Translocation of Insecticides from Soils into Pea Plants

Effects of the Detergent LAS on Translocation and Plant Growth

E. P. Lichtenstein, T. W. Fuhremann, N. E. A. Scopes, and R. F. Skrentny

Experiments were conducted to study quantitatively and qualitatively the penetration of ethyl parathion, diazinon, lindane, and aldrin from sand into the roots of peas and the translocation of these insecticides within the plant system. The effects of the detergent LAS on the uptake of these insecticides and on plant growth were also investigated. All the insecticides, with the exception of diazinon, accumulated within the roots of pea plants while growing in sand treated with insecticides at 5 p.p.m. LAS did not affect the penetration of lindane or aldrin into roots, but significantly reduced the amounts of parathion that penetrated the root system. Apparently, all the insecticides were translocated into the greens, yet the organophosphorus compounds were metabolized and detoxified. Lindane residues in the green plant part were the highest among the insecticides tested, though LAS reduced that translocation. Aldrin, after its penetration into the pea roots, was partially epoxidized into dieldrin which was then translocated to a small extent into the pea greens. Roots were most susceptible to both LAS and pesticide treatments.

Agricultural soils contain residues of various pesticidal chemicals, owing to their direct application or fallout following crop spraying. Some of the insecticidal chemicals penetrate roots and are translocated within the plant (Lichtenstein and Schulz, 1960b). The degree of penetration and the subsequent translocation are functions both of the soil type and the physicochemical properties of the particular compound, such as its water solubility, stability within living cells, etc. (Tietz, 1954; Lichtenstein, 1959; Reynolds, 1962).

Synthetic chemicals produced during the last two decades are widely used in agriculture and industry. Some of these find their way into soil-water systems. The California State Legislature reported (1965) that the detergent, alkyl benzene sulfonate (ABS), was present in the average municipal sewage water at a concentration of 10 p.p.m. Lichtenstein (1966) reported that ABS and LAS (linear alkyl benzene sulfonate) increased the persistence and toxicity of parathion and diazinon in soils. It is the potential interaction of some of the synthetic chemicals within living organisms that are of interest and merit careful investigation. A more complete knowledge is desirable about the fate of synthetic chemicals, such as pesticide molecules within living cells and their effects on cells and their components.

Experiments were conducted at the University of Wisconsin to study the effect of the biodegradable detergent LAS both on the penetration and translocation of several pesticides into pea plants and on plant growth. For this purpose, peas were grown in quartz sand which had previously been treated with a particular pesticide while nutrient solutions or nutrient solutions containing LAS were added during the growing period. LAS, having both a polar-hydrophilic and a nonpolar-hydrophobic (lipophilic) group might affect the penetration and translocation of insecticides with low or moderate water solubility.

Department of Entomology, University of Wisconsin, Madison, Wis.

PROCEDURE

Application of Pesticides and Detergent. The following analytical grade pesticides were used: ethyl parathion, diazinon, aldrin, lindane, Sevin, and simazine. They were applied at 5 p.p.m. in acetone to quartz sand except for simazine, which was applied in methanol. Treatment and mixing of the sand was done as described by Lichtenstein *et al.* (1962). Portions (100 grams) of the sand treated with parathion, diazinon, aldrin, or lindane were extracted and analyzed immediately to establish the initial concentration of the insecticides.

For each treatment, six nonglazed clay pots (opening = 15-cm. I.D.) were filled with pesticide-treated quartz sand. In addition, 16 control pots were filled with untreated quartz sand. The sand in three pesticide-treated pots and in eight control pots was then saturated with a complete plant nutrient solution, whereas the sand in the remaining pots was saturated with a nutrient solution to which LAS had been added at a concentration of 0.005%. All pots were covered with heavy aluminum foil and stood in saucers.

