Systemic Translocation of ^{14}C-Labeled Metalaxyl in Tomato, Avocado, and *Persea indica*

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Accepted for publication 14 October 1980.

ABSTRACT

Zaki, A. I., Zentmyer, G. A., and LeBaron, H. M. 1981. Systemic translocation of ^{14}C-labeled metalaxyl in tomato, avocado, and *Persea indica*. Phytopathology 71:509-514.

Systemic translocation of ^{14}C following treatment with ^{14}C-metalaxyl was demonstrated in tomato, avocado (*Persea americana*) and *P. indica* seedlings. In *P. indica*, the labeled fungicide was readily taken up by the roots and radioactivity was translocated uniformly to the aboveground parts of the plant. Metalaxyl concentrations ranging 67–106 μg/g of dry *P. indica* root tissue were observed after the application of 1 mg of the fungicide as a soil drench. More than 90% of the foliar-applied fungicide remained in or on the surface of *P. americana* leaves up to 28 days after the last application. A small proportion of the applied fungicide was translocated downward to the roots. In tomato and *P. indica* plants, the labeled fungicide was translocated from a lower leaf to the upper leaves and from an upper leaf to the lower leaves. The uptake and subsequent translocation of the fungicide from the stem of avocado or tomato plants was superior to that from the leaves; after the fungicide was taken up by the stem, it was translocated laterally and upward to the leaves. Following leaf or stem application, only a very small proportion of the applied radioactivity was found in the roots (generally less than 1%). Application of Triton B-1956 to *P. indica* leaves or of exogenous IAA with the labeled fungicide to avocado leaves did not enhance the uptake and downward translocation of the fungicide to the roots.

The new fungicide metalaxyl, *N*-(2,6-dimethylphenyl)-*N*-(methoxyacetyl)-DL-alanine methyl ester (common name, metalaxyl) has been found to effectively control diseases caused by the oomycetous fungi (1,2,7,9,10,13). Designated CGA 48988 or Ridomil® (Ciba-Geigy Corporation, Summit, NJ 07901), it has been recommended for experimental use as a foliar spray or as a soil or seed treatment. Benson (1) demonstrated the systemic activity of metalaxyl in azalea by applying it to the soil and bioassaying leaf disks. He concluded that the systemic presence of this fungicide in treated plants could explain its long-term control of Phytophthora root rot of azalea. Zentmyer (13) reported that foliar spraying of *Persea indica* seedlings with metalaxyl reduced or prevented root rot and stem infection of these plants by *P. cinnamomi*. Cohen et al (3) reported that Ridomil (metalaxyl 50 W, containing 50% active ingredient) at the rate of 17.5 mg per plant, provided full protection of tomato leaves against *P. infestans* 1 hr after soil drench application; however, when the fungicide was applied as a foliar spray, systemic translocation occurred neither upward from older leaves, downward from younger leaves, nor from sprayed leaves into fruits. Staub et al (8) suggested that systemic protection against *P. infestans*, achieved by spraying the aboveground parts of tomato and grape plants with Ridomil (metalaxyl 25 W, containing 25% active ingredient), appeared to result from uptake of the fungicide through green stems and petioles.

Quantitative data on the uptake and translocation of metalaxyl is not available at present, presumably because a method for analysis of this fungicide in plants has not yet been developed. Such information is essential for better understanding of the mode of action of this fungicide in controlling plant disease. This investigation was initiated to quantitatively determine the extent of translocation of ^{14}C-labeled metalaxyl in avocado (*P. americana*), in *P. indica*, and in tomato. Special emphasis was placed on evaluating the extent of downward translocation, particularly to the roots following foliar application. Uptake of ^{14}C-labeled metalaxyl by roots and subsequent upward translocation also was examined.

MATERIALS AND METHODS

(U-ring-^{14}C) *N*-(2,6-dimethylphenyl)-*N*-(methoxyacetyl)-DL-alanine methyl ester (= ^{14}C-metalaxyl) was provided by Ciba-Geigy Corporation. The labeled fungicide (4.6 mg; specific activity 43.6 μCi/mg) was dissolved in 4.6 ml of methanol. Final test solutions for foliar application were prepared by mixing an appropriate amount of ^{14}C-metalaxyl with a known amount of unlabeled metalaxyl emulsifiable concentrate formulation (2 EC, containing 0.20 kg active ingredient per liter) and diluting the mixture with a known volume of water to provide the desired final concentration of ^{14}C-metalaxyl. The wettable powder formulation (50 WP, containing 50% active ingredient) was used to dilute the labeled fungicide in the soil-drench treatments. In certain instances, 0.05% indoleacetic acid (IAA) was incorporated in the final test solution. In other experiments, 0.03% Triton B-1956 (Rohm and Haas, Philadelphia, PA 19105) was incorporated in the final test solution. To aid the reader specific treatments are given in detail at the beginning of each of the Results sections to which they apply.

