one week incubation at room temperature (approximately 68° F), the total number of actinomycete colonies per plate was recorded.

Culture medium for fungi in general. To determine the effect of treatment on a wider spectrum of fungi, the dilution plate method was employed using Martin's Rose Bengal Agar (42). This medium contains:

KH_2PO_4 1.0 g	Rose bengal 1:30,000
$MgSO_4 \cdot 7H_2O$ 0.5 g	streptomycin 30 μg/ml
peptone 5.0 g	distilled H_2O 1000 ml
Dextrose 10.0 g	

One ml of a 1:100 soil suspension was added to each plate. After five days the total number of fungus colonies was recorded and as many as possible of the fungi were identified.

Bioassay for the pink root organism, *Pyrenochaeta terrestris*. A technique first described by S. R. Siemer (65) was used to determine the presence of *P. terrestris*. Southport white Globe onion seeds were used throughout the experiments. For each lot of soil three plastic plots of a 1-10 soil-sand mixture were used.

About 50 onion seeds (.22 gm) were planted in each pot. All pots were then watered and covered with papers to prevent rapid drying. After the seeds had germinated, the papers were removed and the pots were watered daily. Once a week, Hoaglund's solution was used instead of plain water to supply nutrients for plant growth. After six weeks the plants were removed from the sand, washed, and the percentage of onion plants with symptoms of pink root was recorded.

RESULTS

Pythium spp.

The soil was well-mixed before use and it was assumed that soil factors were the same in all treatments. Differences in fungicidial action were therefore considered to be due to specificity of chemicals.

Since all particles were very similar in size, and each weighed only three mg, for the purposes of these experiments it was assumed that each particle contained only a single *Pythium* propagule. Thus it was possible to calculate the number of variable propagules per gram of soil.

The first sampling was made 40 days after fumigation. All treatments except Duter initially reduced the population of *Pythium* spp. EP 161, Vorlex and Methyl bromide were most effective. Duter appeared to have stimulated rather than injured this group of fungi.

A second sampling was made 68 days after treatment. By that time, a distinct separation was obvious. In soils treated with the fungicides the *Pythium* spp. were no longer suppressed, although the number of propagules per gram of soil was a little less than in the control. In soils that were fumigated, *Pythium* had not recovered to

any extent.

The third sampling was made 92 days after treatment. Very little recovery of Pythium spp. had occurred in any of the soils that were fumigated, and none at all in soils fumigated with Vorlex or Methyl bromide. In all soils treated with fungicides or the herbicide, populations of viable Pythium spp. propagules were greater than in the untreated soil. No further testing of these soils was needed.

The fumigated soils were assayed a final time on 25 days after treatment. No viable Pythium propagules were detected at any time during the test period in soils fumigated with Vorlex. It also should be noted that the small number of propagules recorded for soil fumigated with Methyl bromide 40 days after treatment and with EP 161, 92 days after fumigation represents only one colony from a total of 48 soil particles plated (Table 1 and Figure 1). Most of the Pythium colonies isolated were P. ultimun.

Fusarium spp.

In determining the population of Fusarium spp. in soil, the dilution plate method was used. Three plates were made from each replicate (jar or bag) and results were recorded after one week incubation at about 68° F.

Thirty-five days after treatment the populations of viable propagules of Fusarium spp. (mostly F. roseum and F. oxysporum)

Table 1. Effect of chemical treatment on number of viable propagules of Pythium spp. per gram of soil.

Chemical Used	Days after Treatment			
	40	68	92	125
Chloropicrin	13.08	19.23	13.07	57.69
EP 161	0	0	6.15	0
Lanstan	19.23	19.23	31.52	38.46
Methyl bromide	6.15	0	0	0
Vapam	13.08	6.15	38.46	13.07
Vidden D	31.54	25.38	38.46	83.07
Vorlex	0	0	0	0
Busan	19.23	76.92	140.76	-
Dexon	25.38	51.53	134.61	-
Duter	115.38	83.84	146.91	-
Phaltan	32.31	45.38	173.07	-
Dacthal	32.31	70.76	140.76	-
Control	63.84	102.30	134.61	-
LSD 0.05	22.9	45.2	17.1	
LSD 0.01	30.8	60.8	23.0	

*Each figure is the average of four replicates.

