Influence of Plant Nutrition on Lindane Penetration and Its Translocation within Pea Plants

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The importance of macro- and micro-plant nutrients was investigated relative to their effects on the penetration of lindane into roots and the translocation of the insecticide within pea plants. Results indicated that the penetration of lindane into the roots of plants that had been grown in nitrogen-, sulfur-, or boron-deficient media had increased by 27, 18, and 23%, respectively, while the translocation of the insecticide into the greens was reduced by 81, 18.1, and 66.8%, respectively. A deficiency in magnesium resulted in reduction of both the penetration and the translocation of lindane, while a deficiency in potassium effected only translocation by reducing the lindane concentration in the greens by 23.9%. Since an intentionally produced deficiency of one element also affected the concentration of others in the plant tissues, a combination of factors could have been responsible for the observed effects. Annulment of the effects of an intentionally produced nitrogen deficiency on the penetration and translocation of lindane in pea plants was partially achieved after resupplying nitrogen to plant roots.

Agricultural soils contain residues of pesticides due to their direct application to soil or "fall out" after crop spraying for pest control. Crop plants growing in such contaminated soils absorb some of these chemicals at various rates and also in some cases translocate them into aerial parts (Lichtenstein and Schulz, 1960; Lichtenstein *et al.*, 1967). The extent of penetration of a given insecticide into plant roots and its subsequent translocation are functions of a particular plant, soil type, and physicochemical properties of a chemical such as water solubility and/or its stability within living cells (Lichtenstein, 1959; Lichtenstein *et al.*, 1970; Reynolds and Metcalf, 1962; Tietz, 1954). While pesticides can influence the nutrient content of plants (Adams and Espinoza, 1969; Voigt, 1955) nutrients can also affect the penetration into and translocation of pesticides within plants. Thus, Casida *et al.* (1952) showed a decreased schradan absorption by pea plants with an increased phosphorus supply, while Hacskaylo *et al.* (1961) reported a reduced dimethoate absorption by cotton plants grown in phosphorus deficient nutrient solutions. Rohrbaugh and Rice (1956) and Rice and Rohrbaugh (1958) showed that 2,4-D was not readily translocated within phosphorus or potassium-deficient tomato plants. With decreasing levels of nitrogen in nutrient solutions, a significant increase in schradan absorption into cotton plants was achieved (Hacskaylo and Ergle, 1955). Yu and Morrison (1969) demonstrated that the amount of mevinphos and phosphamidon that had been translocated into leaves of bean plants was positively correlated with the external supply of nitrogen, potassium, phosphorus, and magnesium, while sulfur and calcium had little or no effect. Available data indicate that the effects of plant nutrients on the absorption and translocation of insecticides in plants vary for different pesticides in different plants. The purpose of the present investigation was to study the effects of both macro- and microelements in nutrient solutions on the penetration of lindane into the roots of pea plants and the translocation of the insecticide into the aerial plant parts.

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METHODS AND PROCEDURES

Growing of Plants. Pea seeds (*Pisum sativum*, variety Alaska Wilt Resistant) were germinated in quartz sand and kept in a growth chamber (12 hr of light at 28° C and 12 hr of dark at 20° C, relative humidity 65 ± 2%). To obtain rapid growth, germinating seeds were covered with a dark cloth for 5 days. This permitted an early transplantation of seedlings into the nutrient solution. After exposure of these 5-day-old seedlings to light for 2 additional days, the seeds were carefully cut off to avoid further utilization of seed nutrients. Six such seedlings were then transplanted into a Hoagland nutrient solution (contained in round jars of 500-ml capacity, 145 mm high and 70 mm wide) which was aerated by bubbling air through it. To maintain a constant volume, glass distilled water was added as necessary. Plants were then allowed to grow for 20 days.