Plant material. Avocado seedlings (*Persea americana* var. *Drymifolia* 'Topa Topa') (hereafter called "avocado") were grown in a greenhouse at 18–24 C for 4–7 mo (15- to 20-leaf stage) in 4.5-L pots containing UC mix. *P. indica* seedlings were grown in 10-cm diameter pots for 80 days (8- to 9-leaf stage), and tomato plants (*Lycopersicon esculentum* 'Rutgers') were grown in 10-cm-diamter pots for 5–6 wk (each tomato plant was composed of two cotyledonary leaves, two primary leaves, two fully expanded young leaves, and two to three partially expanded young leaves).

Fungicide application. For foliar application, a test solution was prepared and dispensed in small vials for treatment of each individual plant. The solution was deposited in small droplets on the upper surface of leaf blades by using a Pasteur pipette. The deposited solution was gently spread (painted) over most of the surface of a leaf blade and allowed to dry before another portion of the solution was applied. A similar procedure was used to apply test solutions to the stem. Potted plants were tipped to a horizontal position during treatment. The pot was gradually rotated during application and the solution was allowed to dry on the surface of the stem before the plant was returned to the upright position. In order to prevent contamination of the soil with the labeled fungicide, several layers of tissue paper were wrapped around the base of the stem at the soil level; the soil surface also was covered with two layers of paper towels, a layer of plastic sheet, and two additional layers of paper towels. Activated charcoal was sprinkled on the surface. Plants were irrigated daily with tap water throughout the experiment. In most treatments, the fungicide was applied repeatedly in small portions at daily intervals for 7–10 days. Plants were incubated for an additional 7–28 days before harvest. In some experiments a single leaf of tomato or of *P. indica* was treated by inserting the leaf blade in a plastic bag containing 0.5 ml

0031-949X/81/05050906/$03.00/0

of test solution (0.436 μCi ^{14}C in 240 μg metalaxyl per milliliter) and folding the bag so that thin films of the test solution were continuously in contact with both surfaces of the leaf throughout the experiment. This procedure allowed foliar uptake and translocation of the fungicide in the presence of free water and also prevented any possible contamination of other plant parts with the radiolabeled fungicide. This method of application, however, can create a negative tension in the xylem, which would draw fluids to the stem and alter the general distribution of the labeled fungicide in the plant. When the fungicide was applied as a soil drench, the test solution was added to the soil around the roots, and the plants were irrigated 24 hr later.

^{14}C analysis. Plants were harvested by removing the aboveground portion and then removing and washing the roots. The shoot was divided into different morphological parts and placed in paper cups. In some experiments, the root system was divided into tap root and feeder roots. Plant parts were dried in an oven overnight at 70 C and dry weights were determined. The dried plant tissue was then finely fragmented, mixed, and a representative sample was analyzed by means of the combustion technique (5,11).

Autoradiography. *P. indica* plants were autoradiographed intact. Avocado plants, being of larger size, were divided into various parts, placed between layers of paper towels, and dried in an oven for 24 hr at 60 C; in some experiments, plants or plant parts were placed between two layers of Saran Wrap to avoid direct contact with the X-ray film and autoradiographed directly without drying. Kodak no-screen X-ray films were used. Exposure time generally exceeded 30 days.

RESULTS

Systemic translocation of ^{14}C-metalaxyl in *P. indica* and tomato plants. Three *P. indica* plants and two tomato plants treated with ^{14}C-metalaxyl by introducing a single leaf blade in a plastic bag containing 0.5 ml test solution (0.436 μCi ^{14}C and 240 μg metalaxyl per milliliter). The labeled fungicide was applied to the uppermost fully expanded leaf of one of the *P. indica* plants, to the third leaf from the apex of the second plant, and to the fifth leaf from the apex of the third plant. An intermediate, partially expanded leaf of each of the two tomato plants was treated similarly.

Two additional tomato plants and one *P. indica* plant were treated by painting the fungicide solution on the entire foliage including the stem. All plants were harvested 14 days after treatment. Each plant was subdivided into various morphological parts and anlyzed for ^{14}C.

The results in Table 1 showed that a small proportion of ^{14}C-metalaxyl (2–5%) was taken up by a single leaf of *P. indica* and tomato plants and was translocated to upper and lower leaves presumably through the stem. Less than 1% (generally less than 0.2% of the total recovered radioactivity) was found in the roots.