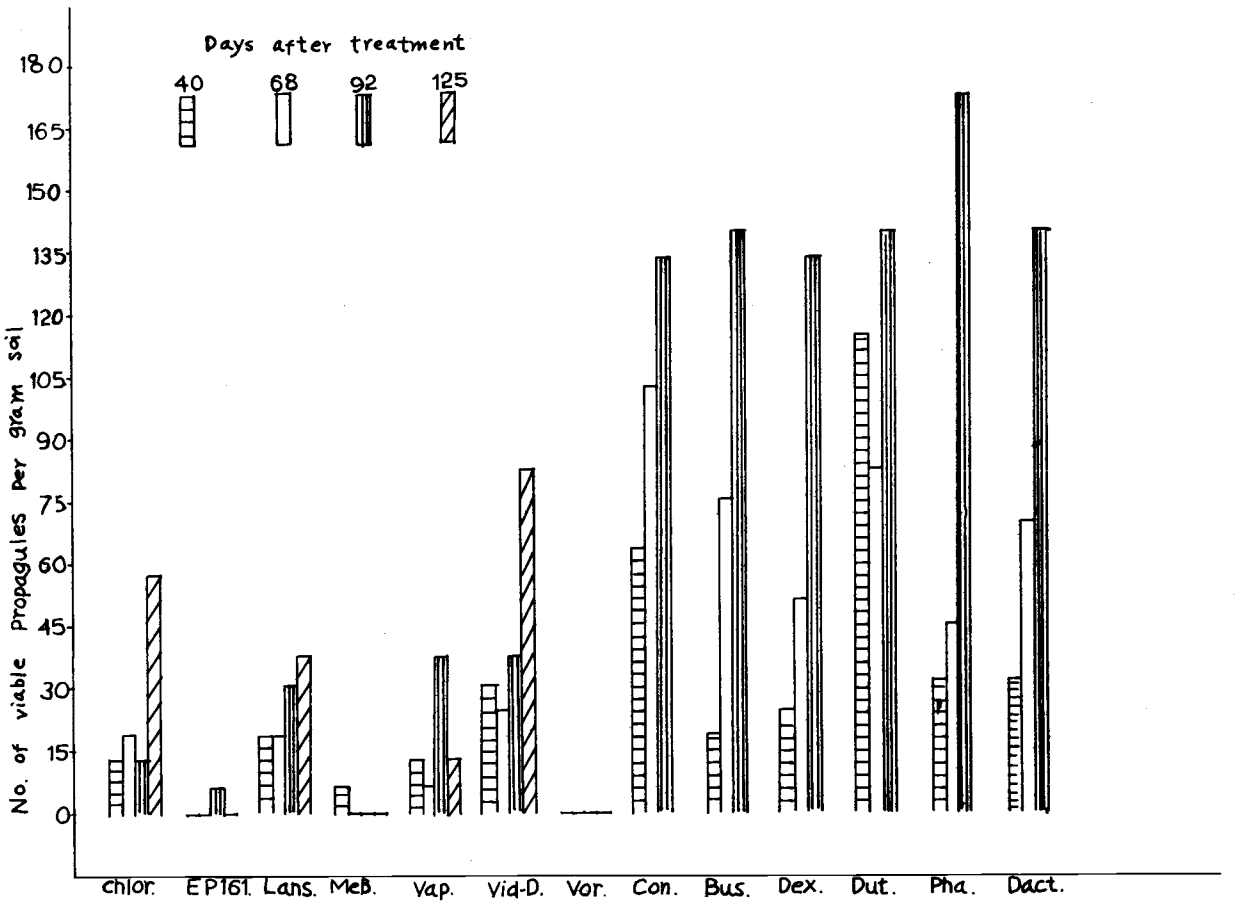

Figure 1. Effect of chemical treatment on number of viable propagules of Pythium spp. per gram of soil.

Chlor. = Chloropicrin	EP 161 = EP 161	Pha. = Phaltan	Dact. = Dacthal
Vap. = Vapam	Lans. = Lanstan	MeB. = Methyl bromide	
Con. = Control	Vid-D. = Vidden D	Vor. = Vorlex	
Dut. = Duter	Bus. = Busan	Dex. = Dexon	

were very low in all treated soils. In the fumigated soils they were practically non-existent. The fungicides other than Phaltan seemed about equally effective in reducing the propagules of Fusarium but were much less effective than the fumigants and their effect did not persist.

Seventy-one days after treatment the number of viable Fusarium propagules in the soil treated with fungicides was not significantly different from that of the untreated soils. All of the fumigated soils yielded very few viable propagules. Recovery of this group of fungi was most rapid in soil treated with Lanstan.

Virtually the same relative conditions prevailed after 94 and 125 days, although in soils fumigated with Lanstan, EP 161 and Vidden D populations of viable Fusarium spp. propagules were increasing rapidly. Soils fumigated with Vorlex, Vapam, Chloropicrin or Methyl bromide still yielded very few Fusarium cultures. These relative populations show most clearly in Figure 2.

Actinomycetes

Jensen's agar medium (27) was used to culture actinomycetes. The colonies were counted after 12 days incubation at room temperature and in indirect sunlight.

All of the treatments initially reduced the population of viable actinomycetes in the soil. Busan and Dacthal were least effective.

Table 2. Effect of soil fungicides and fumigants on number of viable propagules of Fusarium spp. per gram of soil.

