pares the photodegradation as determined by HPLC and microbiological assay. The data obtained by both methods are comparable. About 50% of the drug was degraded in less than 1 month. Thereafter, the rate of degradation became minimal, probably due to a protective film of degradation products formed around the unreacted drug. The degradation products could not be characterized and are believed to be polymeric. Small amounts of the *anti*-oxime of ceftiofur sodium were also observed, indicating inversion of the *syn*-oxime form of ceftiofur sodium used in this study.

Hydrolysis of Ceftiofur Sodium. The hydrolysis of ceftiofur sodium in pH 5, 7, and 9 buffers at 22 °C is shown in Figure 7. The half-life for the hydrolytic degradation is given in Table V. These data are based on the HPLC analysis of ceftiofur sodium. The potencies as a percent of initial concentration (μg/mL) of ceftiofur sodium by HPLC and microbiological assay were similar. The data at 47 °C for HPLC and microbiological assay were also similar (Figure 8) except that degradation was faster compared to 22 °C as expected (Table V). The two methods gave results that were linearly related with $y = 0.96$. The expected hydrolysis products, desfuroyl ceftiofur and furoic acid, were not present, and there was no indication of the appearance of products that could be detected by HPLC. These products are thought to be polymers that do not elute from the HPLC column until the end of the gradient.

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Effect of Endomycorrhizae on the Bioavailability of Bound ^{14}C Residues to Onion Plants from an Organic Soil Treated with [^{14}C]Fonofos†

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Uptake of bound ^{14}C residues from an organic soil treated with radiolabeled fonofos (*O*-ethyl *S*-phenyl ethylphosphonodithioate) by selected *Glomus* endomycorrhiza and onion roots was studied. The hyphae of endomycorrhizal associations were capable of removing ^{14}C residues from the soil and transporting them to onion plants. Bioavailability of soil-bound ^{14}C residues, as measured by ^{14}C residue content in onion, was increased 32 and 40% over that of nonmycorrhizal plants by hyphae of *Glomus intraradices* and *Glomus vesiculiferium*, respectively. The data suggest that under field conditions endomycorrhizal infection may greatly increase the bioavailability of soil-bound pesticide residues to plants.

It is now well established that many commonly used pesticides form bound residues when applied to agricultural soils (Khan, 1982; Katan et al., 1976). These residues may constitute an environmental hazard as their bioavailability and ultimate fate is generally unknown. Recent studies using radiotracer techniques have indicated that bound pesticide residues in soil may become bioavailable to plants (Racke and Lichtenstein, 1985; Khan, 1980; Helling and Krivonak, 1978) and microbes (Khan and Ivarson, 1981, 1982). In general, plants grown in soil containing only ^{14}C-bound residues of pesticides were found to take up 0.1–1.0% of these residues (Khan, 1982). The role of plant roots and soil microbes and the mechanisms of release and removal of these bound pesticide residues remain unclear.

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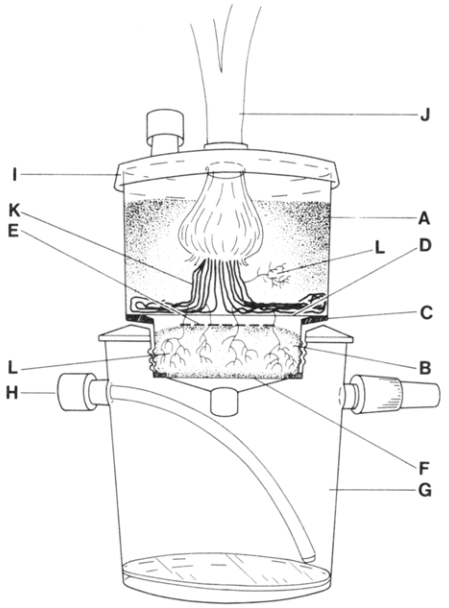

Figure 1. Treatment vessel used to study uptake of bound ^{14}C residues by roots and endomycorrhizae. Modified 150-mL disposable Falcon filter unit: A, upper soil compartment containing non-^{14}C-labeled soil; B, lower soil compartment containing ^{14}C-labeled soil; C, Viceroy rubber fruit jar ring; D, polyester screen with either 43- or 1000-μm mesh; E, 1000-μm mesh polyester screen; F, 0.45-μm membrane filter; G, receptacle for leachate; H, siphon port for leachate removal; I, funnel lid; J, onion; K, onion roots; L, hyphae of endomycorrhizae.

