higher absorbance value was obtained using the purified tannic acid than the technical tannic acid, but only when the color reagent as described here was used —0.1 g. tannic acid to 30 ml. of glacial acetic acid and 70 ml. of orthophosphoric acid.

However, the color intensity was essentially the same for the technical piperonyl butoxide (80%) as for the 100% pure material when the color reagent contained purified tannic acid.

An absorption-concentration curve (Figure 1) was then established for piperonyl butoxide, using the mixed standard solution and a heating period of 12 minutes. Beer's law was obeyed up to 28 μg. of piperonyl butoxide per ml. in the final aliquot.

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INSECTICIDE EFFECTS ON PLANT GROWTH

Effect of Various Insecticides on Growth and Respiration of Plants

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The effects of insecticidal soil residues on the plant growth, morphology (corn and peas), and respiration of root tips of corn, oats, peas, and cucumbers have been investigated. The plants were grown in a "soil" of minimum sorptivity (quartz sand) which had been treated with 18 different insecticides at 30 p.p.m. Although the conditions under which the plants grew were extreme, many insecticides either had no inhibitory effect on plant growth or caused a growth increase. In general, insecticides of the chlorinated hydrocarbon group inhibited plant growth less than the organophosphates and Sevin. Insecticides, which inhibited growth, affected corn more than peas. A significant reduction in the rate of respiration of root tips was caused by lindane (corn, oats), dieldrin (corn, oats), *p,p'*-DDT (oats, peas, cucumbers), methoxychlor (peas), Systox (oats, peas), and Sevin (peas, cucumbers). Parathion significantly increased the respiration of corn root tips.

In most cases the concern about insecticidal residues has been limited to the problem of food contamination: residues on or in crops and insecticidal contamination of meat and milk. However, the effect of pesticidal residues on the biological complex of soils in which our food supply originates also presents a problem of primary importance. Many authors during the past 15 years have investigated the effect of insecticidal residues in soils on crop yield as well as on growth and phytotoxicity (*1–3, 7*). The respiration of root tips of tree seedlings, as affected by various pesticides, has been investigated, to some extent, by Voigt (*9*). As a result of direct applications of insecticides to soils or to crop spraying, many of our soils contain insecticidal residues. It is, therefore, important to find out if and to what an extent crops growing in these soils might be affected.

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An attempt has been made to evaluate the effect of various insecticides on the growth and respiration of corn, oats, peas, and cucumbers. These plants were grown in quartz sand which had been treated with unusually high concentrations of insecticides. If no effect was noticeable under these conditions, probably no harm would be done to crops growing in soils to which insecticides had been applied at "normal" rates. However, if considerable damage to the plant tissue occurred, further investigations would be necessary. Conversely, certain chemicals might affect plants in a beneficial way.

Procedure

Effect of Insecticides on Plant Growth

1. To test the effect of insecticides on plant growth, quartz sand was treated at 30 p.p.m. with various toxicants. Eleven chlorinated hydrocarbon insecticides were used [lindane, chlordan, aldrin, dieldrin, heptachlor, heptachlor epoxide, Shell-4402 (1,3,4,5,6,7,8,8-octachloro - 3a,4,7,7a - tetrahydro - 4,7-methanophthalan), toxaphene, endrin, *p,p'*-DDT, and methoxychlor], five organophosphate insecticides [parathion, methyl parathion, phorate, malathion, and Systox (*O,O*-diethyl *O*-ethyl-2-mercaptoethyl phosphorothioate)], and two carbamates [Sevin (*N* - methyl - 1-naphthyl carbamate) and Isolan], as well as the hydrolysis product of Sevin (1-naphthol). All the insecticides (analytical grade) were applied in an acetone solution to the quartz sand. Control sand was treated with acetone only (*4*). After the acetone had been removed by a gentle air stream on a specially designed apparatus (*5*), the sand was further mixed on paper and then placed in 6-inch wide, nonglazed clay pots. For each insecticidal treatment, two pots were filled with quartz sand, which was then wetted with a complete plant nutrient solution.

Field corn (Golden Glow, Wis.) or peas (Alaska wilt resistant) were used in these experiments. Twenty seeds, which had been placed in untreated wet sand for one day, were then planted in each pot. All of the pots stood in saucers, to which nutrient solution was added as necessary; they were kept in the greenhouse.

Twenty-one days after planting, at a time when peas started to develop flowers, corn and pea plants were carefully removed from the pots by placing the "soil" in a water container. After the roots had been washed, the growth of roots and stems grown in insecticide-treated quartz sand was compared with that of plants grown in acetone-treated sand.