Chemical Used	Days after Treatment			
	35	71	94	125
Chloropicrin	0	8	80	170
EP 161	0	25	500	750
Lanstan	33	142	250	750
Methyl bromide	0	0	8	80
Vapam	0	33	0	80
Vidden D	0	84	250	670
Vorlex	0	33	0	80
Busan 72	258	658	1670	-
Dexon	275	450	1590	-
Duter	225	467	1090	-
Phaltan	483	892	1590	-
Dacthal	283	425	920	-
Control	650	567	1750	-
LSD 0.05	55	120	942	-
LSD 0.01	74	160	1267	-

*Each figure represents average of four replicates.

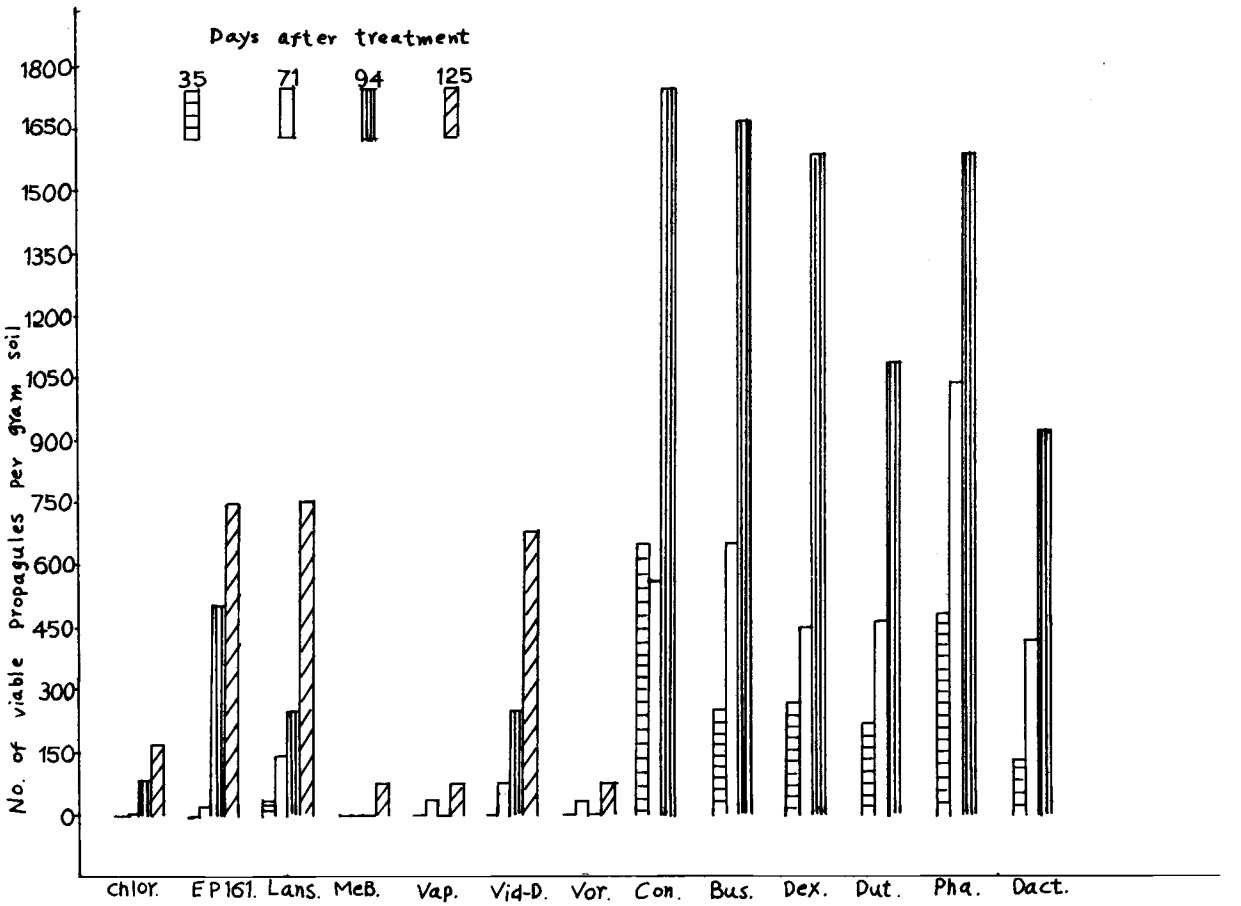

Figure 2. Effect of soil fungicides and fumigants on number of viable propagules of Fusarium spp. per gram of soil.

Chlor. = Chloropicrin
Vap. = Vapam
Con. = Control
Dut. = Duter

EP 161 = EP 161
Lans. = Lanstan
Vid-D. = Vidden D
Bus. = Busan

Pha. = Phaltan
MeB. = Methyl bromide
Vor. = Vorlex
Dex. = Dexon

Dact. = Dacthal

Methyl bromide and chloropicrin were most effective and populations of viable actinomycetes in soils treated with these two fumigants remained very low throughout the test period (Table 3 and Figure 3).

Population of viable actinomycetes in soil treated with all of the fungicides and in soil fumigated with Lanstan soon returned to approximately the same level as in the untreated soil. In soils fumigated with Vorlex and Vapam and to a lesser extent in soils fumigated with EP 161 and Vidden D the actinomycetes increased to several times that of the untreated soil and then gradually returned to about their original pretreatment level.