The role of endomycorrhizal associations in determining the fate of bound pesticide residues in soil has not been investigated. These specialized associations between soil fungi and plant roots are known to improve the uptake of several soil components into the plant (Cooper, 1984). This improved uptake is understood to result from an extensive network of fungal hyphae exploring the soil mass more thoroughly than roots and forming an extended solute capture system for the plant. In addition, hyphae contain enzymes that solubilize various soil nutrients facilitating their uptake by the host plant (Cooper, 1984; MacDonald and Lewis, 1978). This study was undertaken to determine whether selected endomycorrhizal soil fungi could influence the fate of bound residues of fonofos (*O*-ethyl *S*-phenyl ethylphosphonodithioate) in an organic soil. Fonofos, an organophosphorus insecticide, is used in onion cultivation to control onion maggots [*Hylenga antigua* (Meig)] and is known to form bound residues in organic soils (Khan et al., 1976).

MATERIALS AND METHODS

Soil. A Humic Mesiosol organic soil previously described (Khan et al., 1976) was used. The soil was treated in the field with [*ring*-^{14}C]fonofos (10% granular formulation, 7.6 kg·ha^{-1}) and collected after a cropping season (Khan and Belanger, 1987). This soil was exhaustively extracted, until further extraction did not remove any measureable ^{14}C residues, with hexane–acetone (Khan and Belanger, 1987). The ^{14}C-bound (nonextractable) residue content of the soil was 3.213×10^4 dpm/g (dry weight), or 2.1 ppm fonofos equiv. Control soil consisted of soil collected from nearby plots under the same cultural practices that had not received any [^{14}C]fonofos treatment (Khan and Belanger, 1987).

Treatment Vessel. The treatment vessels were 150-mL disposable FALCON filter units (7102; Becton Dickinson and Co., Crockeysville, MD 21030) that had been modified to allow the insertion of a screen into the funnel to form two soil compartments (Figure 1). The compartments were separated by various mesh polyester fiber screens: 43-μm plain mesh (HD7-43, Tetko Inc., 420 Saw Mill River Road, Elmsford, NY 10523) to prevent root but allow hyphal penetration and 1000-μm plain mesh (H27-100) to allow root and hyphal penetration. Screens were sealed onto Viceroy rubber fruit jar rings with Instant Krazy Glue II. Moist soil containing ^{14}C-bound residues, 11.56 ± 0.12 g (dry wt) of soil/treatment vessel, was placed in the bottom funnel compartment. One layer of the 1000-μm mesh screen was placed on top of the soil in all treatments. The screens with attached rubber rings were placed into the funnels and sealed to the funnel lip with 502 epoxy resin and H956 hardener (5:1). Screens with rubber rings were placed so that an air gap equal to the width of the rubber ring (at least 1 mm) separated this screen from the layer of 1000-μm screen resting on top of the soil. Moistened control soil, 39.15 ± 0.43 g (dry wt)/treatment vessel, was then placed above this screen. After insertion of plant material into the vessels, the filter unit caps were replaced and the units were wrapped in aluminum foil.

Plant Material. Surface-sterilized seeds of *Allium cepa* (L.) cultivar Autumn Spice were germinated in sterile quartz sand. Seedlings were transplanted to the treatment vessels after 10 days. Plants were watered every 2–3 days with sterile distilled water and were kept under a 16-h photoperiod of 250 μE·s^{-1}·m^{-2} with a 26–21 °C day–night temperature. Plants were given filter-sterilized Long-Ashton nutrient solution (Hewitt, 1966) once every fourth week to a total of 15-mL spread over 1 week.