In another experiment, in which the labeled fungicide was painted on the stem, the upper leaves, or a lower partially expanded leaf of tomato plants, ^{14}C-metalaxyl was translocated from the upper leaves to lower leaves through the stem (Table 2). A smaller proportion of the labeled fungicide was translocated from older leaves to younger leaves. Uptake and translocation of the fungicide from the stem to the other parts of the plant, particularly to the leaves, were considerably higher than from treated leaves to the other parts of the plant. In most instances, the proportion of ^{14}C found in the roots was very small (less than 1% except in one test [plant #2, Table 2] in which 2.8% of the total recovered radioactivity was detected in the roots). The estimated concentration of the fungicide in the roots varied between 0.0 μg/g of dry root tissue when the fungicide was applied to a lower, partially expanded leaf and 36 μg/g (2.8% of the applied radiolabeled material) when an upper younger leaf was treated. When the fungicide was applied to the stem or to the entire foliage,

TABLE 1. Distribution of ^{14}C in various morphological parts of *Persea indica* and tomato seedlings 14 days after either localized application of ^{14}C-metalaxyl to a single leaf or to the entire foliage

Plant	Site of application	Method of application	Percent total ^{14}C recovered in:				
			Treated leaf	Lower leaves[c]	Upper leaves[d]	Stem	Roots
P. indica	Young uppermost leaf	Inside a plastic bag[a]	95.0	1.12	···	3.77	0.14
	Intermediate leaf	Inside a plastic bag[a]	97.7	0.48	1.5	0.32	0.0
	Older leaf	Inside a plastic bag[a]	94.2	1.3	1.7	2.6	0.17
	Foliage and stem	Painting[b]	99.95	99.95	99.95	99.95	0.05
Tomato	Intermediate leaf	Inside a plastic bag[a]	98.7	0.0	0.52	0.7	0.03
	Intermediate leaf	Inside a plastic bag[a]	95.5	0.15	2.15	1.97	0.2
	Foliage and stem	Painting[b]	99.8	99.8	99.8	99.8	0.15
	Foliage and stem	Painting[b]	99.2	99.2	99.2	99.2	0.8

[a] The ^{14}C-labeled fungicide was applied by introducing a single leaf blade in a plastic bag containing 0.05 ml of solution of the labeled fungicide. The treated leaf blade remained inside the plastic bag in continuous contact with the test solution for 14 days.
[b] The labeled fungicide was painted on the surface of the plant. Plants were harvested 14 days after treatment.
[c] Leaves lower than the treated leaf.
[d] Leaves higher than the treated leaf. The symbol ··· indicates no upper leaves.

TABLE 2. Translocation of ^{14}C-metalaxyl from leaves, stem, or the entire foliage to different parts of tomato seedlings 14 days after treatment

Plant no.	Site of application	Amount of ^{14}C-metalaxyl[a] applied to the plant		Percent ^{14}C recovered in:				Estimated ^{14}C-metalaxyl per gram of root tissue[b] (μg/g)
		μCi	mg	Treated leaf	Other leaves	Stem	Roots	
1	Upper leaves	0.327	1.2	94.2	2.6	2.4	0.85	11
2	Upper leaves	0.327	1.2	89.3	3.8	4.1	2.8	36
3	Lower partially expanded leaf	0.327	1.2	99.3	0.6	0.1	0.0	0.0
4	Lower partially expanded leaf	0.327	1.2	97.7	1.2	0.5	0.53	8
5	Stem	0.26	0.96	···	61.2	38.2[c]	0.6	7
6	Stem	0.26	0.96	···	65.9	33.6[c]	0.43	5
7	Entire foliage	0.436	2.4	99.9	99.9	99.9	0.1	2.5
8	Entire foliage	0.436	2.4	99.8	99.8	99.8	0.2	3

[a] A test solution of ^{14}C-metalaxyl was painted on the surface of the plant.
[b] Each figure is based on the amount of fungicide applied to each plant, the percent recovery of ^{14}C in the roots, the total recovery of the labeled fungicide from all parts of the plant, the dry weight of the entire plant, and the dry weight of the roots. The assumption was made that ^{14}C-metalaxyl was not degraded or metabolized in the plant, which may not be true (see Discussion).
[c] Treated stem.

the estimated concentration in the roots 14 days after treatment was between 2.5 and 7 μg/g of dry root tissue.