Preparation of Nutrient-Deficient Solutions. Basically, Hoagland modified nutrient solution containing the following elements was used: nitrogen, 140 ppm [as $Ca(NO_3)_2 \cdot 4H_2O$ or $NaNO_3$]; phosphorus, 31 ppm (as $NaH_2PO_4 \cdot H_2O$); potassium, 130 ppm (as KCl); calcium, 200 ppm [as $Ca(NO_3)_2 \cdot 4H_2O$, or $CaCl_2 \cdot 2H_2O$]; magnesium, 49 ppm (as $MgSO_4 \cdot 7H_2O$ or $MgCl_2 \cdot 6H_2O$); sulfur, 64 ppm (as $MgSO_4 \cdot 7H_2O$ or Na_2SO_4); manganese, 0.5 ppm (as $MnCl_2 \cdot 4H_2O$); copper, 0.5 ppm (as $CuCl_2 \cdot H_2O$); zinc, 0.05 ppm (as $ZnCl_2$ 95%); boron, 0.5 ppm (as H_3BO_3); molybdenum, 0.01 ppm (as $H_2MoO_4 \cdot H_2O$); and iron, 2.24 ppm (as $FeSO_4 \cdot 7H_2O$ + NaEDTA). A deficiency of a particular element was created by eliminating this element selectively from the complete nutrient solution. Whenever a particular anion or cation was removed from the complete nutrient solution, the simultaneous removal of another important cation or anion was restored by adding an appropriate substitute salt. Nitrogen or calcium was removed by eliminating $Ca(NO_3)_2 \cdot 4H_2O$ from the nutrient solution, while the calcium was replaced by $CaCl_2 \cdot 2H_2O$ and nitrogen was replaced by $NaNO_3$. Magnesium or sulfur was removed by eliminating $MgSO_4 \cdot 7H_2O$ while sulfur was replaced by Na_2SO_4 and magnesium was replaced by $MgCl_2 \cdot 6H_2O$. Micronutrient elements were selectively eliminated by withholding the appropriate salts.

The pH of the nutrient solution (pH 6.0 to 7.5) was checked every other day and adjusted to that of the control (complete nutrient solution) with either 0.1 *N* NaOH or 0.1 *N* HCl. All tests with complete or deficient nutrient solutions were conducted in four replicates of six plants each.

Exposure of Plants to Lindane and Plant Harvesting. After 19 days of growth the plants were transferred to a freshly prepared complete (control) or deficient nutrient solution. An appropriate amount of lindane in 1 ml of acetone was then added to yield a concentration of 5 ppm. The plants were allowed to grow for an additional 24 hr, during which time the insecticide could penetrate into the root system. After that the plants were removed and the roots were washed with running tap water, followed by drying with blotting paper. This procedure did not differentiate between the residues within the root system and those adhering to the outside of the root epidermis. Analytical data referring to the residues "in roots" are to be interpreted in that way. Roots and greens from each replicate were then separated and the fresh weight was determined. They were then placed into round jars (130 mm tall and 30 mm in diameter), covered with redistilled hexane:acetone (1:1) and kept in a freezer for future analysis.

Annulment of Nitrogen-Deficiency Effects. Experiments were also conducted to determine if the effects of a nitrogen deficiency on the penetration and translocation of lindane could be reversed by resupplying this particular element. For this purpose plants were grown for 15 days in a complete or in a nitrogen-deficient nutrient solution (Table V). After this time each set was exposed to lindane, as described, for 24 hr (total growing period = 16 days) and prepared for analysis as described. In two other experiments, sets of plants (replicated four times) were grown as described for 15 days. A portion of those grown in the nitrogen-deficient solution was then placed for 1 or 7 days into a complete nutrient solution. This was done to annul the effects of the nitrogen deficiency on the plants. After day 16 or 22 these plants were removed and transferred into a lindane treated (5 ppm) complete nutrient solution for 24 hr (Table V, day 17 and 23). These tests contained two sets of controls; one [Table V, complete (CK)] in which plants were grown for 16 days or 22 days in a complete nutrient solution prior to the 1-day exposure to lindane, and another one (Table V, N-deficient) in which plants were grown for the *total* period in a nitrogen-deficient nutrient solution.