Water Use. Soil water contents were maintained at 181.72 ± 1.21% by injecting measured amounts of sterile distilled water determined from weight loss over 2–3-day periods. This allowed precise monitoring of water use and minimized errors due to capillary rise or variability caused by leaching of released radiolabeled materials from the compartment of soil containing ^{14}C-bound residues. Leaching of solution from the soil containing ^{14}C-bound residues to the treatment vessel receptacle was not observed.

Mycorrhizal Inoculum. Fresh chopped leek (*Allium porrum* L.) root inocula of *Glomus intraradices* and *Glomus vesiculiferium* was used for the mycorrhizal treatments. These inocula were produced by the host plant soil–culture system (Menge, 1984) with sterilized turface as the soil medium (Plenchette et al., 1982). Inoculum was surface-sterilized according to Furlan and Fortin (1973) and 0.1 g (dry weight) placed in the rooting zone of control soil either prior to or after γ irradiation of the vessel plus soils. The percent of root infection was determined after roots were stained with acid fuschin (Berch, 1979) by a glass slide transect technique (Plenchette et al., 1982). This technique determines, at 100× magnification, the percent of root sections observed containing visible evidence of root infection by endomycorrhizae. The leek root inocula of *G. intraradices* and *G. vesiculiferium* had 78 and 84% levels of infection, respectively.

Treatments. The experimental design was a completely randomized design consisting of six replicates and eight treatments. These treatments and the possible uptake processes that each treatment was designed to represent are summarized in Table I. Soils were γ-irradiated after placement in the treatment vessels with 1.2 MRad to kill soil microfauna and microflora (Mosse 1973). γ-Irradiation was performed by RadioChemical Canada Ltd. (Kanata, ON) using a ^{60}Co source. An additional treatment, which did not contain plants, was handled under the same conditions throughout the experiment in order to determine the release of ^{14}C residues from soil due to abiotic processes.

Plant Harvest. Plant samples were harvested after 90 days of growth. Care was taken to separate leaf and bulb tissues from the root system. Roots were cut just above the variable mesh screen and thereby divided into those in contact with cold vs hot soil. Each of these root samples was separately rinsed in four changes in distilled water to remove adhering soil particles. Dry weights were determined, and then samples were analyzed for ^{14}C.

^{14}C Analysis. Combustion of plant tissues to $^{14}CO_2$ was done in a Packard sample oxidizer, Model 306. The $^{14}CO_2$ was absorbed in and mixed with an appropriate volume of oxisorb and oxiprep (Packard Instrument Canada, Ltd.). Samples were analyzed in a Beckman Series 8000 liquid scintillation spectrometer, using an external standard. Samples displayed variable chemiluminescence, which decayed after a 2-week period. Ten consecu-

Table I. Treatment of Soil and Experimental Conditions for Studying the Uptake of Bound ^{14}C Residues from an Organic Soil Treated with [^{14}C]Fonofos

treatment and contact with ^{14}C-labeled soil compartment	mesh size, μm	γ-irrad[a] rel to inoc	inoculum
(a) Root plus Mycorrhizal Hyphae			
root + *G. vesiculiferium*	1000	before	*G. vesiculiferium*
root + *G. intraradices*	1000	before	*G. intraradices*
(b) Mycorrhizal Hyphae Only			
G. vesiculiferium hyphae	43	before	*G. vesiculiferium*
G. intraradices hyphae	43	before	*G. intraradices*
indigenous mycorrhizal species hyphae	43	none	none
(c) Control Treatments			
root only	1000	before	none
inoculum contaminants	43	before	nonmycorrhizal[b]
abiotic transport processes[c]	43	after	nonmycorrhizal