The effect of Triton B-1956 on the downward translocation of ^{14}C-metalaxyl in healthy and infected *P. indica* plants. *P. indica* plants were treated with ^{14}C-metalaxyl either in the presence of 0.03% of Triton B-1956 (Rohm and Haas) or in its absence. The test solutions were applied to the leaves at daily intervals for 7 days. At the end of this period each plant had received 0.7 μCi and 1.4 mg ^{14}C-metalaxyl. Some plants received no treatment and were kept as controls. At the end of the treatment with the test solutions, the plants were segregated into two groups. One group was transferred to a soil infested with *Phytophthora cinnamomi* and the other group was transferred to uninfested soil. All plants were harvested after 17 days. Plants were removed from soil and their roots were washed. One plant from each treatment was analyzed for ^{14}C and two plants were autoradiographed. Control, untreated healthy, or diseased plants also were autoradiographed.

In all treatments most of the radioactivity (approximately 95%) remained in the treated leaves (Table 3). Triton B-1956 did not appear to enhance the uptake and subsequent translocation of the labeled fungicide to the stem and root. Approximately 2.5% of the recovered radioactivity, which amounted to approximately 26 μg of metalaxyl per gram of root tissue, was found in the roots of plants grown in uninfested soil. In infested soil, treated plants as well as untreated controls showed severe root rot symptoms (>90% of the roots were infected). The proportion of ^{14}C found in infected roots was about 0.5% of the total recovered radioactivity, which amounted to approximately 16–19 μg of ^{14}C-metalaxyl per gram of dry root tissue. These data could indicate either that up to 19μg/g concentration of metalaxyl in the roots was not sufficient to protect the plant against disease, or that the translocated ^{14}C was no longer associated with active metalaxyl.

Autoradiograms of foliage-treated plants (Fig. 1A) were consistent with the results of ^{14}C analysis. They showed that most of the applied radioactivity had remained either within or upon the surface of the treated leaves while a small proportion was translocated to the stem and downward to the roots.

Uptake of ^{14}C-metalaxyl by roots of healthy and diseased *P. indica* plants. *P. indica* plants were treated with ^{14}C-metalaxyl as a soil drench. Six plants each were treated with 10 ml of test solution containing 2 mg of ^{14}C-metalaxyl wettable powder (50% active ingredient). The total radioactivity applied was approximately 0.5 μCi per plant. A second group of six plants was treated with a lower concentration of the labeled fungicide. Each plant of this latter group was treated four times at daily intervals with 10 ml of solution containing in addition to the labeled fungicide, 0.1 mg of metalaxyl (wettable powder formulation). After this series of treatments each plant had received 0.7 μCi of the labeled fungicide. Three plants of each group were then transferred to a soil infested with *P. cinnamomi* and the other three plants were transferred to uninfested soil. All plants were harvested 17 days after transfer. Disease severity was estimated and the plants were analyzed for ^{14}C by autoradiography and by the combustion technique.

The labeled fungicide was taken up readily from the soil by the roots of healthy *P. indica* plants and was translocated uniformly to the stem and leaves (Fig. 1B). More than 50% of the recovered radioactivity was found in the leaves. The proportion of the recovered radioactivity found in the stem ranged 5–8% of the total. Although the amount of label that was not taken up by the plant and presumably had remained in the soil was high (89–97% of the applied fungicide), the estimated concentration of the fungicide in the roots also was high (Table 4 and Fig. 1B). The concentration of the fungicide in the diseased roots was 67 μg/g of dry root weight. This concentration appeared to cause a partial reduction in disease severity since all plants treated with the higher concentration (1 mg ^{14}C-metalaxyl per plant) had only 50–60% of their roots diseased, compared to >90% diseased roots of untreated plants.

The effect of concentration of ^{14}C-metalaxyl on downward translocation to the roots of avocado plants. Avocado plants (20-leaf stage) were treated with 500 μg/ml ^{14}C-metalaxyl solution or with 1,920 μg/ml of solution. The test solutions were applied to the upper surface of all leaves and to the stem. Each plant was treated with 5 ml of the test solution on the first day and with 1 ml of solution on each of the 10 following days. At the end of this period each plant had received 7.5 mg of the labeled fungicide (a total radioactivity of 1.52 μCi), or 28.8 mg (a total radioactivity of 1.61 μCi). Plants were

TABLE 3. Distribution of ^{14}C in healthy and infected *Persea indica* plants 17 days after treatment of the leaves ^{14}C-metalaxyl in the presence or absence of the spreader Triton B-1956.

Percent diseased roots	Treatment	Soil type	Percent of total ^{14}C recovered in:			Estimated μg metalaxyl per gram of root tissue[a]
			Treated leaf	Stem	Roots	
0	No Triton B-1956	Uninfested	94.2	3.4	2.4	25.8
>90	No Triton B-1956	Infested	95.5	4.0	0.5	16.0
0	Triton B-1956	Uninfested	93.0	4.5	2.5	27.0
>90	Triton B-1956	Infested	94.1	5.4	0.5	19.0

[a] Each figure is based on the amount of fungicide applied to each plant, the percent recovery of ^{14}C in the roots, the total recovery of the labeled fungicide from all parts of the plant, the dry weight of the entire plant, and the dry weight of the roots. The assumption was made that ^{14}C-metalaxyl was not degraded or metabolized in the plant, which may not be true (see Discussion section).