ANALYTICAL PROCEDURES

Nutrient Elements. To determine if a desired nutrient deficiency has been achieved, 35 to 40 plants (5 to 6 plants per glass jar) were grown as described in complete and deficient nutrient solutions. After 20 days of growth, roots and greens were separately dried at 105° C for 24 hr, followed by direct reading emissions spectroscopic analyses for P, K, Ca, Mg, Cu, Zn, B, and Fe as described by Christensen *et al.* (1968). The analyses were performed by the Wisconsin Alumni Research Foundation Institute Laboratory, Madison, Wis. Analyses for nitrogen were performed in the Department of Soils, University of Wisconsin, utilizing the standard micro Kjeldahl method, and analyses for sulfur were performed according to the method described by Bardsley and Lancaster (1965).

Insecticide. Roots or greens were removed from the hexane–acetone mixture, cut with a scissors into small pieces and placed into a Waring blender. The hexane–acetone solvent mixture in the storage jar was then quantitatively transferred into the Waring blender. NaCl (100 g) was added and the insecticide was extracted from the plant material. The solvents were filtered through a Buchner funnel and the plant material was reextracted twice with 70 ml of a fresh solvent mixture. Acetone was later removed from the filtrate by two 70-ml washings with 1% aqueous Na_2SO_4, finally resulting in a hexane phase and a water acetone phase. The hexane phase from roots was then dried over anhydrous Na_2SO_4 and adjusted to volume for analysis. The hexane phase from greens was also dried over anhydrous Na_2SO_4, followed by a Florisil column cleanup procedure as described by Lichtenstein *et al.* (1967). This cleaned-up hexane phase was also adjusted to volume for analysis.

Hexane extracts of roots and greens were analyzed by gas–liquid chromatography (glc) as described (Lichtenstein *et al.*, 1969).

For tlc analysis, aliquots of the hexane extracts were spotted on 20 × 20 cm glass plates coated with aluminum oxide G containing calcium sulfate as a binder (Merck, Darmstadt). The chromatograms were developed with 1% acetone in hexane, followed by spraying with the reagents as described by Mitchell (1957) and subsequent exposure to uv light for 10 min. Employing this method, only one spot was observed which had the same R_f value as reference grade lindane.

After the first thin-layer chromatogram had been developed, the same spotting procedure was repeated, except that two portions of the extract were spotted side by side. After development of the chromatogram, one-half of the plate was covered with aluminum foil and the other half was sprayed and visualized as described. The unsprayed portion of the aluminum oxide G layer, corresponding to the lindane spot on the sprayed portion of the plate, was then scraped off the plate and extracted with hexane. Aliquots of this hexane extract were than analyzed by glc.

The amounts of lindane measured in that way within roots are referred to as the quantity that *penetrated* into this plant tissue, while the amounts recovered from the greens are referred to as that quantity that was *translocated* from the roots into the greens. This would not account for potential metabolites of lindane in roots or greens.

RESULTS AND DISCUSSION

Effects of Nutrient Deficiencies on Plant Composition. Elemental analyses of plants grown in nutrient solutions that were deficient in one particular macronutrient element showed that a deficiency of that element had indeed been achieved (Table I). The extent of this deficiency varied in both roots and greens. In the roots, for example, the nitrogen content had been reduced by about 50% and the magnesium content by close to 90%. However, a deficiency of one element also had an effect on the quantities of others. Thus, in nitrogen-deficient roots, the amounts of phosphorus, potassium, and zinc were larger than in control roots, while the amounts of most of the other elements were reduced. In greens grown in nitrogen-deficient media, a marked deficiency of nitrogen was observed while the concentrations of most other elements were larger than in the control plants. In the presence of an intentionally created deficiency of phosphorus in roots (19.5% of control), the nitrogen content in the roots was not affected, while concentration of potassium and zinc was increased and that of all the other elements was decreased. Similar results were obtained when deficiencies of other macronutrient elements were produced.