Plant Growing and Harvest Procedure. Pea seeds (Alaska Wilt Resistant) were surface sterilized by soaking them for 10 minutes in water-diluted Clorox (Clorox Co., Oakland, Calif.) containing 0.5% of sodium hypochlorite (Sanwal, 1963) to obtain a high germination rate. The seeds were then washed for 2 hours in running tap water and allowed to germinate in vermiculite. When roots were 1 to 2 cm. long, 25 seedlings were removed and planted through holes in the aluminum foil cover of each pot, which prevented excessive water evaporation from the sand and possible pickup of pesticidal vapors by the pea leaves. The plants grew for 26 days (Figure 1) in the laboratory under GRO-LUX lamps (T = 22 ± 2° C., RH = 40 ± 5%, 9 hours of light per day). Half of the pots in each treatment were watered during the growing period with nutrient solution added to the saucers as necessary, while the remainder were watered with nutrient solution containing 0.005% LAS (Atlantic Refining Co., Chicago, Ultrawet K Soft, Sample 98509). In this way, pea plants were obtained from three replicated pots for each pesticidal treatment after watering with nutrient

Figure 1. Pea plants grown in quartz sand that was watered with plant nutrient solution containing 0.005% of LAS (linear alkyl benzene sulfonate) or with nutrient solution (– –)

solution only and from three replicated pots that had been watered with nutrient solution containing LAS.

The greens from each pot were cut at harvest time 1.0 to 1.5 cm. above the "soil" surface; the length of the greens of each plant from one particular pot was then measured, and the total fresh weight from each pot determined. Approximately 15 grams of green material were then removed from the three replicated pots for dry matter determinations. The remaining greens from each of three replicated pots were then placed into individual plastic bags and frozen for future analyses of insecticidal residues. Since in some cases not enough green plant parts were available, additional pea plants were grown as described for thin-layer chromatographic investigations.

The sand and roots in each pot were separated by pouring the top layer of sand carefully into a plastic bag. The roots were then pulled out gently. The remainder of the sand was added to the bag and frozen for future extraction and analysis.

The roots were placed on a 10-mesh sieve and washed with cold tap water to remove sand particles. They were then dried with blotting paper, and the total fresh weight of roots from one particular pot was determined. They were next placed into individual plastic bags and frozen for future analysis. This procedure did not differentiate between residues within the root system and those adhering to the outside of the root epidermis. Analytical data referring to residues within the root are to be understood and interpreted in that way.

Extraction Procedures. Roots and greens grown in either parathion-, diazinon-, aldrin-, or lindane-treated sand as well as the sand itself were analyzed for insecticidal residues. Redistilled benzene and acetone (4 to 1) were used for the extraction of parathion residues, and redistilled hexane and acetone (1 to 1) were used for the other insecticides. In the latter case, the acetone was removed from the extract with water.

The sand, prior to the extraction, was passed through an 8-mesh screen both for mixing and for removal of root particles. It was then air dried to a moisture content of approximately 3%. A 2 to 1 solvent to sand ratio was used for extraction in a homogenizer (Volu-Mix, Lourdes Instrument Corp.).

Roots and greens were cut into 0.5- to 1-cm. pieces and placed in an extraction jar. To facilitate grinding of the plant material, some hexane-washed quartz sand (half the amount of the plant material) was added. Roots and greens were extracted for 15 minutes in the homogenizer using 5 ml. of solvent per gram of plant material. For the detection of possible water-soluble metabolites of diazinon, the water-acetone phase of these particular extracts was concentrated at 50° C. in a flash evaporator to approximately 40 ml. This concentrate was then re-extracted with three 100-ml. portions of chloroform–diethyl ether (1 to 1) and was further concentrated and adjusted to volume with chloroform.

Cleanup Procedures. Two cleanup procedures were used.

Extracts of roots and greens containing aldrin or lindane residues were passed through a 10-gram Florisil (60- to 100-mesh) column (17-mm. I.D.) and eluted with 150 ml. of 6% ether in redistilled hexane. Extracts containing diazinon residues were treated similarly except that 10% ether in redistilled hexane was used.

These extracts were then subjected to the Sweep cleanup procedure (Storherr and Watts, 1965) with the Kontes-Sweep codistillation apparatus. Residues of the chlorinated hydrocarbon insecticides were passed through borosilicate glass wool packed Sweep columns and eluted with redistilled acetone at 245° C. Residues of the organophosphorus insecticides were passed through similar Sweep columns and eluted with redistilled benzene–acetone (4 to 1) at 190° C.

A total of 18 extracts were finally prepared for each of the individual insecticidal treatments—i.e., three replicates from treated sand, three from treated sand watered with LAS, and three each of roots or greens grown in these sands.

Analytical Procedures. The extracts were analyzed by gas-liquid chromatography, thin-layer chromatography, and bioassay procedures.