TABLE 4. Distribution of ^{14}C in *Persea indica* plants 17 days after the application of ^{14}C-metalaxyl as a soil drench

Percent diseased roots	Type of application	Amount of ^{14}C-metalaxyl applied to each plant		Percent of total ^{14}C recovered in:			Estimated μg of metalaxyl per gram of root tissue[a]
		mg	^{14}C (μCi)	Leaves	Stem	Treated roots	
0	Soil drench, one treatment, uninfested soil	1.0	0.5	58.2	6.5	35.3	106
60	Soil drench, one treatment, infested soil	1.0	0.5	68.7	5.7	25.6	67
0	Soil drench, four times, uninfested soil	0.2	0.7	45.0	8.5	46.8	25
90	Soil drench, four times, infested soil	0.2	0.7	86.3	7.4	6.3	1.5

[a] Each figure is based on the amount of fungicide applied to each plant, the percent recovery of ^{14}C in the roots, the total recovery of the labeled fungicide from all parts of the plant, the dry weight of the entire plant, and the dry weight of the roots. The assumption was made that ^{14}C-metalaxyl was not degraded or metabolized, which may not be true (see Discussion).

harvested 7 days after the last treatment. Four plants from each group were analyzed for ^{14}C-radioactivity and two plants were autoradiographed. In all cases, >96% of the recovered radioactivity was found in the treated leaves. The treated stems contained 0.9–3.5%, the tap roots contained 0.04–0.08%, and the feeder roots contained between 0.02 and 0.05% of the recovered radioactivity.

The estimated concentration of the fungicide in the roots (tap and feeder roots) of plants treated with the lower concentration of the fungicide ranged 0.45–0.68 μg/g, and in the roots of plants treated with the higher concentration it was between 1.6 and 1.9 μg/g. Autoradiograms of these plants did not show radioactivity in their roots.

Distribution of radioactivity in avocado plants treated with ^{14}C-metalaxyl in the presence or absence of exogenous IAA. Avocado plants (10- to 12-leaf stage) were treated with test solutions containing ^{14}C-metalaxyl or with test solutions containing the labeled fungicide and 0.05% IAA. One-half milliliter of a test solution was applied to each plant each day for 7 days in succession. Test solutions were applied either to the stem or to the uppermost four to five leaves. At the end of this treatment, each plant had received 6.6 mg (1.12 μCi) of ^{14}C-metalaxyl, and 0.0 or 1.5 mg IAA. Plants were harvested 7 or 28 days after treatment.

The ^{14}C-labeled fungicide was taken up more readily by the stems than by the leaves of avocado plants (Table 5). Once it was taken up by the stem, the labeled fungicide was translocated laterally and possibly upward to the leaves. Between 9 and 18% of the recovered radioactivity was found in the leaves of avocado seedlings 7 days after treatment of the stem. In contrast, only 0.5–0.85% of the recovered radioactivity was found in the roots. This amounted to approximately 6 μg metalaxyl per gram of root tissue. When the