Effect of Chemical Treatments on Total Number of Fungi Recovered by the Dilution Plate Method.

Soil dilution plates of Martin's Rose bengal agar (35) were used. For the first and second samplings a 1/100 soil dilution was used, but for the third and fourth samplings a 1/1000 dilution was used. Fungus colonies were counted after one week incubation at room temperature.

Thirty-three days after application of the chemicals, all treated soils except those treated with Dexon, Duter and Dacthal had reduced total fungus populations (Table 4 and Figure 4). The fumigants, particularly Methyl bromide, chloropicrin, Vorlex and EP 161 had inactivated practically all of this group of fungi (carbohydrate

Table 3. Effect of chemical treatments on number of variable propagules of actinomycetes per gram of soil.

Chemical Used	Days after Treatment			
	40	67	98	131
Chloropicrin	0	8	0	14
EP 161	83	415	635	492
Lanstan	33	350	542	334
Methyl bromide	0	34	41	100
Vapam	167	959	1958	634
Vidden D	111	509	617	500
Vorlex	108	1025	1600	650
Busan 72	333	367	425	-
Dexon	109	356	575	-
Duter	192	525	533	-
Phaltan	175	323	434	-
Dacthal	292	311	450	-
Control	400	425	417	-
LSD 0.05	33	125	270	
LSD 0.01	44	168	363	

Each figure is the average of four replicates. All figures reduced to nearest 1000.

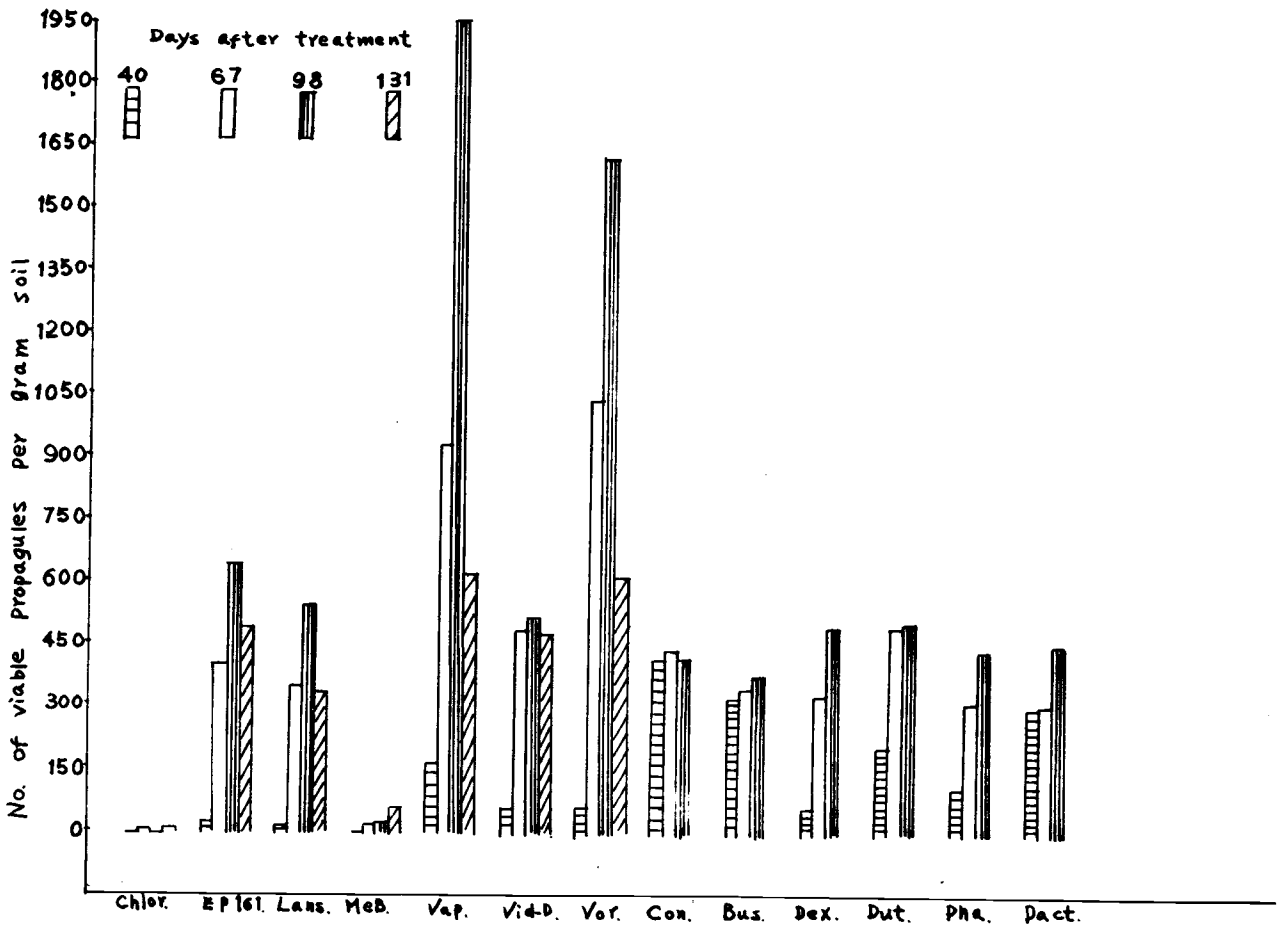

Figure 3. Effect of chemical treatments on number of viable propagules of actinomycetes.