[a] γ-Irradiation of assembled vessel and soils either before or after inoculum placement in treatment vessel (1.2 MRad). [b] Nonmycorrhizal inoculum refers to chopped leek roots without any endomycorrhizal symbionts. [c] Abiotic transport processes such as volatilization, capillarity, or bulk flow of soil solution.

tive readings were averaged to establish a mean sample reading. Samples from control plants grown without any ^{14}C-labeled soil were counted to establish background levels for the scintillation counter. Roots in direct contact with ^{14}C-labeled soil were not analyzed for radioactivity due to potential surface contamination by adhering soil particles. Therefore, total root radioactivity was calculated from total root dry weight (roots in contact with ^{14}C-labeled soil plus roots in contact with non-^{14}C-labeled soil) and the radioactivity per gram dry weight determined for roots in the non-^{14}C-labeled soil. After the experiment was completed, soils were exhaustively extracted with hexane–acetone to determine the amounts of ^{14}C released and not taken up into plants.

RESULTS AND DISCUSSION

Plant Growth and Water Use. Roots did not show any visible growth abnormality except where the roots had encountered the barriers to downward and horizontal growth. Characteristics of pot-bound conditions were evident in this case. Symptoms of soil toxicity in onion, due to prior extraction of soil with organic solvents (Helling and Krivonak, 1978), were not observed. In our study, plant roots also had access to nonextracted soil in the upper soil compartment in each treatment vessel.

At harvest, 37%, 42%, and 21% of total plant mass were located in the leaf, bulb, and root tissues, respectively. In treatments with roots in both soil compartments, approximately 68% of the total root mass was in the lower ^{14}C-labeled soil compartment. Treatments in which roots were restricted to the upper soil compartment had significantly less total plant growth and water use than treatments in which roots were allowed to grow into the lower compartment (Table II). A comparison of treatments in which mycorrhizae were present indicates that plants with roots restricted to the upper soil compartment had smaller root systems (Table II). This reduced root growth may relate to the influence of roots encountering the narrow-mesh screen sooner and the resulting decreased growth rate due to becoming pot-bound in the more limiting soil volume of the upper compartment.

Mycorrhizal treatment of onion, under the growth conditions used in this study, did not stimulate plant growth. Growth enhancement has often been observed in onion (Furlan and Fortin, 1973) especially under conditions in which the supply of nutrients and water to roots is limiting plant growth. In this study, the small soil volume in the treatment vessel may have been the most limiting factor, and the potential benefit from mycorrhizal infection, resulting from mycorrhizal exploration of additional soil mass, was not expressed.

Mycorrhizal Infection. Levels of mycorrhizal infection with *G. vesiculiferium* and *G. intraradices* were high, and no significant level of contamination by nonmycorrhizal fungi was noted (Table II). No significant differences were found in the level of mycorrhizal infection for roots in the upper and lower soil compartments, indicating that the extracted soil was not inhibitory to hyphal growth and the infection process. Pesticides are known to have varying effects on endomycorrhizae (Trappe et al., 1984); however, studies with fonofos have not been previously reported. Our data indicate that fonofos residues at these levels have little or no influence on *Glomus* endomycorrhiza. These residues were mostly soil-bound and therefore of low bioavailability.

Onion root pieces grown in non-γ-irradiated soil were cultured and fungal isolates similar to *Chrysosporium pannorum*, *Fusarium sporotrichoides*, and *Lasiobolus pulcherrinus* (Dalpé, Y., personal communication) were obtained. The relationships between these isolates and residue uptake processes were not determined but were assumed to be insignificant since only rare root infection with *Lasiobolus* was observed on root preparations. In addition, these fungi are not aggressive root pathogens.