Gas-liquid chromatography was used to detect insecticidal residues. A Jarrell-Ash gas chromatograph, Model 28-700, equipped with a 100-mc. tritium electron affinity ionization detector and operated at 20 volts was employed to detect parathion, aldrin, and lindane residues. A 1.22-meter glass column (4.0 mm. I.D.) containing a 1 to 1 mixture of 5% Q.F. 1 and 5% DC 200 coated on Anakrom AS, 80- to 90-mesh, was conditioned for 7 days at 250° C. before use. A column pressure of 16 p.s.i. of nitrogen gave a flow rate of 100 ml. per minute. The injector temperature was maintained at 250° C., and the detector cell at 210° C. The oven-temperature was 190° C.

Extracts containing diazinon residues were analyzed with the same instrument, but a hydrogen flame detector

was used. For these analyses, a 1.73-meter glass column (4.0-mm. I.D.) with the previously mentioned packing was used. A column pressure of 20 p.s.i. of nitrogen gave a flow rate of 100 ml. per minute. The injector temperature was maintained at 230° C. and the detector cell at 210° C. The column temperature was 190° C. The air flow was 0.028 cu. meter (1 cu. foot) per hour, and the hydrogen flow was adjusted to produce a background current of 8×10^{-9} amp. full-scale deflection. Extracts were analyzed at constant temperatures and also by employing temperature programming for both the hexane fractions (150° to 200° C., 5° per minute) and the water-acetone fractions (120° to 180° C., 10° per minute).

In addition to diazinon, five potential diazinon metabolites were obtained from the Geigy Agricultural Chemicals Co. These were: *A*, 2-isopropyl-4-methyl-6-hydroxy-pyrimidine; *B*, 2-isopropyl-4-methyl-6-mercaptopyrimidine; *C*, 2-isopropyl-4-methyl-6-ethoxy-pyrimidine; *D*, Diazoxon (*O*-diazinon); and *E*, dithionotetraethyl-pyrophosphate. These compounds were used for comparison with the actual samples under investigation.

After the various extracts had been analyzed by gas-liquid chromatography, the remainder of the three replicates was pooled and used for further investigations by thin-layer chromatography and bioassay procedures.

Thin-layer chromatography was used for further identification of the insecticides and their possible metabolites. Parathion or diazinon residues were spotted on a silica gel–coated (silica gel G, containing calcium sulfate as a binder, DESAGA-Heidelberg) glass plate (20 × 20 cm.), 2.5 cm. above the lower edge.

Chromatograms with parathion residues were developed with hexane–chloroform–anhydrous methanol (7:2:1). They were then sprayed successively with a palladium chloride solution (0.5 gram of palladium chloride in 2% HCl) and 5*N* sodium hydroxide.

Chromatograms containing diazinon residues were developed with benzene–chloroform–ethyl acetate (2:2:1), (Geigy Chemical Corp. method, private communication), followed by spraying with 0.1% of Rhodamine B in ethyl alcohol (95%), exposure to UV light, and additional successive sprays with 0.5% palladium chloride and 5*N* sodium hydroxide. Under these conditions, diazinon ($R_f = 0.57$), and compounds *E* ($R_f = 0.65$), and *B* ($R_f = 0.36$) were visible with yellow colors, whereas the compounds *A* ($R_f = 0.08$) and *D* ($R_f = 0.27$) were visible under UV light with dark blue colors. Compound *C* ($R_f = 0.51$) was also visible under UV light, but only before being sprayed with 5*N* NaOH.

Aliquots of extracts containing lindane or aldrin residues were spotted on aluminum oxide G containing calcium sulfate as a binder (Merck, Darmstadt). The chromatograms were developed with 5% acetone in hexane, followed by spraying with reagents as described by Mitchell (1957) and subsequent exposure to UV light for 30 minutes.

Bioassay procedures were used to reveal the presence of toxic substances within the materials under investigation. Two insects (*Drosophila melanogaster* Meigen, Diptera and *Folsomia fimetaria* L., Collembola) were employed because of their varying susceptibility to different insecticides (Scopes and Lichtenstein, 1967). Aliquots of the various extracts were pipetted in duplicate onto filter paper (Whatman No. 2, 5.5 cm. diam.) lining the bottom of 4-ounce test jars. The solvent was evaporated, then the filter paper was wetted with water. Folsomia were then exposed to the treated paper for 24 hours and then removed. The same filter paper was wetted and Drosophila flies were introduced and exposed to the now one-day-old residue. Mortality counts of both the Folsomia and the Drosophila flies were performed at different intervals during the respective exposure periods.