Anatomical studies were also conducted. Primary roots of corn and peas were studied histologically from fresh transverse sections cut freehand, and from microtomed sections, cut serially in transverse and longitudinal planes. The fresh sections were taken 1 and 6 cm. back from the tip of the root and then stained with phloroglucinol-HCl to reveal the extent of xylem differentiation. These freehand sections also permitted a survey of tissue responses in more mature regions. For microtomy, root tips 1 cm. long were removed from representative primary roots, fixed in FPA (*6*), and processed according to standard procedures. Serial longitudinal sections 10 microns thick were made. Serial transverse sections (15 microns thick) were made through the distal 5 mm. of the root. The sectioned root tips were stained in hemalum, safranin, and Fast Green.

In evaluating the effect of the insecticides, tissues from comparable positions in the treated roots were compared to sections from control plants. Longitudinal sections as close as possible to the median were selected. Similarly, transverse sections at comparable measured distances from the base of the promeristem of the root apex in each sample were utilized in comparisons. Because of the large volume of material to be studied, analyses were made on two microtomed root tips randomly chosen from the representative corn and pea roots sampled in each treatment. Whenever tissue responses were caused by an insecticide, additional root tips were sectioned for further studies.

2. Five insecticides (lindane, chlordan, methyl parathion, phorate, and Sevin) were selected for further investigations. Each insecticide was applied to quartz sand at seven different concentrations (30, 16, 8, 4, 2, 1, and 0.5 p.p.m.), and 20 corn or pea seeds were planted in each of the differently treated quartz sand samples. After 21 days, root and stem measurements were made to determine the threshold concentration of a particular insecticide which no longer caused a significant reduction in plant growth.

3. Insecticidal effects on root growth with time were also investigated. A loam soil (Miami silt loam), of a much higher sorptive capacity than a quartz sand, was treated with lindane at a concentration of 50 p.p.m. Ten 6-inch wide clay pots were filled with insecticide-treated soil and ten with an untreated one. Twenty germinated seeds of bitter blue lupines with a root length of $^1/_4$ to $^1/_2$ inch were planted in each of the pots. In this way the effect of lindane on root growth only was tested, rather than on seed germination and root growth. Roots grown in two treated and two untreated soils were measured 2, 4, 6, 10, and 14 days after planting.

Effect of Insecticides on Respiration of Plant Tissues. The effect of the insecticides mentioned above (except Isolan and Shell-4402) on the respiration of excised root tips was studied with corn (Golden Glow, Wis.), oats (Sauk, Wis.-Brand), peaks (Alaska wilt resistant), and cucumbers (Straight Eight). The chemicals were applied, in an acetone solution, to quartz sand at 30 p.p.m. as described above. For each insecticide used, four replicated 4-inch wide plastic pots were prepared, and 14 seeds of corn, oats, peas, or cucumbers were planted in the treated sand. Control plants were grown in quartz sand treated with acetone only. The sand was wetted with nutrient solution after planting and all the pots were kept at 72° ± 2° F.

Table I. Effect of Insecticides in Quartz Sand on Growth of Corn and Pea Plants as Expressed in Root and Stem Measurements, 21 Days after Seeding

(Insecticidal treatment. 30 p.p.m.)