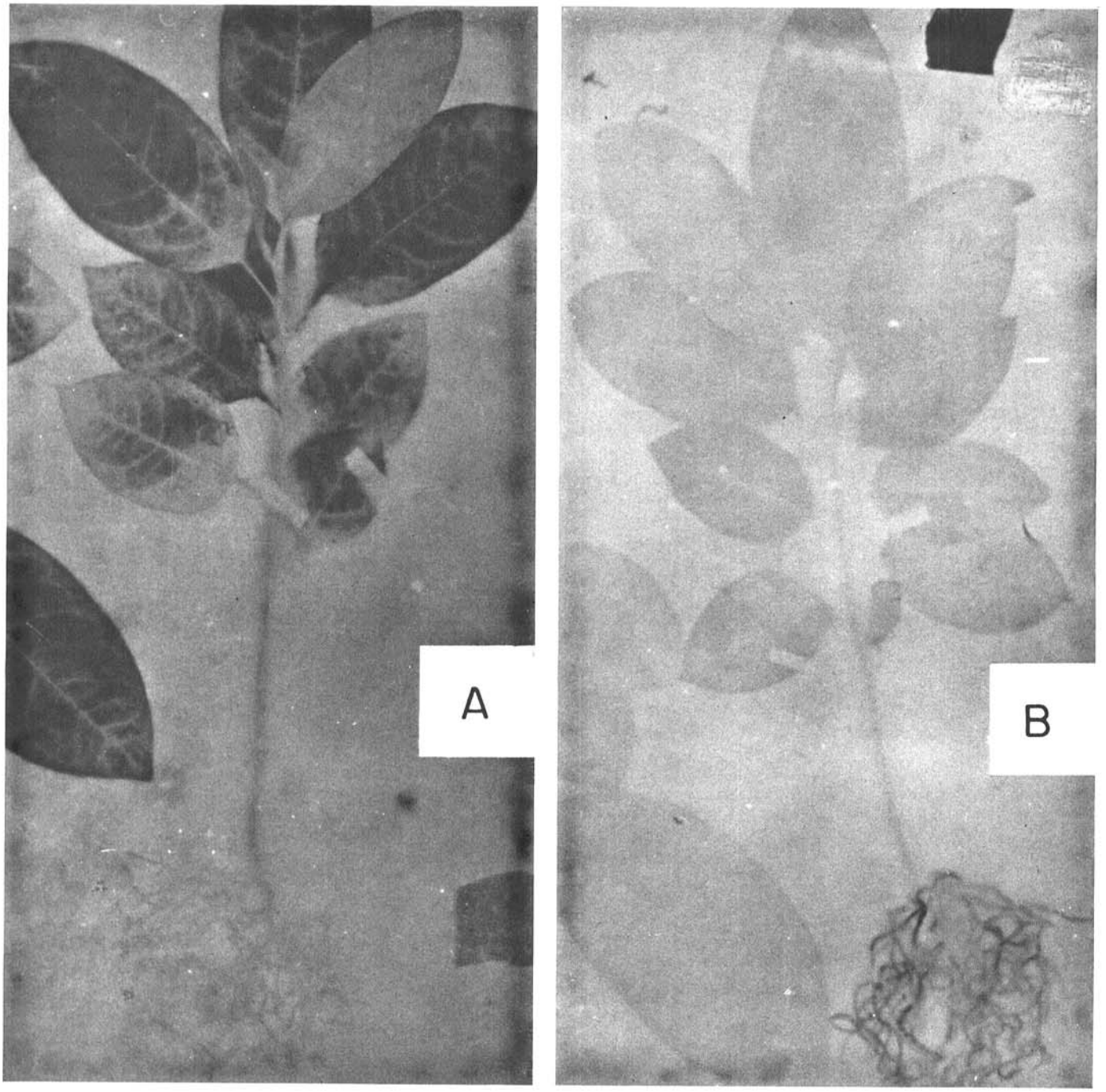

Fig. 1. Autoradiograms of *Persea indica* seedlings treated with ^{14}C-metalaxyl as **A,** a foliar application (radioactivity was detected in the lower part of the stem and in the root) or **B,** a soil drench (radioactivity was found in the root and in the foliage and was distributed uniformly in the leaves except in the veins where the level of radioactivity was very low; autoradiograms of nontreated seedlings did not show radioactivity).

fungicide was applied to the upper leaves, a considerable amount was translocated to the stem and lower leaves, and a very small amount was translocated to the roots (Table 5). There was no apparent difference between the concentration of the fungicide in the roots of plants treated with the fungicide alone and in those treated with the fungicide and IAA.

In plants analyzed 28 days after treatment with the labeled fungicide (Table 5), a high proportion of the recovered radioactivity was found in the leaves of stem-treated plants that received no growth regulator. IAA tended to reduce the translocation of metalaxyl out of the treated stems. When the upper leaves were treated and plants were analyzed 28 days after treatment, most of the radioactivity was found in the treated leaves of plants to which IAA or no growth regulator was added. The estimated concentration of the labeled fungicide in the roots after 28 days from treatment was between 0.7 and 2.6 μg/g in stem-treated plants and 0.7 to 2.2 μg/g in foliage-treated plants. Autoradiograms of foliage-treated avocado plants (Fig. 2A)

TABLE 5. Distribution of ^{14}C in avocado seedlings treated with test solutions of ^{14}C-metalaxyl with or without exogenous indoleacetic acid (IAA), 7 days or 28 days after treatment