RESULTS AND DISCUSSION

Translocation of Insecticides into Pea Plants as Affected by LAS. Results obtained from the analyses of sand and plant parts are summarized in Table I. There are two points of major interest: one pertains to the differences observed between the residue levels of the chlorinated hydrocarbon and organophosphorus insecticides within the plant system, while the other refers to the tremendous differences between the insecticidal residues that were recovered from the roots and those that were finally translocated into the green plant parts.

PARATHION. Twenty-six days after the application of parathion at 5 p.p.m., the sand remained toxic to both Folsomia (100% mortality after exposure for 24 hours to extracts representing 5 grams of sand) and Drosophila (38 to 54% mortality after exposure for 24 hours to extracts representing 5 grams of sand). As reported elsewhere (Scopes and Lichtenstein, 1967), Drosophila are less susceptible to parathion than Folsomia.

Only 5% of the originally applied insecticide dosage was recovered from the sand. In addition to parathion, *p*-nitrophenol was detected by thin-layer chromatography. The effect of LAS on the persistence of parathion in sand as reported earlier was not noticeable (Lichtenstein, 1966). This, however, was not surprising since, in the previously described experiments, higher concentrations of LAS had been used.

Extracts of pea roots were very toxic to both test insects and the equivalents of only 0.05 gram of root material killed nearly all the insects within a 3-hour exposure time. Analysis by gas-liquid chromatography revealed that parathion had actually accumulated within the roots, where its concentrations were 224 to 649 times higher than in the sand. However, in the presence of LAS, the amount of parathion in the root was significantly reduced by two thirds. The roots also contained *p*-nitrophenol in addition to parathion as evidenced by thin-layer chromatography.

Although the concentration of parathion in the roots was large, the greens did not contain any measurable insecticidal residues. Using bioassay procedures, however, extracts of greens had some toxicity (100% mortality of Folsomia after exposure for 3 hours to extracts representing 5 grams of pea greens). In addition, spots with R_f values identical to paraoxon and *p*-nitrophenol were detected by thin-layer chromatography in extracts of greens grown in LAS-free sand. Parathion apparently was metabolized and detoxified after penetrating the root system, thus preventing its detection within the green parts of the plant.

DIAZINON. Extracts of diazinon-treated sand and of peas grown therein were all toxic to Folsomia (100% mortality after exposure for 3 hours to extracts represent-

Table I. Effects of LAS on the Penetration of Insecticide Residues into Pea Plants Grown in Parathion-, Diazinon-, Aldrin-, or Lindane-treated Quartz Sand (5 P.P.M.)

Insecticidal treatment	Recovered from sand and peas, 26 days after insecticidal application and plant growth					
	Sand		Roots		Greens	
	...	LAS[a]	...	LAS	...	LAS
Parathion p.p.m.[b]	0.24 ± .05[c]	0.24 ± .05	155.67 ± 13[d]	53.67 ± 23[d]	Trace	[e]
BA[f]	T − F.D.	T − F.D.	T − F.D.	T − F.D.	T − F	T − F.D.
Diazinon p.p.m.	0.01 ± .001	0.01 ± .003	.09 ± .05	0.07 ± .02	[e]	[e]
BA	T − F	T − F	T − F	T − F	T − F.D.	T − F.D.
Aldrin p.p.m.[g]	2.30 ± .13	2.57 ± .47	51.5 ± 9.9	68.4 ± 8.0	0.19 ± .07[h]	0.49 ± .14[h]
%D[i]	1	1	11	12	93	80
BA	T − D.	T − D.	T − D.	T − D.	T − D.	T − D.
Lindane p.p.m.	0.62 ± .22	0.65 ± .35	82.6 ± 26	72.3 ± 21	22.9 ± 8.5[j]	3.05 ± 2.5[j]
BA	T − F.D.	T − F.D.	T − F.D.	T − F.D.	T − F.D.	T − F.D.