	Corn					Peas				
	Roots		Stems			Roots		Stems		
	Cm.	% ck.[b]	Cm.	% ck.	R/S[a]	Cm.	% ck.	Cm.	% ck.	R/S
Control	27.3 ± 2.56[c]		26.4 ± 2.63		1.03	16.6 ± 1.82		23.5 ± 1.86		0.71
Lindane	2.1 ± 0.64	8[d]	13.5 ± 2.56	51[d]	0.16	5.7 ± 0.76	34[d]	6.7 ± 1.34	29[d]	0.85
Chlordan	4.1 ± 0.57	15[d]	11.9 ± 3.14	45[d]	0.35	16.7 ± 1.46	101	18.5 ± 2.17	80[d]	0.90
Aldrin	27.6 ± 3.17	101	22.9 ± 2.07	87[d]	1.21	19.6 ± 1.16	118[d]	26.7 ± 2.23	114[d]	0.72
Dieldrin	20.8 ± 2.86	77[d]	27.6 ± 2.49	105	0.75	19.7 ± 2.71	119[d]	28.6 ± 2.21	122[d]	0.69
Heptachlor	29.4 ± 3.35	108	26.0 ± 3.26	98	1.13	18.7 ± 1.14	113[d]	27.6 ± 2.23	118[d]	0.68
Hept. epoxide	26.1 ± 3.55	96	28.4 ± 3.47	108	0.92	17.8 ± 1.58	108	28.9 ± 2.56	122[d]	0.62
Shell–4402	23.5 ± 3.71	86[d]	24.4 ± 5.60	93	0.96	19.8 ± 2.05	119[d]	29.1 ± 2.07	124[d]	0.68
Toxaphene	23.7 ± 3.87	87[d]	23.3 ± 1.73	88[d]	1.02	17.9 ± 1.38	108	26.8 ± 1.94	114[d]	0.67
Endrin	28.7 ± 3.64	105	26.2 ± 2.23	99	1.10	16.9 ± 2.03	102	28.2 ± 1.90	120[d]	0.59
p,p'-DDT	33.1 ± 4.28	121[d]	26.3 ± 3.02	100	1.26	17.0 ± 1.09	103	27.4 ± 1.80	117[d]	0.62
Methoxychlor	26.4 ± 3.79	97	22.9 ± 3.74	87[d]	1.15	18.1 ± 1.25	109[d]	28.1 ± 1.65	120[d]	0.64
	1% LSD 2.77		2.71			1.36		1.73		
Control	41.2 ± 5.36		35.6 ± 3.12		1.16	20.1 ± 2.45		25.9 ± 2.21		0.78
Parathion	19.3 ± 6.18	47[d]	24.5 ± 3.25	69[d]	0.78	20.1 ± 2.30	100	26.1 ± 3.36	101	0.77
Methyl parathion	10.7 ± 2.09	26[d]	26.3 ± 3.15	74[d]	0.41	16.5 ± 2.35	82[d]	17.8 ± 2.51	69[d]	0.93
Phorate (Thimet)	17.0 ± 2.81	41[d]	25.1 ± 3.21	70[d]	0.68	15.0 ± 1.80	75[d]	29.1 ± 3.47	112[d]	0.51
Malathion	28.7 ± 4.79	69[d]	37.4 ± 6.71	105	0.78	20.4 ± 2.26	102	24.7 ± 3.16	95	0.83
Systox	30.6 ± 2.77	74[d]	33.4 ± 4.32	94	0.91	17.5 ± 1.90	87[d]	33.2 ± 2.65	128[d]	0.52
Sevin	5.7 ± 1.18	14[d]	16.1 ± 2.19	45[d]	0.35	5.9 ± 1.11	29[d]	12.2 ± 2.03	47[d]	0.45
	1% LSD 3.14		3.54			1.69		2.47		
Control	15.9 ± 2.32		31.5 ± 3.62		0.51	10.2 ± 1.51		39.7 ± 5.15		0.26
1-Naphthol	15.4 ± 3.28	97	30.5 ± 3.96	97	0.41	9.0 ± 1.73	88	33.0 ± 5.78	83[d]	0.28
Isolan	14.7 ± 2.51	93	31.7 ± 5.60	100	0.46	15.9 ± 1.76	156[d]	29.4 ± 6.54	74[d]	0.54
	1% LSD 2.56		4.48			1.54		5.41		

[a] R/S = ratio $\frac{\text{root length}}{\text{stem length}}$.
[b] % Check = in % of control plants.
[c] Standard deviation.
[d] Significantly different at 1% level.