Chlor. = Chloropicrin
Vap. = Vapam
Con. = Control
Dut. = Duter

EP 161 = EP 161
Lans. = Lanstan
Vid-D. = Vidden D
Bus. = Busan

Pha. = Phaltan
MeB. = Methyl bromide
Vor. = Vorlex
Dex. = Dexon

Dact. = Dacthal

Table 4. Effect of soil fungicides and fumigants on number of viable propagules of total fungi per gram of soil.

Chemical Used	Days after Treatment			
	33	62	92	124
Chloropicrin	33	42	1330	330
EP 161	42	2762	9170	2750
Lanstan	1625	6090	32000	19340
Methyl bromide	0	33	1000	170
Vapam	358	2917	5420	3170
Vidden D	3050	3467	49080	19750
Vorlex	33	167	670	80
Busan 72	5675	9959	42340	-
Dexon	8208	11775	52890	-
Duter	7200	8542	25500	-
Phaltan	4125	8492	37170	-
Dacthal	6117	8742	43420	-
Control	7792	11142	52500	-
LSD 0.05	822	1975	10050	
LSD 0.01	1105	2656	13510	

Each figure is the average of four replicates.

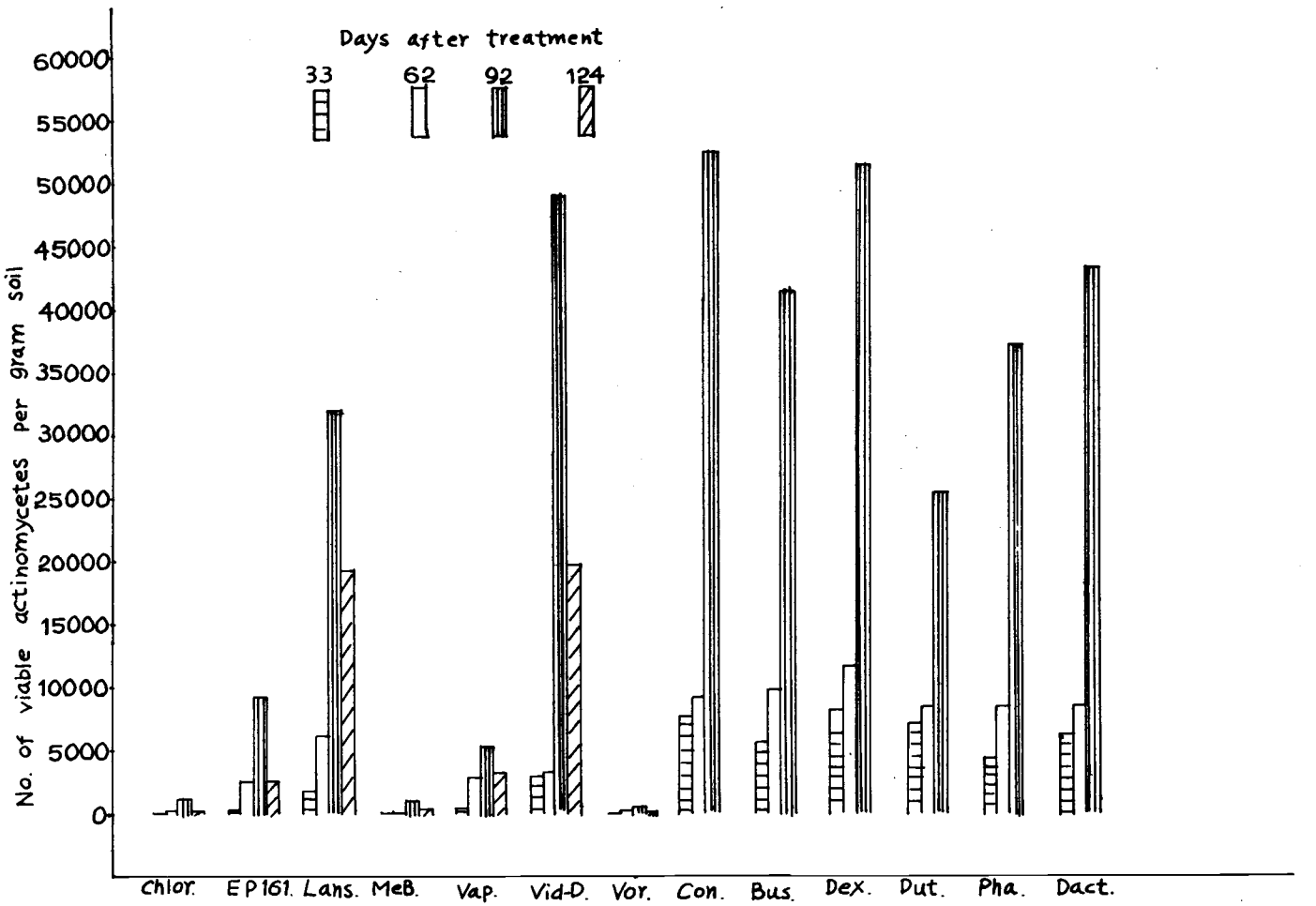

Figure 4. Effect of soil fungicides and fumigants on number of viable propagules of total fungi per gram of soil.

Chlor. = Chloropicrin
Vap. = Vapam
Con. = Control
Dut. = Duter
EP 161 = EP 161
Lans. = Lanstan
Vid-D. = Vidden D
Bus. = Busan
Pha. = Phaltan
MeB. = Methyl bromide
Vor. = Vorlex
Dex. = Dexon
Dact. = Dacthal

reducing fungi).

Sixty-two days after soil treatments, the fungicidal action of Phaltan had practically disappeared. Soil treated with Dexon, Duter and Busan had populations of viable propagules that were not significantly different from those of the untreated soil. All other treatments fell in the range of effective chemicals. Soils treated with Methyl bromide, Chloropicrin or Vorlex yielded very few viable propagules.

The fungi isolated most frequently were *Penicillium*, *Mortierella* and *Mucor* spp. Other fungi in decreasing order of frequency were identified as *Alternaria*, *Rhizopus*, *Trichoderma*, *Aspergillus*, *Cephalosporium*, *Stemphyllium*, *Epicoccum*, *Chaetomium*, *Sclerotinia*, *Monilia* and some unidentified groups.

Effectiveness of Chemical Treatments in Controlling the Onion Pink Root Organism (*Pyrenochaeta terrestris*) in Soil

There is as yet no direct quantitative method of determining the number of viable propagules of the onion pink root organism *Pyrenochaeta terrestris* in soil. The bioassay technique described by Siemer (79) gives at least a partial assay and was employed in these studies.