			Stem-applied ^{14}C recovery					Leaf (upper)-applied ^{14}C					
Site of application[a]	IAA applied (mg/plant)	Incubation (days)	Treated stem (%)	Leaves (%)	Tap roots (%)	Feeder roots (%)	Estimated ^{14}C-metalaxyl in roots[b]	Treated leaves	Lower leaves[c]	Stem	Tap roots	Feeder roots	Estimated ^{14}C-metalaxyl in roots[b]
Stem	0	7	81.0	18.1	0.4	0.5	6.0						
Stem	0	28	36.0	62.1	1.6	0.2	2.6						
Stem	1.5	7	89.8	9.5	0.4	0.4	5.9						
Stem	1.5	28	97.0	2.8	0.0	0.1	0.7						
Upper leaves	0	7						86.2	6.6	6.1	0.4	0.5	4.5
Upper leaves	0	28						98.2	3.2	3.4	0.4	0.1	2.2
Upper leaves	1.5	7						98.2	0.7	0.2	0.1	0.2	4.0
Upper leaves	1.5	28						99.5	0.2	0.2	0.0	0.1	0.7

[a] Each plant was treated with 6.6 mg ^{14}C-metalaxyl (1.12 μCi) with or without IAA.

[b] Each figure is based on the amount of fungicide applied to each plant, the percent recovery of ^{14}C in the roots, the total recovery of labeled fungicide from all parts of the plant, the dry weight of the entire plant, and the dry weight of the roots. The assumption was made that ^{14}C-metalaxyl was not degraded or metabolized, which may not be true. (see Discussion).

[c] Untreated leaves lower than the treated ones.