Total ^{14}C Residue in Onion Plants. After 90 days of growth, ^{14}C residues were found in onion plants (Table III). Plants in the *G. vesiculiferium* treatment in which both roots and hyphae were in contact with soil containing bound ^{14}C residues contained 0.11% of the original soil-bound ^{14}C residue. This amount of ^{14}C residue in onion was low but similar to that found in other studies. Uptake levels at 0.46–1.06% of bound [^{14}C]dinitroaniline from a soil–sand mixture into soybean (*Glycine max*) (Helling and Krivonak, 1978) and 0.53% of bound [^{14}C]prometryne from an organic soil into oats (*Avena sativa*) (Khan, 1980) have been reported. In comparison to the above noted studies, lower levels of ^{14}C residue in onion may relate to restricted root growth in the limited soil volume of the treatment vessel, low plant mass, and low level of available ^{14}C residue for uptake.

On a plant and per gram dry mass basis, the greatest amount of ^{14}C was found in treatments in which both mycorrhizal-infected roots and mycorrhizal hyphae were located in soil containing bound [^{14}C]fonofos residues (Table III). Treatments to control for transport of ^{14}C due to either inoculum contaminants or abiotic processes did not contain significant amounts of ^{14}C residues (Table III). Control treatments for physical processes, such as the capillary rise of soil water from the lower to the upper soil compartment, accounted for only 6.2% of the mean ^{14}C residues found in plants of treatments in which roots plus mycorrhizal hyphae penetrated the lower ^{14}C-labeled soil compartment. The mean ^{14}C residue uptake in hyphae-only treatments accounted for 34% of that in root plus hyphae treatments. The presence of mycorrhizal hyphae on roots increased radiolabeled residues uptake by 40 and 32% over the root only treatments for *G. vesiculiferum* and *G. intraradices*, respectively (Table III).

Influence of Mycorrhizal Species on ^{14}C Residues in Plants. *G. intraradices* hyphae only treatments contained significantly greater amounts of ^{14}C residue on a plant and a per gram dry mass basis than either the *G. vesiculiferium* hyphae only or indigenous species hyphae only treatments. Although differing enzyme sys-

Table II. Plant Mass, Water Use, and Level of Mycorrhizal Infection of Onion after 90 Days of Growth in Organic Soil Containing Bound ^{14}C Residues of Fonofos[a]

treatment and contact with ^{14}C-labeled soil compartment	leaf mass, g	bulb mass, g	root mass, g	plant mass, g	infection, %	water use, g H_2O/plant
(a) Root plus Mycorrhizal Hyphae						
root + *G. vesiculiferium*	0.39 b	0.54 a	0.21 ab	1.14 ab	75.1 b	142.2 bc
root + *G. intraradices*	0.39 b	0.55 a	0.22 a	1.22 a	87.9 ab	152.2 bc
(b) Mycorrhizal Hyphae Only						
G. vesiculiferium hyphae	0.30 b	0.36 b	0.16 c	0.81 c	81.2 ab	66.9 e
G. intraradices hyphae	0.32 b	0.35 b	0.17 bc	0.83 c	91.3 a	98.9 d
indigenous species	0.31 b	0.37 b	0.14 cd	0.82 c	47.5 c	118.4 cd
(c) Control Treatments						
root only	0.59 a	0.36 b	0.15 c	1.09 ab	0 d	207.4 a
inoculum contaminants	0.38 b	0.32 b	0.10 d	0.76 c	0 d	136.9 bc
abiotic transport processes	0.51 a	0.33 b	0.16 c	1.00 b	0 d	173.2 b

[a] Mean separation within a column by Duncan's multiple-range test, $P = 0.05$; six replicates.

Table III. Total Amount of ^{14}C Residue in Tissues of Onion after 90 Days of Growth in Organic Soil Containing Bound ^{14}C Residues of Fonofos[a]

treatment and contact with ^{14}C-labeled soil compartment	total dpm/plant	dpm/g dry mass
(a) Roots plus Mycorrhizal Hyphae		
roots + *G. vesiculiferium*	454.8 a	398.9 a
roots + *G. intraradices*	428.6 a	351.3 a
(b) Mycorrhizal Hyphae Only		
G. *vesiculiferium*	140.2 d	173.1 c
G. intraradices	219.2 c	264.1 b
indigenous species	84.9 de	103.5 c
(c) Control Treatments		
roots only	325.3 b	298.4 b
inoculum contaminants	36.9 e	48.6 d
abiotic transport processes	26.8 e	26.8 d

[a] Mean separation within a column by Duncan's multiple-range test, $P = 0.05$; six replicates.