Onion plants grown in the sand-soil mixture containing soil treated with Duter were stunted. Plants grown in mixtures containing

soil treated with the other chemicals grew as rapidly as those in untreated soil.

The first seeding was made 20 days after application of chemicals to the soils and the first readings were made six weeks later. Phaltan and Busan were the only chemicals that did not cause any reduction in the pink root organism.

The fumigants reduced the incidence of P. terrestris much more than the fungicides. Almost no disease developed in plants grown in soil fumigated with EP 161, Vorlex, Vapam, Chloropicrin or Methyl bromide. Results obtained with Vidden D or Lanstan were somewhat less spectacular.

The second seeding was started 56 days after chemical treatment. All 12 chemicals appeared to be more or less effective although the degree of control varied greatly.

By the time of the third assay, started 94 days after treatment of the soil, populations of viable propagules of P. terrestris in the soils treated with the fungicides were not significantly different from those in untreated soil and in soils fumigated with Vidden D or Lanstan were only slightly reduced.

Throughout the four month test period, almost no pink root appeared in plants grown in the soils fumigated with EP 161, Vorlex, Vapam, Chloropicrin or Methyl bromide. These five chemicals obviously were most toxic to Pyrenochaeta and reestablishment of this

species was very slow. None of the chemicals completely eliminated the pink root fungus from the soil.

Table 5. Bioassay of *Pyrenochaeta terrestris* percentage of onion plants infected per pot treatment.

Chemical Used	Days after Treatment*			
	20	56	94	125
Chloropicrin	0.24	0.21	12.47	0.21
EP 161	0.24	1.09	3.13	0
Lanstan	25.74	27.54	39.02	22.78
Methyl bromide	0.39	0.47	3.70	0.91
Vapam	0	0.58	6.66	0.66
Vidden D	26.80	24.03	38.53	26.89
Vorlex	0.69	0.82	11.46	0.23
Busan 72	66.12	34.22	52.12	-
Dexon	47.99	41.99	67.12	-
Duter	51.16	41.53	61.91	-
Phaltan	62.86	36.14	58.22	-
Dacthal	46.75	36.78	59.34	-
Control	66.91	55.72	63.48	-
LSD 0.05	9.48	9.08	37.33	
LSD 0.01	12.75	12.21	50.20	

*Time indicates number of days until seeds were planted. Disease readings were made six weeks later. Each figure is the average of four replicates.