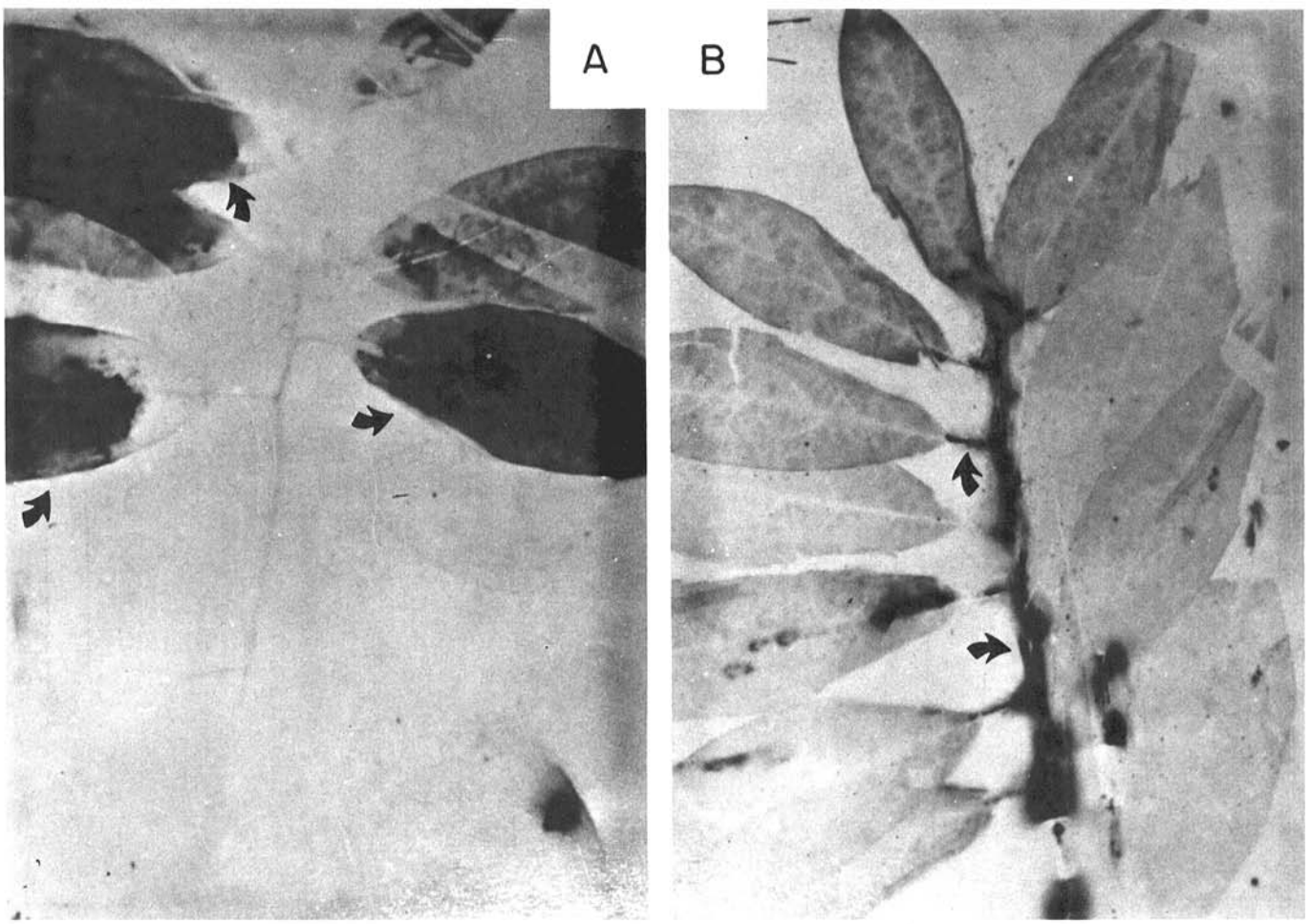

Fig. 2. Autoradiograms of avocado seedlings treated with ^{14}C-metalaxyl. **A,** The labeled fungicide was applied to the six uppermost leaf blades (arrows) (some radioactivity was detected in the lower part of the stem and petioles and very slight radioactivity was detected in leaf blades lower than the treated ones) or **B,** The labeled fungicide was applied to the stem and petioles (arrows) (considerable radioactivity was found in the leaf blades and no radioactivity was detected by autoradioactivity in the roots of either stem- or foliage-treated plants).

indicated a limited downward translocation of the labeled fungicide from the upper leaves to the stem and a slight translocation to lower leaves. In stem-treated plants (Fig. 2B) the autoradiograms showed considerable radioactivity in the leaves. Autoradiograms of roots from foliage-treated or stem-treated plants did not show any radioactivity.

The amount of labeled fungicide applied to each plant (6.6 mg) did not cause any phytotoxicity symptoms; neither did the addition of exogenous IAA.

DISCUSSION

Quantitative and qualitative data were obtained on the distribution of radioactivity in avocado, *P. indica*, and tomato plants following a localized application of ^{14}C-metalaxyl. The radioactivity measurements were assumed to represent the actual distribution of the fungicide. Based on metabolism studies in tobacco, potatoes, and other crops (Ciba-Geigy Corporation, *unpublished*), this assumption would likely be justified for the short-term experiments. However, in plants not harvested until 21 or 28 days after applications of metalaxyl, it is likely that only 30–60% of the total ^{14}C found in the plant or soil still was associated with the parent fungicide. Data obtained in this investigation are in agreement with findings by other workers (2,3,13) concerning the systemic activity of this new fungicide in plants. Autoradiograms of treated *P. indica* plants clearly showed that the labeled fungicide was taken up by the roots and was translocated upward. The distribution of radioactivity in the stem and leaves was highly uniform except in the veins where the level of radioactivity appeared to be low or completely absent. Unlike the systemic fungicide benomyl (4,6,12), ^{14}C-metalaxyl appeared neither to accumulate at the margins of the leaf blades nor to accumulate in certain leaves more than in others.

When ^{14}C-metalaxyl was applied to a single *P. indica* or tomato leaf, a small proportion, generally 1–5%, of the recovered radioactivity was translocated to other parts of the plant. Most of the recovered radioactivity (95–99%) remained in or on the surface of the treated leaf. In tomato, ^{14}C-metalaxyl was translocated from young leaves to old lower partially expanded leaves, and to a lesser degree from partially expanded older leaves to upper younger leaves. When the labeled fungicide was applied to the stem of tomato or avocado plants, 10% to more than 50% of the radioactivity was taken up and was translocated mostly to the leaves. Much more translocation occurred out of treated tomato stems compared to avocado stems. The proportion of radioactivity translocated to the roots of all foliar-treated avocado and tomato plants tested generally was less than 1%. In *P. indica* seedlings, a higher proportion of the recovered radioactivity (up to 2.8%) was detected in the roots. This proportion of radioactivity amounted to approximately 25 μg ^{14}C-metalaxyl per gram of root tissue and was not sufficient to protect *P. indica* seedlings from infection by *P. cinnamomi*. Higher concentrations of the fungicide in the roots (67–106 μg/g) were obtained following the application of the fungicide as a soil drench. This amount appeared to provide a partial protection of the roots of *P. indica* against disease.

These findings could suggest that for the control of root pathogens, it is more efficient to apply metalaxyl to the soil than to apply it to the foliage. Applying ^{14}C-metalaxyl to the entire foliage of tomato and avocado plants instead of to one single leaf or to the stem did not result in an increase in the amount of fungicide that was translocated to the roots. In some instances, the amount in the roots was less following application of the fungicide to the entire foliage. In avocado, the application of the growth regulator IAA with the labeled fungicide to the foliage or to the stem did not appear to significantly alter the downward translocation of the fungicide to the roots.

In this investigation, it was not possible to assert that ^{14}C-metalaxyl was translocated in the symplast. However, the uniform distribution of the labeled fungicide in *P. indica* plants as shown by autoradiography and the slow, but definite, downward movement of the labeled fungicide may suggest a certain degree of translocation of this fungicide in the phloem.

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