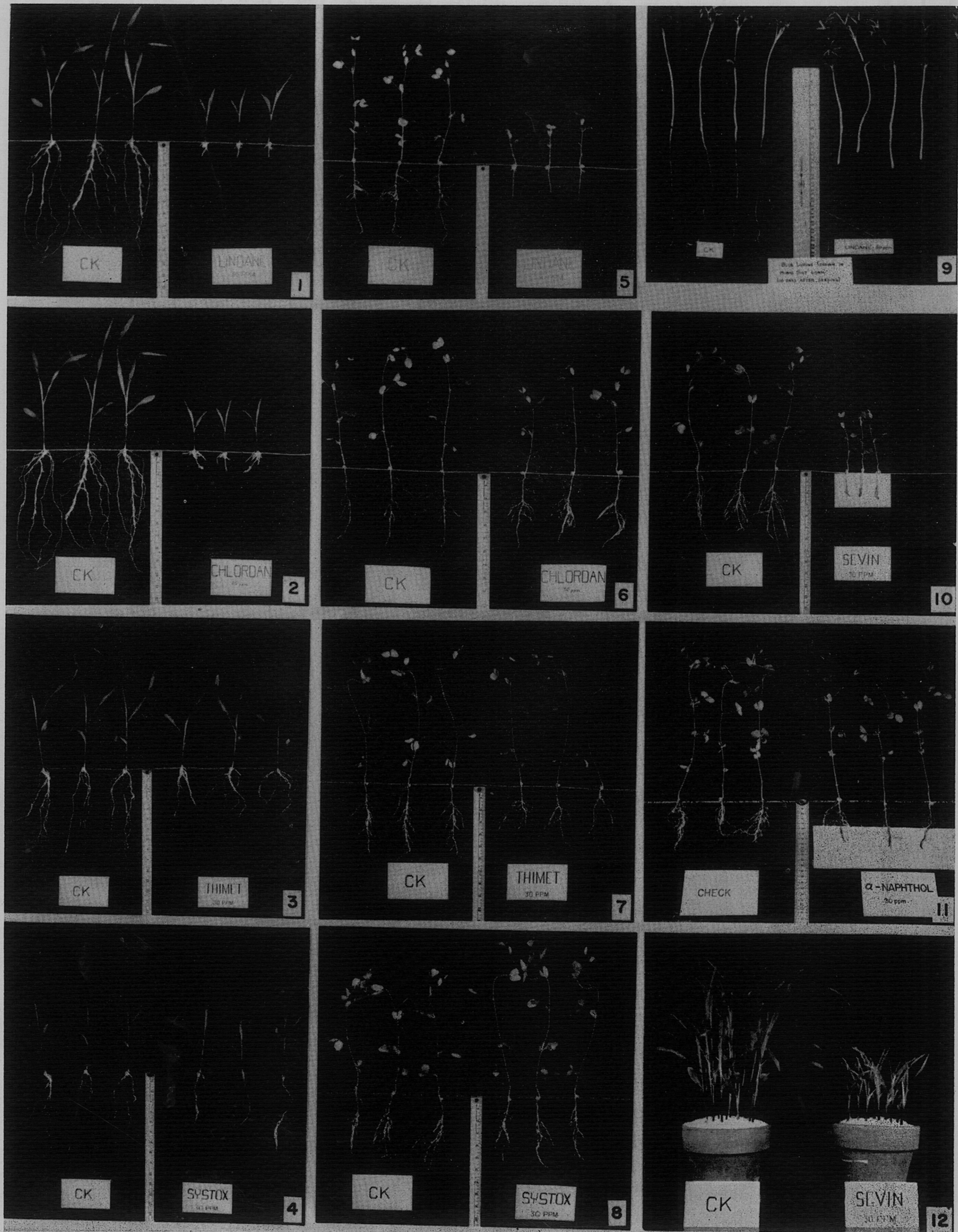

Figure 1. Effect of various insecticidal residues on growth of corn and peas

In each picture, control plants are on left

Corn. 1 lindane, 2 chlordan, 3 Thimet, 4 Systox, 12 Sevin

Peas. 5 lindane, 6 chlordan, 7 Thimet, 8 Systox, 10 Sevin, 11 1-naphthol

9. Effect of 50 p.p.m. lindane in silt loam on blue lupines

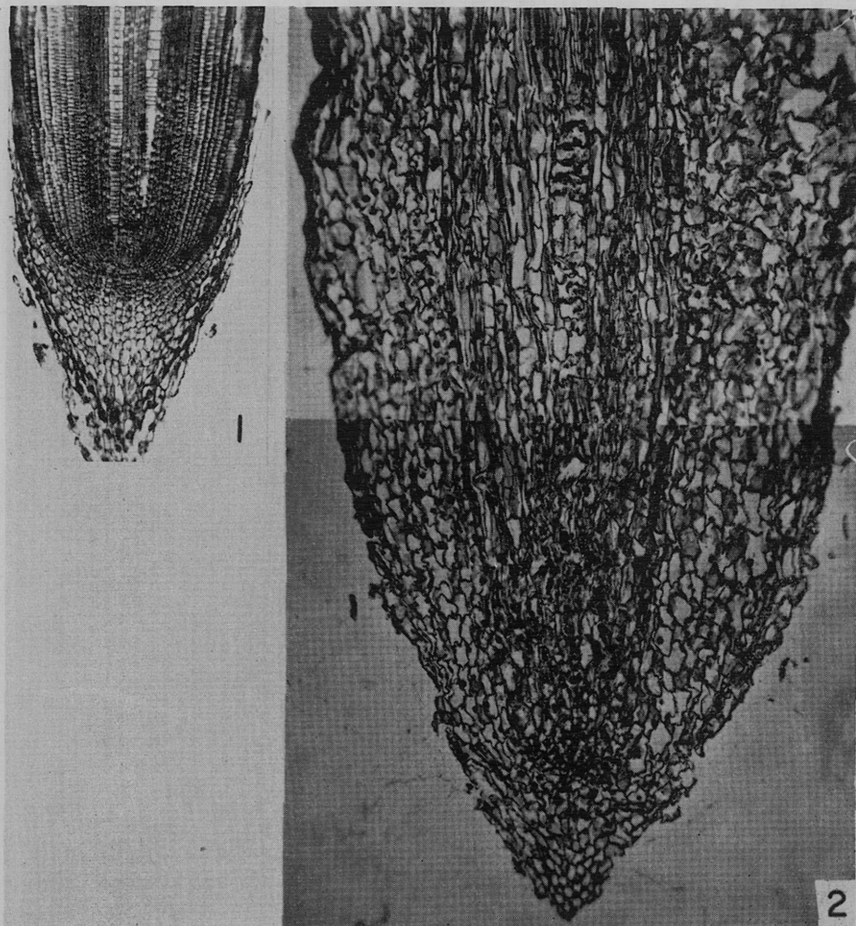

Figure 2. Histological effects of 30 p.p.m. lindane in quartz sand on corn root tips

Magnification of control (1) and treated (2) is identical (X 75)

In the initial studies the effect of the age of seedlings on the rate of respiration was investigated. For this purpose the amount of oxygen taken up by excised root tips of corn and peas was measured after 5, 10, 15, and 20 days of growing time.

In all of the other studies, seedlings were prepared for analysis 7 days after planting. Approximately 100 mg. of excised root tips, 10 mm. long and of equal diameter, were placed in single-side-arm reaction flasks, containing plant nutrient solution which had a pH of 4.8. In addition, 10-mm. portions of excised root tips were used for the determination of dry matter content of these tissues. The uptake of oxygen was determined using the direct method of Warburg (*8*). The shaking rate of the flasks was 105 complete strokes per minute and the temperature of the bath was kept at 25° C. After the flasks had been shaken for 30 minutes, manometer readings were made at 10-minute intervals for $2^1/_2$ hours. Results were finally expressed in microliters of oxygen taken up per 100 mg. of fresh weight of tissue per hour, as well as in microliters of oxygen taken up per milligram of dry weight of tissue per hour (Q_{O_2}).

Results and Discussion

Effect of Insecticides on Plant Growth

1. The growth of corn and pea plants was in some cases inhibited, in others stimulated or not affected at all by the various insecticides used (Table I). This was dependent on the particular insecticide as well as the kind of plant. Of the insecticides applied, lindane and Sevin were most damaging under the conditions used and reduced growth of both corn and pea plants. Roots affected by lindane were short and club-shaped and generally lacked any branch roots (Figure 1). Roots grown in Sevin-treated sand were shorter and thicker than roots grown in untreated sand. Branch roots were short and formed within 0.5 cm. of the apex. Moreover, the lower portions of the root system had a dark purplish color. No effect on the length of either corn or pea roots due to 1-naphthol was noticed, though the lower part of the root system also had a purplish color. Chlordan noticeably inhibited the growth of corn plants.