[a] LAS (linear alkyl benzene sulfonate) added at 0.005% with nutrient solution to sand, in which plants grew.
[b] Recovered in p.p.m. by gas-liquid chromatography. Data obtained by thin-layer chromatography are reported in text.
[c] Standard deviation.
[d] Differences observed between treatments with and without LAS are significant at the 1% level.
[e] No measurable amounts detected.
[f] BA = Bioassay. Residues from extracts of sand or peas were toxic (T) to either *Folsomia fimetaria* (T − F.), to *Drosophila melanogaster* (T − D.), or to both test insects (T − F.D.). No insect mortalities were obtained with extracts from untreated sand or plants grown therein.
[g] Total of aldrin plus dieldrin.
[h] Differences observed between treatments with and without LAS are significant at 10% level.
[i] Dieldrin in per cent of total residue (aldrin + dieldrin) recovered.
[j] Differences observed between treatments with or without LAS are significant at 5% level.

ing 20 grams of sand or 2 grams of plant material). With Drosophila, mortalities were observed with greens even after the flies had been exposed to the one-day-old residues on filter paper. Since no control mortalities occurred, the presence of toxic substances in all these materials was indicated. Diazinon was the least persistent of the insecticides, and nearly all of the applied dosage had disappeared from the sand after 26 days. Contrary to results with parathion, roots of plants from diazinon-treated sand contained only small amounts of diazinon and no residues could be detected in the hexane fraction of the greens. Extracts of sand, roots, or greens gave negative results with thin-layer chromatography.

Investigations of the water-acetone fractions of the sand or plant extracts with hydrogen-flame gas chromatography revealed nontoxic analogs of diazinon in the extracts from pea greens. Plants grown in sand that had been treated with diazinon only, contained the potential metabolites *B* and *C* while those grown in sand that also had been treated with LAS contained only *C*.

Neither diazinon nor some of its toxic metabolites could be detected in extracts of the pea greens, even though these extracts were toxic to both test insects. Therefore, an additional experiment was conducted in which sand was treated with diazinon at the higher dosage of 25 p.p.m. Peas were grown in this sand, which was watered only with nutrient solution. After the peas had grown for 15 days, the sand, roots, and greens were extracted and analyzed as described, by gas-liquid chromatography and thin-layer chromatography. This time, after a fivefold increased dosage of the insecticide had been applied, diazinon was detected in the greens at a concentration of 0.27 p.p.m. The presence of the diazinon residues was undoubtedly related to the higher concentration of the insecticides in the sand and possibly also to the shorter growing time (15 days instead of 26) of the peas. The concentration of diazinon in the roots was 35 times larger (9.45 p.p.m.) than in the greens and amounted to 15% of the insecticidal concentration in the sand (1.87 p.p.m.). Diazinon was also detected in the sand, roots, and greens with thin-layer chromatography. In addition, roots contained compound C (2-isopropyl-4-methyl-6-ethoxy-pyrimidine). Results of this experiment suggest that the insect mortalities obtained with greens grown in sand treated with diazinon at 5 p.p.m. were probably due to this insecticide which was not detected by the other analytical methods employed.

ALDRIN. Folsomia, which is more resistant to aldrin than Drosophila (Scopes and Lichtenstein, 1967) did not die after their exposure to extracts from aldrin-treated sand or plants grown therein. Though aldrin is relatively volatile, 100% mortalities of Drosophila were obtained within 20 hours even when the flies were exposed to the wet filter paper to which aliquots of sand (1 gram) and root (0.1 gram) extracts had been added one day previously. With extracts representing 5 grams of greens, the flies were exposed immediately after the application of the extracts, resulting in a 90% mortality within a 5-hour exposure time.

Aldrin was more persistent in the sand than the other insecticides and 48% of the applied dosage was recovered after 26 days. The concentration of aldrin residues in the roots was not affected by the presence of LAS, but it was 22 to 27 times higher than the concentration in the sand at harvest time. Conversely, the concentration of aldrin residues in the greens amounted to only small fractions (0.1 to 0.2) of that in the sand at harvest time, but the presence of LAS resulted in 2.5 times higher residues in the greens as compared with those that were grown in LAS-free sand.

Thin-layer chromatography confirmed the presence of aldrin in the sand, and the presence of aldrin and dieldrin in the plant parts.