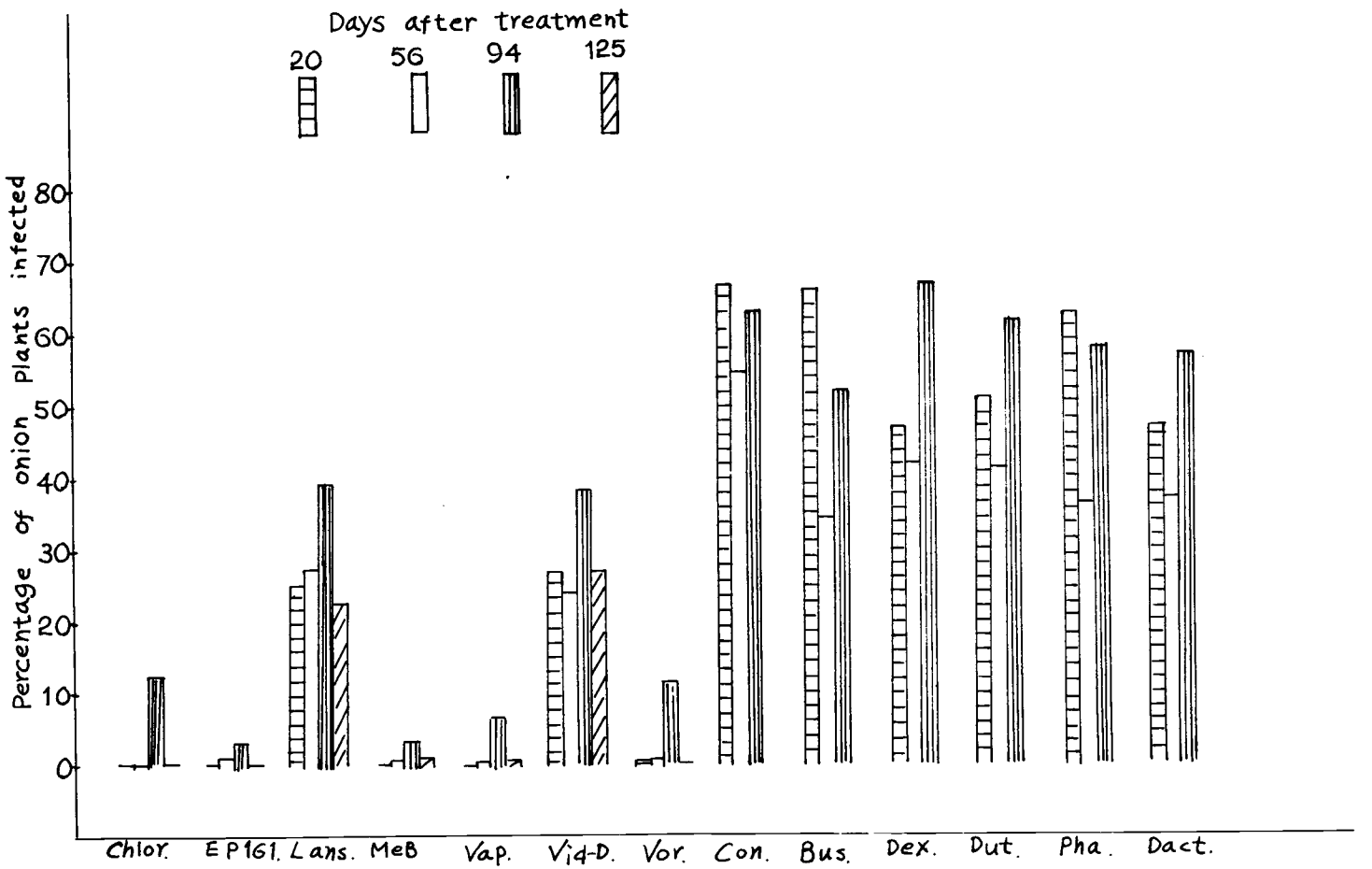

Figure 5. Bioassay of Pyrenochaeta terrestris percentage of onion plants infected per pot treatment.

Chlor. = Chloropicrin
Vap. = Vapam
Con. = Control
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EP 161 = EP 161
Lans. = Lanstan
Vid-D. = Vidden D
Bus. = Busan

Pha. = Phaltan
MeB. = Methyl bromide
Vor. = Vorlex
Dex. = Dexon

Dact. = Dacthal

DISCUSSION

That the efficiency of soil fungicides and fumigants is influenced by the physical and toxic properties of chemicals, method of application, environment and soil conditions has long been known. Since some of these factors are different in each test, differences in the observed effectiveness of fungicides are inevitable. It is only through the accumulation of data concerning the effect of the various chemicals under all sorts of conditions that trends in their possible application to any particular pathogen or group of microorganisms can be demonstrated.

This experiment was done entirely in the laboratory and greenhouse, and in the absence of external recontamination or recolonization. The effectiveness of a chemical in this test does not necessarily mean that it will also be effective against the same organism under field conditions because air contamination, soil contamination, soil moisture and aeration, weather and many other factors make the field conditions very complex.

Since relatively small amounts of soil were used in the tests, the soil and chemicals could be mixed very thoroughly and fumigants could not escape until the seal was removed from the glass jars. Thus each chemical was provided the opportunity to exert its maximum fungitoxic action. Such mixing of the fungicide with the soil, or

confinement of toxic vapors, cannot be achieved in the field.