The anatomical studies revealed that many insecticides caused no change in the structure of either corn or pea tissues. Others caused responses ranging from inhibited growth and precocious tissue differentiation to severe hypertrophy and hyperplasia.

The more pronounced tissue responses fall into two general types. One type, which might be designated "growth inhibition," involved the presence of differentiated cells of the protophloem, protoxylem, metaxylem, and in many cases the endodermis close to the root apex, suggesting that cells back of the root apex failed to elongate in advance of differentiation. Sevin induced these inhibitive responses in peas, in which numerous tracheary elements were differentiated close to the apex in a unique wedge pattern at each of the three protoxylem points. Precocious and prolific development of branch roots accompanied this response of peas to Sevin. Corn responded in a similar fashion to Sevin with differentiation of tracheary elements close to the apex and a peculiar cell wall change evidenced by retention of the safranin stain in a band of cells located peripherally in the vascular cylinder and including the endodermis. Dieldrin induced similar but less striking growth inhibition effects in corn roots. Walls of endodermal cells stained red with safranin to the promeristem, and the protoxylem differentiated close to the apex. Precocious branching of roots was noted. Corn responded similarly to chlordan with responses of the above nature, including the retention of safranin in cells at the periphery of the vascular cylinder extending distally to the promeristem. Chlordan further induced some hypertrophy in xylem and phloem parenchyma of corn, and a limited modificaton of the root apex organization. Minor variations among treatments with other insecticides in the level of xylem and phloem differentiation were not greater than the variation expected among controls; Shell-4402 caused a weak inhibitory response in corn as noted histologically.