The conversion of aldrin to dieldrin in both soils and plants is a function of biological factors (Lichtenstein and Schulz, 1960a, 1960b). The experiments discussed here

not only confirmed these findings but also shed some light on the penetration of aldrin into plant systems. The results indicate that there was no appreciable conversion of aldrin to dieldrin in the quartz sand, and the amount of dieldrin found (1% of the totally recovered residues) was probably contained within small root particles that could not be separated from the sand. The amount of dieldrin in roots, though containing large amounts of residues, was only 11 to 12% of the totally recovered aldrin and dieldrin. Within the greens, however, nearly all the recovered residues were in the form of dieldrin. Aldrin (water solubility 0.01 p.p.m.), owing to its lipide-soluble properties, penetrated the root system. However, the aldrin apparently was epoxidized to dieldrin within the root system. Once this had been accomplished, the 10 times more water-soluble dieldrin was translocated to a small extent into the green parts of the plant, where the residues were only 0.37% and 0.71% of those found in the roots.

LINDANE. Extracts of lindane-treated sand and of plants grown therein were toxic to both Folsomia and Drosophila. According to these data, the greatest amount of toxicants was in the roots (100% mortality after exposure of both test insects for 3 hours to extracts representing 0.1 gram of roots) and the smallest in the sand (50% mortality after exposure of Folsomia for 3 hours to extracts representing 4 grams of sand). Analyses of the sand by gas-liquid chromatography showed that at harvest time only 12.8% of the originally applied lindane was present. However, the insecticide had accumulated within the roots where its concentration was 111 to 133 times greater than that in the sand. LAS did not affect this penetration into the root system. The amount of lindane translocated into the greens was the highest of the insecticides tested, probably owing to both its higher water solubility (6.6 p.p.m.) as compared to aldrin (0.01 p.p.m.) and its greater stability in comparison with the organophosphorus compounds. The amounts of lindane in greens grown in the absence of LAS were 7 times larger than in those that were grown in lindane-treated sand containing LAS. These differences were significant (5% level) and indicate an effect of LAS in reducing the translocation of lindane from the roots to the greens. Since the detergent has a polar, hydrophilic group as well as a nonpolar, lipophilic group, the insecticide could have been bound by the LAS to some organic substances within the root tissues, thus diminishing the translocation of lindane into the greens.

Lindane (R_f = 0.47) was found in sand, roots, and greens using thin-layer chromatography. In addition, an unknown compound (R_f = 0.18) was detected in both sand samples and another one (R_f = 0.65) in roots grown in LAS-free sand. These two compounds had R_f values different from 1,2,3-trichlorobenzene and 1,3,5-trichlorobenzene. Neither of these trichlorobenzenes, nor 1,2,4-

Table II. Effects of Pesticides and LAS in Quartz Sand on Growth of Pea Plants

(Pesticidal treatment = 5 p.p.m., growing time = 26 days, T = 22 ± 2° C, R. H. = 40 ± 5%, light day = 9 hrs.)

	Pea Greens								Pea Roots, Fresh Weight			
	Length				Fresh Weight							
Treatment	Cm.[a]	L%[b]		PCk%[c]	Gram[d]	L%		PCk%	Gram[e]	L%		PCk%
None	27.0	100	100	...	0.92	100	100	...	0.50	100	100	...
None + LAS[f]	14.9	54[g]	...	100	0.41	44[g]	...	100	0.26	52[g]	...	100
1% LSD:L%[h] =	12.06				0.46				0.20			
5% LSD:L% =	8.92				0.34				0.15			
Parathion	23.9	100	88	...	0.80	100	87	...	0.35	100	70[i]	...
Parathion + LAS	10.9	44[g]	...	73	0.40	50[g]	...	98	0.23	66	...	88
Diazinon	25.6	100	95	...	0.84	100	91	...	0.36	100	72[i]	...
Diazinon + LAS	8.7	34[g]	...	58	0.31	37[g]	...	76	0.16	44[g]	...	62
Aldrin	28.0	100	104	...	1.04	100	113	...	0.47	100	94	...
Aldrin + LAS	15.3	53[g]	...	103	0.51	49[g]	...	124	0.28	60[g]	...	108
Lindane	22.2	100	82	...	0.76	100	83	...	0.30	100	60[j]	...
Lindane + LAS	12.0	54[g]	...	80	0.44	58[k]	...	107	0.19	63	...	73
Sevin	20.6	100	77	...	0.66	100	72	...	0.43	100	86	...
Sevin + LAS	11.6	56[k]	...	78	0.40	60	...	98	0.21	49[g]	...	81
Simazine	10.3	100	39[j]	...	0.24	100	26[j]	...	0.31	100	62[j]	...
Simazine + LAS	11.0	106	...	78	0.37	154	...	90	0.25	81	...	96
L%[l]: 1% LSD	9.84				0.39				0.16			
5% LSD	7.28				0.28				0.12			
PCk[m]: 1% LSD	11.0				0.42				0.18			
5% LSD	8.17				0.31				0.13			