Table IV. Allocation of ^{14}C Residue within Onion after 90 Days of Growth in Organic Soil Containing Bound ^{14}C Residues of Fonofos[a]

treatment and contact with ^{14}C-labeled soil compartment	% of total plant ^{14}C in leaf	bulb	root
(a) Roots plus Mycorrhizal Hyphae			
roots + *G. vesiculiferium*	81.2 a	11.1 a	7.5 b
roots + *G. intraradices*	78.5 a	11.9 a	9.7 b
(b) Mycorrhizal Hyphae Only			
G. vesiculiferium	40.1 b	3.5 b	56.4 a
G. intraradices	32.1 b	3.4 b	64.6 a
indigenous species	38.2 b	5.3 b	56.5 a
(c) control treatment[b]			
root only	77.1 a	8.6 ab	14.4 b

[a] Mean separation within a column by Duncan's multiple-range test, $P = 0.05$; six replicates. [b] Other control treatments not included due to their low total dpm values.

Table V. Onion Tissue ^{14}C Residue Concentration (dpm·g^{-1} Dry Weight) after 90 Days of Growth in Organic Soil Containing Bound ^{14}C Residues of Fonofos[a]

treatment and contact with ^{14}C-labeled soil compartment	leaf	bulb	root
(a) Roots plus Mycorrhizal Hyphae			
roots + *G. vesiculiferium*	960.2 a	100.7 a	125.7 d
roots + *G. intraradices*	881.0 a	95.5 a	191.6 cd
(b) Mycorrhizal Hyphae Only			
G. vesiculiferium	192.1 c	15.7 b	469.7 b
G. intraradices	212.4 c	21.9 b	842.9 a
indigenous species	121.8 c	13.7 b	319.6 bcd
(c) Control Treatment[b]			
roots only	438.9 b	77.9 a	367.3 bc

[a] Mean separation within a column by Duncan's multiple-range test, $P = 0.05$; six replicates. [b] Other control treatments not included due to their low total dpm values.

Table VI. Bioavailability of Bound ^{14}C Residues of Fonofos from an Organic Soil[a]

treatment and contact with ^{14}C-labeled soil compartment	% orig soil-bound ^{14}C residue[b] onion	soil extract	% ^{14}C in soil extract onion
(a) Roots plus Mycorrhizal Hyphae			
roots + *G. vesiculiferium*	0.11 a	1.19 a	8.73 a
(b) Mycorrhizal Hyphae Only			
G. vesiculiferium	0.04 b	1.36 a	2.59 b
(c) Control Treatments			
roots only	0.08 a	1.57 a	5.00 a
abiotic transport processes	<0.01 c	1.73 a	0.46 c
no plants		<0.01 b	

[a] Mean separation within a column by Duncan's multiple-range test, $P = 0.05$; six replicates. [b] Original soil-bound ^{14}C residues were 2.1 ppm fonofos equiv (dry weight) of soil.

tem capacities for release of bound residues between species is possible, it is likely that the higher levels of infection and significantly greater total water use in the *G. intraradices* treatment, 13% higher infection and 48% greater water use then *G. vesiculiferium*, relate to these differences in total ^{14}C residue uptake. Although the indigenous species hyphae only treatment had 20% greater water use than the *G. intraradices* hyphae only treatment, the lower level of ^{14}C residue in the indigenous treatment was likely due to the significantly lower level of mycorrhizae infection (Table II).