The second type of tissue response involved hypertrophy and hyperplasia, and was observed in roots grown in lindane-treated sand (Figure 2). Characteristic organization of the root apex was severely altered. Irregular enlargement of scattered cells of the vascular cylinder and occasionally the cortex resulted in a general broadening of the root. Stimulation of cell division, primarily in the vascular cylinder, distorted the appearance of the root in section. The pericycle was the most stimulated region. The xylem and phloem were less affected in peas than in corn. The irregular cell growth and accelerated cell division produced an extremely disorganized pattern in these tissues. In peas the proliferated cells often differentiated as tracheids, and small necrotic areas were found in the root apex. Lindane also induced the precocious differentiation of protoxylem, metaxylem, and phloem in peas, and of the endodermis in corn associated with limited root elongation as noted above. Characteristic of lindane-treated plants, particularly peas, was the occurrence of multiple nuclei in cells of the proliferating regions of the root tip.

Eleven of the 18 insecticides tested caused a reduction in the growth of corn roots and nine a reduction of corn stems. Peas, however, were less affected and only five insecticides reduced root growth and six stem growth. Moreover, growth of pea plants (roots and stems) was increased when they were grown in quartz sand which had been treated with aldrin, dieldrin, heptachlor, Shell-4402, or methoxychlor. In other cases, roots and stems of the same plant reacted differently to the same insecticide. Phorate and Systox, while inhibiting root growth of peas, caused a slight increase in stem growth. Isolan caused an increase in the growth of pea roots, while inhibiting stem growth. All the five organophosphate insecticides tested inhibited corn root growth, while pea roots were inhibited only by methyl parathion, phorate, and Systox.

In general, insecticidal residues of the chlorinated hydrocarbon group were the least toxic. However, they are more residual than the organophosphate insecticides.

The conditions under which the plants grew were extreme. The quartz sand does not possess the insecticide-retention qualities of any agricultural soil and an insecticidal concentration of 30 p.p.m. is far above what normally might be expected as an insecticidal residue content in agricultural soils. Therefore, effects of some insecticidal residues on growth of plant tissues reported in this study might not be noticeable under "normal" conditions.

2. After corn and pea plants were grown in quartz sand treated with lindane, chlordan, methyl parathion, phorate, and Sevin at various concentrations, threshold data (insecticidal concentrations which no longer caused stunting of plant growth) were obtained (Table II). Lindane was the most toxic insecticide used and applications of 0.5 p.p.m. (corn) or 1.0 p.p.m. (peas) no longer caused a significant reduction in root growth. The threshold concentration obtained with Sevin was twice (corn) or four times (peas) as high, though still more toxic than any other insecticide (except lindane) tested.

Pea plants were able to grow in 2 to 8 times higher insecticidal concentrations than corn plants, without showing significant stunting in growth.

3. Roots of bitter blue lupines, grown in a Miami silt loam, were stunted by a lindane concentration of 50 p.p.m. (Table III and Figure 1). The damage occurred soon after the seeds had germinated. Two days after planting, roots grown in lindane-treated loam soil were significantly shorter than those grown in an untreated loam. Six days after planting, lindane had caused a 60% reduction in root growth. From then on no further reduction occurred. Under the conditions of these experiments, where a pot depth of 16 cm. might have become a limiting factor, roots of bitter blue lupines grew in overall length only during the first 6 days after planting, and the damage due to lindane occurred during that growing period.

Effect of Insecticides on Respiration of Plant Tissue. In initial studies the rate of respiration of root tips (corn and peas) 10 and 15 mm. long was investigated. It was found that the amount of oxygen taken up per hour per 100 mg. fresh weight of 10-mm. root tips was 118% (corn) to 130% (peas) of that taken up by 15-mm. root tips. Therefore, all future investigations were conducted with 10-mm. root tips.

Not only the length of the root tips but the age of the seedling proved to have an effect on the rate of respiration (Figure 3). The absolute amounts of oxygen taken up by corn or pea root tips grown in either untreated or lindane-treated quartz sand declined with time. This might have happened because the root tips utilized had grown farther away from the seed and its food supply, which might be necessary for vigorous respiration processes. The differences in the rate of respiration observed between root tips of corn grown in untreated and lindane-treated quartz sand remained similar during the 20 days after planting.