In experiments with micronutrient elements substantial

Table I. Effects of Macronutrient Element Deficiencies on the Mineral Composition of Pea Plants

Nutrient solution	Mineral content of plants (on oven-dry weight basis)										
	%						ppm				
	N	P	K	Ca	Mg	S	Mn	Cu	Zn	B	Fe
Roots											
Complete (CK)	4.10	0.82	5.80	0.64	1.03	2.06	406	68.5	26.0	34.5	1000[b]
% CK[a]	100	100	100	100	100	100	100	100	100	100	100
Deficient in											
N	2.10	1.89	9.05	0.45	0.28	1.86	75.0	52.0	31.5	23.0	880
% CK	51.2	230	156	70.3	27.2	90.3	18.5	75.9	121	66.7	88.0
P	4.02	0.16	7.65	0.47	0.45	1.05	275	67.5	28.5	22.0	1000
% CK	98.0	19.5	132	73.4	43.7	51.0	67.7	98.4	110	63.8	100
K	3.98	1.37	0.79	0.61	1.65	1.50	348	46.5	69.0	33.5	1000
% CK	97.1	167	13.6	95.3	160	72.8	85.7	67.9	265	97.1	100
Ca	4.90	1.71	3.85	0.08	0.48	1.87	410	71.0	85.5	34.5	1000
% CK	120	208	66.4	12.5	46.6	90.8	101	104	329	100	100
Mg	3.76	1.66	9.30	0.55	0.10	1.58	410	46.5	78.5	31.0	1000
% CK	91.7	202	160	85.9	09.7	76.7	101	67.9	302	89.9	100
S	4.40	0.89	6.05	0.73	0.62	0.40	328	33.0	22.0	23.0	880
% CK	107	108	104	114	60.2	19.4	80.8	48.2	84.6	66.7	88.0
Greens											
Complete (CK)	4.28	0.51	3.55	1.59	0.32	0.45	44.0	11.1	23.5	35.5	75.0
% CK	100	100	100	100	100	100	100	100	100	100	100
Deficient in											
N	1.94	0.77	3.20	1.41	0.37	0.80	45.0	17.5	44.5	44.5	100
% CK	45.3	151	90.1	88.7	116	178	102	158	189	125	133
P	3.70	0.11	3.20	1.15	0.35	0.31	39.0	14.8	36.5	39.0	105
% CK	86.4	21.6	90.1	72.3	109	68.9	88.6	133	155	110	140
K	4.06	0.70	0.74	2.37	0.70	0.51	77.5	19.8	47.5	53.5	95.0
% CK	94.8	137	20.8	149	219	113	176	178	202	151	127
Ca	5.88	0.73	2.80	0.50	0.67	0.90	103	37.5	56.0	67.0	175
% CK	137	143	78.9	31.4	209	200	234	338	238	189	233
Mg	4.14	0.63	3.95	1.41	0.04	0.38	57.5	13.6	30.0	48.0	90.0
% CK	96.7	123	111	88.7	12.5	84.4	131	122	128	135	120
S	4.42	0.36	3.25	1.35	0.29	0.10	46.5	07.9	30.0	32.0	58.0
% CK	103	70.6	91.5	84.9	90.6	22.2	106	71.2	128	90.1	77.3

[a] % CK = in percent of control (complete nutrient solution). [b] Upper limit of detectability.

reductions in the concentrations of each particular element were also obtained and the effects on the concentrations of other elements were noticeable (Table II).

Growing of plants in nutrient-deficient solutions generally resulted in a decreased production of plant material (Table III). Thus, the fresh weight of roots was reduced most in magnesium and boron-deficient nutrient media, while the greatest reduction in the fresh weight of greens occurred with plants that were grown in nitrogen, calcium, magnesium, or boron-deficient nutrient solutions.

Effects of Nutrient Deficiencies on the Penetration and Translocation of Lindane in Pea Plants. After plants were grown in the absence of one particular nutrient element, lindane had penetrated into the roots to various degrees and was also translocated at different levels into the greens (Table IV). The quantity of lindane in roots and in greens was determined by glc and was confirmed qualitatively by tlc. Additional confirmation was obtained by glc analysis of areas isolated from thin-layer plates. The penetration of lindane into the plant roots grown in nitrogen or sulfur-deficient media had increased by 27 and 18%, respectively, while the translocation of the insecticide into the greens was reduced by 81 and 18.1%, respectively. A deficiency in magnesium resulted in reduction of both the penetration and the translocation of lindane, while a deficiency in potassium affected translocation only by reducing the lindane concentration in the greens by 23.9%. Rice and Rohrbaugh (1958) showed a reduced translocation of 2,4-D in potassium-deficient tomato plants. Yu and Morrison (1969) also observed reduced translocation of mevinphos and phosphamidon in potassium-deficient bean plants.