[a] Average length of one plant-green, determined from the means of 3 replicates each consisting of 22–25 plants.
[b] L%: Data obtained with LAS in per cent of those that were obtained in the absence of LAS.
[c] PCk%: Data obtained with pesticides in per cent of those that were obtained without pesticides (= 100).
[d] Average fresh weight of one plant, determined from the mean of plants grown in 3 replicated pots.
[e] Average fresh weight of one plant root, determined from the mean of roots grown in 3 replicated pots.
[f] LAS (0.005%) added within nutrient solution to quartz sand.
[g] Differences observed between treatments with LAS and those without LAS are significant at the 1% level.
[h] Values of least significant difference for the comparison of data obtained in the presence or absence of LAS, but without pesticidal treatment ("None").
[i] Differences observed between treatments with *a* particular pesticide and those without the pesticide are significant at the 5% level.
[j] Differences observed between treatments with *a* particular pesticide and those without the pesticide are significant at the 1% level.
[k] Differences observed between treatments with LAS and those without LAS are significant at the 5% level.
[l] Values of least significant difference for the comparison of data obtained in the presence or absence of LAS for one particular pesticidal treatment.
[m] Values of least significant difference for the comparison of data obtained with or without pesticides.

trichlorobenzene could be detected in the greens with gas chromatography.

At a treatment rate of 5 p.p.m., all the insecticides with the exception of diazinon accumulated within the roots of the pea plants while growing in insecticide-treated sand. LAS did not affect the penetration of lindane or aldrin into roots, but significantly reduced the amounts of parathion that penetrated the root system. Apparently, all the insecticides were translocated into the greens, yet the organophosphorus compounds were metabolized and detoxified. Lindane residues in the green plant parts were the highest among all the insecticides tested, while only small amounts of aldrin residues had been translocated.

When interpreting these data in terms of actual growing conditions, it should be borne in mind that the quartz sand is not a soil and does not have the binding capacities of organic soil matter. If organic matter had been present, the insecticidal chemicals would have been less available for penetration, translocation, and toxicity effects (Lichtenstein, 1959).

Effects of LAS and Pesticides on Plant Growth. At the end of the 26-day growing period, length and weight measurements of plant parts were performed as previously described. The results were then averaged and expressed for one plant, evaluated statistically and summarized in Table II. The detergent by itself caused a significant reduction (1% level) of the length and fresh weight of the plant parts by 46 to 56%. This reduction with LAS was also noticeable in the presence of the insecticides (42 to 62%). With simazine, however, no additional growth reduction occurred after the plants were exposed also to LAS. In the same way, no additional reduction in the fresh weight of roots occurred with LAS when lindane or parathion were present.

The effects of pesticides on plant growth were less noticeable than the effect of LAS (PCk%, Table II). Only simazine caused a significant reduction (1% level) in the length of greens and fresh weight of greens and roots by 41, 74, and 38%, respectively. Roots were most susceptible to the pesticidal sand treatment. In addition to simazine, the presence of either parathion, diazinon or lindane also resulted in a reduction of the fresh root weight by 30, 28, and 40%, respectively.

The dry weight of green plant parts was not affected by the pesticides, LAS, or combinations thereof.

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Received for review March 29, 1967. Accepted May 31, 1967. Approved for publication by the Director of the Wisconsin Agricultural Experiment Station. Research supported in part by a grant from the U. S. Public Health Service Communicable Disease Center, CC-297 (formerly EF-168). Contribution from the Wisconsin Agricultural Experiment Station as a collaborator under North Central Regional Cooperative research project 85, entitled Reduction of Hazards Associated with the Presence of Residues of Insecticidal Chemicals in the Environment.