Table II. Threshold Concentration of Insecticides (in P.P.M.), Which Did Not Cause a Reduction in Root or Stem Lengths of Corn and Peas, Grown in Treated Quartz Sand

(Concentrations used. 30, 16, 8, 4, 2, 1, 0.5 p.p.m.)

	Corn		Peas	
	Roots	Stems	Roots	Stems
Lindane	0.5	<0.5	1	2
Chlordan	4	16	30	16
Methyl parathion	2	2	16	16
Phorate (Thimet)	16	8	8	30
Sevin	1	0.5	4	4

Table III. Effect of Lindane on Root Growth of Bitter Blue Lupines in Miami Silt Loam

(Treatment 50 p.p.m.)

Growing Time, Days	Root Length, Cm.[a] Control	Root Length, Cm.[a] Treated	% Ck.[b]
2	4.43 ± 1.25[c]	2.97 ± 1.41	67.0
4	10.83 ± 1.10	5.95 ± 0.94	54.9
6	13.42 ± 2.22	5.39 ± 0.55	40.2
10	12.53 ± 3.55	4.88 ± 0.63	38.9
14	13.21 ± 1.78	5.88 ± 1.06	44.5

[a] All differences obtained at various time intervals are significant at 1% level.
[b] Treated in % of control plants.
[c] Standard deviation.

Table IV. Effect of Insecticides on Respiration of Root Tips, Grown in Insecticide-Treated (30 P.P.M.) Quartz Sand

(μl. Oxygen uptake in % of control)

	Corn		Oats		Peas		Cucumbers	
Insecticide	A[a]	B[b]	A	B	A	B	A	B
Lindane	70.8[c]	77.6[c]	77.1[c]	127.7[c]	103.9	98.8	82.2	73.9[c]
Chlordan	97.2	105.5	123.0[c]	107.3	93.6	91.7	98.0	91.0
Aldrin	82.8	89.0	82.9[c]	89.5	96.6	100.0	100.0	93.0
Dieldrin	72.4[d]	76.2[d]	62.7[d]	65.8[d]	101.9	103.8	107.2	72.2[c]
Heptachlor	99.2	95.5	99.4	98.0	109.9	117.0[d]	127.2	100.4
Hept. epoxide	114.9	105.5	87.9	82.8[c]	100.1	111.0	103.2	96.1
Toxaphene	105.9	93.9	89.0	78.8[d]	108.3	99.0	114.5	119.3
Endrin	84.8[d]	93.3	85.5	82.8	95.7	93.2	97.6	110.7[c]
p,p'-DDT	89.7[c]	92.6	73.0[c]	73.5[c]	92.6[c]	89.7[d]	78.3[d]	83.8[c]
Methoxychlor	91.2	93.3	82.4	82.8	88.0[d]	89.7[c]	79.4[d]	99.3
Parathion	117.0[c]	132.6[d]	92.1	105.9	95.8	98.0	68.0[d]	85.4
Methyl parathion	107.8	138.5[d]	75.8[d]	107.2	90.9[d]	95.9	73.0[d]	96.4
Phorate (Thimet)	86.6	96.4	92.4	118.0[d]	91.9[c]	106.0	88.3[c]	108.9
Malathion	99.2	111.7	93.0	103.3	102.2	102.1	93.3	106.4
Systox	95.5	102.3	83.7[d]	88.9[d]	83.8[d]	87.1[d]	83.7[c]	96.3
Sevin	58.4[d]	83.1	46.0[d]	106.3	72.3[d]	90.0[c]	50.0[d]	61.9[d]
1-Naphthol	61.7[d]	87.3	70.2[d]	102.0	91.5[c]	124.6[d]	87.9[c]	99.3

[a] Per 1 mg. dry weight.
[b] Per 100 mg. fresh weight.
[c] Significant at 5% level (*t*-test).
[d] Significant at the 1% level (*t*-test).