Among the micronutrient elements tested, only boron had a significant effect on both the penetration and translocation of lindane (Table IV). Thus, roots from plants that were grown in boron-deficient media contained 23% more lindane than those from control plants, while the translocation into the greens was reduced by 66.8%.

All this indicates that the penetration of lindane into pea roots and the translocation of the insecticide into the greens were affected after the plants had grown in solutions deficient in nitrogen, potassium, magnesium, sulfur, or boron. Since the concentration of other elements was also affected, a combination of factors could have been responsible for the observed effects.

Annulment of Nitrogen Deficiency Effects. The effect of adding nitrogen to plants previously deficient in this element showed a marked improvement in growth as indicated by increased greening of leaves and a subsequent increase in the fresh weight as compared to nitrogen-deficient controls. The effects of an intentionally produced nitrogen deficiency on the

Table II. Effects of Micronutrient Element Deficiencies on the Mineral Composition of Pea Plants

Nutrient solution	Mineral content of plants (on oven-dry weight basis)										
	%						ppm				
	N	P	K	Ca	Mg	S	Mn	Cu	Zn	B	Fe
					Roots						
Complete (CK)	3.73	0.82	4.05	0.95	1.17	2.05	252	80.5	49.0	25.1	835
% CK[a]	100	100	100	100	100	100	100	100	100	100	100
Deficient in											
Mn	3.81	1.60	9.55	0.61	0.23	1.81	2.00	75.5	71.5	31.0	1000[b]
% CK	102	195	236	64.2	19.7	88.3	0.80	93.8	146	123	120
Cu	5.20	0.94	4.80	0.76	1.06	2.07	348	13.6	19.5	27.8	800
% CK	139	115	118	80.0	90.6	101	138	16.9	39.8	111	95.8
Zn	4.02	0.89	5.30	0.85	1.04	2.10	280	95.5	12.5	27.8	1000
% CK	108	108	131	89.5	88.9	102	111	119	25.5	111	120
B	4.29	1.28	7.75	1.05	0.59	1.85	352	78.5	26.0	16.6	1000
% CK	115	156	191	110	50.4	90.2	140	97.5	53.1	66.1	120
Fe	4.62	0.99	3.95	0.76	1.33	1.50	372	75.5	27.5	25.4	64.0
% CK	124	121	97.5	80.0	114	73.2	148	93.8	56.1	101	07.7
Mo	3.76	0.89	4.05	0.71	1.17	1.93	338	85.0	22.0	27.8	970
% CK	101	108	100	74.7	100	94.1	134	106	44.9	111	116
					Greens						
Complete (CK)	3.96	0.36	2.35	1.59	0.31	0.31	47.5	09.5	20.0	32.0	75.0
% CK	100	100	100	100	100	100	100	100	100	100	100
Deficient in											
Mn	4.77	0.61	4.05	1.63	0.34	0.41	2.0	15.0	37.5	50.0	105
% CK	120	169	172	102	110	132	4.2	158	187	156	140
Cu	3.56	0.47	2.75	1.55	0.29	0.32	45.0	05.0	19.5	33.5	71.0
% CK	89.9	131	117	97.5	93.5	103	94.7	52.6	97.6	105	94.7
Zn	4.06	0.54	3.10	1.72	0.32	0.36	57.5	09.9	11.5	37.0	80.0
% CK	102	150	132	114	103	116	121	104	57.5	116	107
B	4.58	0.58	3.45	1.67	0.38	0.49	77.5	12.6	31.5	08.6	100
% CK	116	161	147	105	123	158	163	133	157	27.0	133
Fe	4.27	0.51	4.15	1.83	0.41	0.27	62.5	11.1	15.0	35.5	32.0
% CK	108	142	177	115	132	87.1	132	117	75.0	111	42.7
Mo	3.81	0.49	2.55	1.76	0.32	0.32	49.6	09.5	23.5	34.5	80.0
% CK	96.2	136	108	111	103	103	104	100	117	108	107

[a] % CK = in percent of control (complete nutrient solution). [b] Upper limit of detectability.