The soil moisture content gradually decreased in both treated and untreated soils since both the polyethylene bags and the glass jars were left unsealed to allow aeration to take place. Any effects caused by drying should have been equal in all soils.

Field application of Dexon has been recommended for control of Pythium spp. In this test, initially Dexon showed some effectiveness against Pythium ultimum, but the fungus recolonized rapidly.

Dacthal, Busan and Phaltan all gave some control of Pythium but by the time the final tests were conducted, Pythium populations were higher than in the control soil. This may be due to lack of competitors or antagonists in the treated soil as shown in the assay for total fungi and actinomycetes.

Vapam reduced Pythium propagules for a short period after fumigation, but the effect was not consistent. Methyl bromide, Vorlex and EP 161 gave almost complete control of Pythium.

Fusarium spp. were almost completely inactivated for about 70 days after fumigation with Chloropicrin or Methyl bromide and the recovery rate was particularly slow in soil treated with Methyl bromide, perhaps because of the increased population of actinomycetes. Recovery in Chloropicrin-treated soil was slightly more rapid. Here actinomycete populations were very low and Trichoderma spp. predominated. Apparently Trichoderma is somewhat less

antagonistic to Fusarium spp. than the actinomycetes. Vorlex, Vapam, Vidden D and Lanstan were less effective in reducing population of viable propagules of Fusarium spp., but in soils treated with these chemicals recovery of this group of fungi was slow.

Chloropicrin killed almost all the actinomycetes present in soil. Methyl bromide reduced actinomycete populations, but not as drastically as Chloropicrin. Since actinomycetes multiplied rather slowly, the number of colonies on plates of soil treated with EP 161, Vidden D, Lanstan, Dexon, Duter, Busan, Phaltan and Dacthal did not change very much. The number of propagules of actinomycetes increased rapidly following fumigation with Vapam and Vorlex. This might have resulted from lack of antagonists and competitors in soil as shown in slow increase of total fungi.

The dilution plate method was used to estimate population of actinomycetes and total fungi in soil. This method favors heavy sporulating fungi such as Penicillium and Trichoderma. Fungi such as Pyrenochaeta and Pythium are never encountered in this method.

Recovery of fungi in Methyl bromide treated soil was very slow and Penicillium spp. predominated. Trichoderma predominated in Chloropicrin-treated soil but was rarely found in Vidden D- and Lanstan-treated soils. Mortirella and Penicillium were encountered in appreciable number in almost all soils except those treated with Chloropicrin. The recovery of fungi in Chloropicrin and Vorlex-

treated soils was rather slow. The total number of fungi in Vidden D- and Lanstan-treated soils increased to very high levels probably because of non-fungicidal action of these chemicals to Penicillium, Aspergillus, Cephalosporium, etc., that are heavy sporulating fungi.

In field experiments on control of pink root disease in Eastern Oregon by Hess (26), Pack (57), and Siemer (65), many fungicides and fumigants were applied to the soil. Most of them were ineffective or resulted in only insignificant reduction in severity of the disease. A few have consistently resulted in reduced severity of disease and/or increased yields and increased bulb size. The results of these tests may provide a possible explanation for the results obtained in the field.

SUMMARY

1. Laboratory and greenhouse tests were made to determine the effect of a group of fumigants and fungicides on population of viable propagules of a limited number of important groups of soil microorganisms. Materials tested were Busan 72, Chloropicrin, Dacthal, Dexon, Duter, EP 161, Lanstan, Methyl bromide, Phaltan, Vapam, Vidden D and Vorlex.

2. A dilution plate method was used to determine the population of *Fusarium* spp., Actinomycetes and total fungi; a soil particle method was used for *Pythium* spp., and a bioassay technique employing susceptible onion seedlings for *Pyrenochaeta terrestris*.

3. For control of *Fusarium* spp. in soil, Methyl bromide, Vorlex, Vapam, and Chloropicrin were most effective in reducing the population of viable propagules to very low levels. Only Methyl bromide permanently inactivated almost all the *Fusarium* propagules.

4. EP 161, Methyl bromide and Vapam were most effective against *Pyrenochaeta terrestris*. They inactivated almost all propagules of the fungus and the rate of recovery was very slow.

5. Duter was phytotoxic to onions as all seedlings grown in Duter treated soil were stunted.

6. Methyl bromide, Vorlex and EP 161 gave the best control of

Pythium spp. and recovery in soil treated with these chemicals was slow. Dexon did not reduce *Pythium* population in soil in these tests.

7. Chloropicrin killed almost all the actinomycetes. Recovery of actinomycetes in soils treated with either Methyl bromide or Chloropicrin was very slow. On the other hand, the total number of actinomycetes became tremendously high in soil treated with Vorlex or Vapam.

8. The total fungus population increased rapidly in soil treated with Lanstan or Vidden D with *Penicillium* accounting for more than 90 percent of the colonies isolated.

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