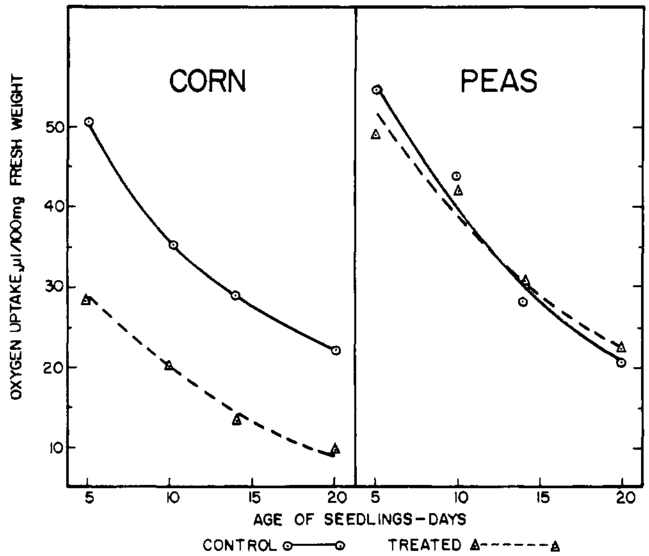

Figure 3. Effect of age on respiration of root tips grown in lindane-treated (30 p.p.m.) quartz sand

Table V. Dry Matter Content of 10-Mm. Root Tips of Various Crops Grown in Insecticide Treated (30 P.P.M.) Quartz Sand

	(Per cent of control)			
	Corn	Oats	Peas	Cucumbers
Lindane	110	168	94	90
Chlordan	108	88	98	93
Aldrin	107	108	103	93
Dieldrin	106	104	102	...
Heptachlor	96	98	107	79
Hept. epoxide	97	94	111	93
Toxaphene	88	88	87	104
Endrin	110	97	98	113
p,p'-DDT	103	101	97	105
Methoxychlor	102	102	102	125
Parathion	114	115	102	126
Methyl parathion	129	142	107	132
Phorate (Thimet)	111	128	116	123
Malathion	113	111	100	114
Systox	107	107	105	115
Sevin	148	232	125	124
1-Naphthol	141	145	136	113

The effect of various insecticidal residues in quartz sand on the respiration of root tips of corn, oats, peas, and cucumbers is summarized in Table IV. Usually (*8*), the amount of oxygen taken up by respiring cells is expressed in microliters of oxygen per milligram dry weight of tissue per hour (Q_{O_2}). On this basis (Table IV, column A), many insecticides caused a significant reduction of cell respiration. Corn and oats were primarily affected by the chlorinated hydrocarbon insecticides, while peas and cucumbers were more susceptible to the organophosphates.

Sevin and *p,p'*-DDT caused a significant reduction in the respiration of all four plants investigated. The most striking effect was observed with Sevin, which caused a reduction of 28 to 54% in the uptake of oxygen per milligram dry weight per hour. Even 1-naphthol caused a reduction in root tip respiration of all four plants.

However, the amount of dry matter within the plant tissues was affected by some insecticides (Table V), especially by methyl parathion, Sevin, and its hydrolysis product 1-naphthol. Cucumbers were most susceptible and the dry matter content in their root tissue had increased in response to endrin, methoxychlor, Sevin, and all the organophosphate insecticides used. Corn and pea plants were least affected in this respect. Conversely, the dry matter content of corn, oats, and peas grown in toxaphene-treated sand was reduced.

Presentation of respiration data on a dry matter basis (Q_{O_2}) is based on "an effort to estimate the active portion of cell constituents" (*8*). However, if part of this dry matter is not alive, but increases cell weight and cell volume, then this dry matter does not represent an estimation of the actual live cell constituents. If, for instance, the oxygen uptake of 100 mg. of fresh tissue A is 50 µl. per hour, its dry weight is 5 mg., then the Q_O value is 10 µl per mg. per hour. When tissue B is used, the oxygen uptake per 100 mg. of fresh tissue might also be 50 µl. per hour. However, if its dry weight is 10 mg., the Q_{O_2} value would be 5 µl. per mg. per hour as compared to 10 when tissue A is used. Therefore, although the rate of respiration is different on a dry weight basis, there is no change on a fresh weight basis.

Because of this difficulty in comparing respiration data of various tissues, the amount of oxygen taken up per 100 mg. of fresh tissue is also presented (Table IV, column B). On this basis, some of the reductions in the rate of respiration registered on a dry weight basis were no longer noticeable. However, a definite reduction in the rate of respiration of root tips on both the dry and the fresh weight basis was caused by lindane (corn), dieldrin (corn, oats), *p,p'*-DDT (oats, peas, cucumbers), methoxychlor (peas), Systox (oats, peas), and Sevin (peas, cucumbers). Parathion caused a significant increase in the respiration of corn root tips.

Conclusions

Growth and respiration of corn, oats, peas, and cucumber plants are affected by various insecticidal residues. Some chemicals cause a reduction in plant growth as well as in cell metabolism, others do not affect the growing plant at all, and some even enhance plant growth. There seems to be no straight relationship between the effect of insecticides on root growth and on the respiration of root tips.

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