Table III. Effects of Nutrient Element Deficiencies on the Fresh Weights of Pea Plants

Nutrient solution	Fresh weights of plants grown for 20 days in nutrient-deficient solutions			
	Roots		Greens	
	Grams[a]	% CK	Grams[a]	% CK
	Macronutrient elements			
Deficient in				
I N	4.45 ± 0.36	63.0[b]	4.63 ± 0.28	30.1[b]
II P	5.99 ± 0.43	84.2	8.81 ± 0.29	67.4[c]
II Ca	3.48 ± 0.92	48.9[c]	3.53 ± 0.91	27.0[b]
III K	4.45 ± 0.15	79.0	6.26 ± 0.16	49.1[b]
IV Mg	3.89 ± 0.20	34.9[b]	4.44 ± 0.26	26.4[b]
IV S	6.46 ± 0.32	57.9[c]	12.34 ± 0.53	73.2[b]
Control for				
I	7.06 ± 1.03	100	15.39 ± 1.33	100
II	7.11 ± 0.46	100	13.07 ± 1.19	100
III	5.63 ± 0.84	100	12.74 ± 1.53	100
IV	11.15 ± 1.05	100	16.85 ± 0.61	100
	Micronutrient elements			
Deficient in				
I Mn	3.80 ± 0.38	42.0[b]	7.28 ± 0.60	52.0[b]
I Zn	8.65 ± 1.50	95.7	12.05 ± 1.64	86.1
II Cu	7.49 ± 1.02	106	15.95 ± 1.08	104
III B	3.44 ± 0.18	35.9[b]	7.00 ± 0.22	43.6[b]
III Fe	6.11 ± 0.41	63.7[b]	12.06 ± 0.47	75.1[c]
III Mo	7.83 ± 0.19	81.6[c]	15.56 ± 0.20	96.9
Control for				
I	9.04 ± 1.08	100	13.99 ± 0.93	100
II	7.06 ± 1.03	100	15.39 ± 1.33	100
III	9.59 ± 0.87	100	16.06 ± 0.57	100

[a] Average of four replicated tests. [b] Differences in fresh weights between plants from nutrient-deficient solution and those in controls were significant at the 1% level. [c] Differences in fresh weights between plants from nutrient-deficient solution and those in controls were significant at the 5% level.

Table IV. Penetration and Translocation of Lindane into Pea Plants Grown in Different Nutrient Element Deficient Solutions

Nutrient solution	Lindane in plants after 24-hr exposure to the insecticide (5 ppm)			
	Roots		Greens	
	ppm[a]	% CK[b]	ppm[a]	% CK[b]
	Macroelements			
Deficient in				
I N	67.43 ± 2.27	127[c]	3.59 ± 0.52	18.4[c]
II P	52.82 ± 3.68	93.8	7.32 ± 0.69	87.2
II Ca	58.59 ± 2.31	104	7.11 ± 1.55	84.7
III K	52.72 ± 1.88	96.9	16.24 ± 0.86	76.1[d]
IV Mg	43.35 ± 1.77	84.6[d]	6.16 ± 0.58	36.9[c]
IV S	60.82 ± 1.97	118[c]	13.67 ± 0.39	81.9[c]
Control for				
I	53.06 ± 0.98	100	19.54 ± 1.59	100
II	56.30 ± 2.59	100	8.39 ± 0.76	100
III	54.37 ± 2.12	100	21.34 ± 2.34	100
IV	51.26 ± 1.37	100	16.69 ± 0.40	100
	Microelements			
Deficient in				
I Mn	41.04 ± 1.79	85.6	18.53 ± 0.78	97.3
I Zn	51.45 ± 2.55	107	16.58 ± 1.74	87.0
II Cu	53.36 ± 2.21	101	19.22 ± 3.65	98.4
III B	67.51 ± 4.25	123[c]	4.74 ± 1.53	33.2[c]
III Fe	54.26 ± 2.44	98.8	13.73 ± 1.22	96.1
III Mo	55.49 ± 0.96	101	14.69 ± 2.29	103
Control for				
I	47.93 ± 1.89	100	19.05 ± 1.31	100
II	53.06 ± 0.98	100	19.54 ± 1.59	100
III	54.91 ± 3.03	100	14.29 ± 1.22	100