Allocation of ^{14}C Residue in Onion. Significant differences in allocation of radiolabeled residues were found among the treatments. Treatments in which only mycorrhizal hyphae were responsible for ^{14}C residue uptake had a much greater allocation to roots, ca. 8 times more (Table IV). The ^{14}C residue concentrations (dpm·g^{-1} tissue dry mass) in roots of hyphae-only treatments were greater than in treatments where root uptake was also involved (Table V). These data indicate a selective partitioning of ^{14}C residues in onion that is dependent upon the method of uptake. Thus, ^{14}C residue from hyphae-only uptake is distributed throughout the plant but accumulates in the root, and ^{14}C residue from root-only uptake results in a greater portion translocated to the shoot. In the root plus hyphae treatments, allocation appears to be dominated by the root-only uptake allocation pattern. This may be a consequence of the limited soil volume in the treatment vessel, reducing the influence of greater exploration of soil mass by hyphae than roots and therefore dominance of allocation by the hyphal pat-

tern. Therefore, the influence of endomycorrhizae on pesticide allocation within onion has important consequences for the potential bioaccumulation into edible portions of plant materials.

Extraction of Bound ^{14}C Residues from Soil. The soil was extracted to determine the level of extractable ^{14}C residues at the end of the experiment. Significant differences were found among treatments (Table VI). As the amount of extractable ^{14}C residue in soils was negligible at the start of the experiment and in controls with bound ^{14}C residues watered throughout the experiment but not containing plants, it is likely that exudates from the root leached into the soil containing bound ^{14}C residues and released some of the bound ^{14}C residue. It appears that intimate contact between roots and the soil-bound pesticide residues is not a requirement for bioavailability of pesticide residues.

The amount of ^{14}C residue extractable with hexane–acetone from soil at harvest exceeded the amount of ^{14}C residue in the plant by 1 order of magnitude. In this study the soil volume was limited, and root plus hyphal exploration of the soil mass was extensive. Under these circumstances one could expect greater amounts of the extractable ^{14}C residue to be taken up into onion if it was readily bioavailable. Therefore, either the ^{14}C residue extractable by hexane–acetone was not bioavailable or onion root and hyphal permeabilities for fonofos and its residues were limiting. The relationship between hexane–acetone extractability and eventual bioavailability remains undetermined.

These data indicate that bound ^{14}C residues in soil treated with [^{14}C]fonofos become bioavailable and are taken up into onion plants. Previously, workers had shown negligible (Khan et al., 1976) or limited (Khan and Belanger, 1987) fonofos uptake into onion from soil containing both bound and extractable residues. The mechanism of uptake and the form of ^{14}C absorbed by hyphae and roots were not elucidated. It remains unclear whether or not the uptake occurs directly from the bound residue reservoir in soil and to what extent soil chemical and/or biological processes are involved in releasing bound residues. The treatments (Table I) indicated negligible $^{14}CO_2$ assimilation by onion (Table III). Interestingly, Khan and Belanger (1987) determined by high-temperature distillation procedures that in these soils the parent compound was the major constituent present in the form of bound residues, and Lichtenstein et al. (1983) found that most of the ^{14}C extractable from soil treated with [^{14}C]fonofos was the parent compound. Our data indicate that hyphae of *Glomus* endomycorrhizal fungi are able to take up and transfer to onion ^{14}C pesticide residues from soil originally containing only bound ^{14}C residues. The addition of endomycorrhizae to onion roots increased ^{14}C residue uptake by 32–40%. It appears that under field conditions endomycorrhizal infection would greatly increase the total uptake of bound insecticide residues into plants due to the extensive exploration of soil mass by endomycorrhizal hyphae. The exploration of soil mass by hyphae has been estimated to be at least 1 order of magnitude greater than that by roots. Furthermore, endomycorrhizal infection may also alter the allocation of insecticide within the plant. Consideration of the potential use and manipulation of endomycorrhizae in agriculture will have to include the role of these associations in determining the fate of pesticides in the soil and in plants.

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