[a] Average of four replicated tests. [b] % CK = in percent of control. [c] Differences in lindane concentrations in plant parts from nutrient-deficient solution and those from controls were significant at the 1% level. [d] Differences in lindane concentrations in plant parts from nutrient-deficient solution and those from controls were significant at the 5% level.

Table V. Annulment of the Effects of Nitrogen Deficiency on the Penetration and Translocation of Lindane into Pea Plants

Total growing period	Nutrient solution	Lindane in plants after exposure to the insecticide during the last day of the growing period: Roots ppm[a]	Roots % CK[b]	Greens ppm	Greens % CK
16	Complete (CK)	45.19 ± 1.90	100	14.36 ± 1.57	100
	N-Deficient	64.00 ± 3.91	142[c]	2.91 ± 0.81	19.4[c]
17	Complete (CK)	41.99 ± 1.64	100	11.28 ± 0.99	100
	N-Deficient	60.09 ± 0.76	143[c]	2.76 ± 0.99	20.7[c]
	N-Deficient + N[e]	57.78 ± 2.45	138[c]	3.96 ± 0.81	35.4[c]
23	Complete (CK)	51.94 ± 3.31	100	11.62 ± 0.70	100
	N-Deficient	62.77 ± 0.61	121[d]	2.34 ± 0.29	20.1[c]
	N-Deficient + N[e]	54.14 ± 0.60	104[f]	7.64 ± 1.12	65.7[d,f]

[a] Average of four replicated tests. [b] % CK = in percent of control (complete nutrient solution). [c] Differences in lindane concentrations in plant parts from N-deficient nutrient solution and those from controls (complete nutrient solution) were significant at the 1% level. [d] Differences in lindane concentrations in plant parts from N-deficient nutrient solution and those from controls (complete nutrient solution) were significant at the 5% level. [e] Plants were grown for 15 days in N-deficient nutrient solution followed by growing them for 1 day (17 days total growing period) or 7 days (23 days total growing period) in a complete nutrient solution prior to the exposure to lindane for one additional day in a complete nutrient solution. [f] Lindane concentrations measured in plant parts after the addition of N for 7 days (23 day growing period) were significantly different (at the 1% level) from those N-deficient plants to which no N was added.

penetration and translocation of lindane in pea plants could partially be reversed (Table V). With plants grown for 15 days in a nitrogen-deficient nutrient solution, more lindane had penetrated on day 16 into the roots and less had been translocated into the greens in comparison to control plants (Table V, 16 days, N-deficient). When nitrogen was resupplied by transferring the 15-day-old plants for 1 day into a complete nutrient solution prior to the exposure to lindane for one additional day (Table V, 17 days, N-deficient + N), a reduction in the effects of nitrogen deficiency in roots and greens appeared to be noticeable. This reduction, however, proved to be statistically nonsignificant. However, when nitrogen was resupplied from day 16 to 22 for 1 week (Table V, 23 days, N-deficient + N), prior to lindane treatment, the effects of the nitrogen deficiency (usually leading to an increased penetration of lindane into roots) was completely eliminated. With plants grown for 23 days in nitrogen-deficient media, the amount of lindane recovered from the greens was reduced by 79.9% in comparison to the control plants, while the addition of nitrogen for 1 week from day 16 to 22 resulted in a reduction of only 34.3%. Thus a partial annulment of the nitrogen-deficiency effect on lindane translocation was achieved.

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