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MINERALIZATION AND UPTAKE OF TRIAZINE PESTICIDE IN SOIL-PLANT SYSTEMS

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ABSTRACT: Deep-rooted trees planted as a buffer zone can intercept runoff and eroded sediments, thus reducing non–point-source pollution due to agricultural chemicals. In this study, *Populus* sp. were grown in bioreactors with an agricultural soil (silt-loam) and in a silica-sand media; both were spiked with ^{14}C uniformly ring-labeled atrazine. The plants took up over 11% of the ^{14}C labeled atrazine applied to the silt-loam soil and over 91% of that applied to the silica sand media, with the majority of the ^{14}C accumulating as nonphytotoxic metabolites in the leaves. Research suggests that, in addition to nutrient uptake, poplar tree buffer strips may be effective in removing atrazine from agricultural percolation and runoff water.

INTRODUCTION

Nitrate-nitrogen and atrazine (2-chloro, 4-ethylamino, 6-isopropylamino-s-triazine) are the most frequently detected non–point-source pollutants in surface water and ground-water samples of the Midwest throughout the year. Thurman et al. (1991) detected atrazine in 98%, alachlor in 86%, and deethylatrazine in 86% of stream flow sampled in the midwestern United States after crop planting, nitrogen fertilizer application, and pesticide application. Adams and Thurman (1991) found atrazine and deethylatrazine at concentrations of 33.2 and 4.7 mg/L, respectively, in water samples taken 2 d after atrazine application from a 0.3 m depth lysimeter in experimental plots planted with corn. Deethylatrazine was the major transformation product (compared to deisopropylatrazine) and was detected at concentrations up to 5 μg/L in water samples from the underlying aquifer, and atrazine was detected at 4.1 μg/L, 120 d after application.

Plant buffer zones with deep-rooted trees installed next to streams have the potential for retarding agricultural chemical movement out of the root zone by increasing evapotranspiration and adsorption and for reducing chemical concentrations in soil via uptake of the chemicals and enhanced biotransformation (Paterson and Schnoor 1992). The plant buffer zones may be engineered to intercept tile-line drainage and shallow surficial ground-water infiltration into streams. Fig. 1 is a conceptual diagram of a tree buffer zone grown to intercept, retard, and uptake agricultural chemicals transported from the adjacent field. Pesticide transported out of the root zone by advective flow can be retarded if the pesticide has a high affinity for sorption to naturally occurring organic matter in soil, to root exudates, and

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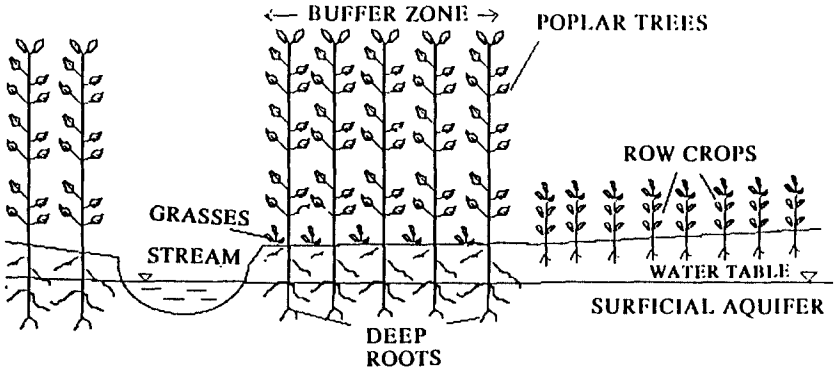

FIG. 1. Buffer-Zone Concept to Intercept Eroded Sediments and Runoff, Enhance Removal of Agricultural Chemicals in Soil by Uptake, Adsorption, and Biotransformation

to the roots. In the soil, many pesticides first bind with organics to form low molecular-size polycondensates like fulvic acids, and the pesticide can then slowly accumulate into nonextractable humin fractions to form bound residues (Andreux et al. 1990), which may not be bioavailable. In addition, the plants can uptake the parent pesticide or pesticide metabolites for metabolization in the plant (Lamoureux et al. 1973), thus reducing pesticide residues in the soil. The plant roots also increase microbial activity in the rhizosphere by providing additional attachment and growth sites, and increasing the soil organic carbon content by the root mass itself and by exuding organics, all of which can potentially enhance biotransformation of pesticides.

Hybrid-poplar (*Populus* sp.) buffer research was first initiated between streams and row cropped fields in 1988. A 6 m wide tree buffer was installed along a portion of a stream in late spring of 1988 at a density of 33,500 trees per hectare. The poplar-tree cuttings have preformed root initials that enable root sprouting from the entire buried length of the planted stem (Licht 1990) and allow root placement at desired depths. After two growing seasons, the trees averaged over 4.5 m high and developed dense roots over 1.8 m deep. Well samples showed that nitrate concentrations near the surface water table were reduced by over 90% beneath the popular buffer compared to water sampled beneath the upgradient corn field (the edge of corn field was 5 m upgradient of edge of buffer strip and wells were 6 m apart) (Licht 1990).

McFarlane et al. (1990) studied the uptake, translocation, and metabolism of nitrobenzene in several terrestrial plants including poplars. All species were able to metabolize nitrobenzene to polar metabolites and insoluble by-products. Volatilization from leaves was the major fate pathway for nitrobenzene. Anderson and Walton (1991) used plants with different root types to study the effect of vegetation on TCE (trichloroethylene) fate. They found that the plant root systems enhanced the mineralization of TCE to CO_2 in the soil and that plant uptake was not significant compared to mineralization from the soil. Plant uptake and accumulation of TCE or its metabolites was correlated with water uptake by the plant. Trapp et al. (1990) used a chamber ecosystem to study uptake and metabolism of several organic chemicals by barley plants. They found that nearly 60% of the atrazine-ring ^{14}C found in the plant after one week was metabolites, pri-

marily hydroxyatrazine, which were either transformed in the soil or in the plant.

For any plant to uptake a phytotoxic chemical and survive, it needs to have detoxification mechanisms, such as metabolizing the chemical or conjugating the chemical in plant material, to form less-phytotoxic materials. Shimabukuro (1967) found that the roots and shoots of pea plants could independently metabolize atrazine to deethylatrazine, a less-phytotoxic metabolite. Atrazine was translocated through the xylem to the shoot, which had a higher ability to metabolize atrazine compared to the roots. Corn, on the other hand, has an unique ability to detoxify atrazine and simazine to their hydroxy products, which are not phytotoxic to most plants. Formation of glutathione and cysteine conjugates of the triazines in plants are also important detoxification mechanisms (Lamoureux et al. 1970). Beynon et al. (1972) found that accumulation of total atrazine was more than 10 times higher in the leaf of maize plants compared to the stem. They also found that 40% of atrazine applied to maize sap at 10 ppm was broken down to hydroxyatrazine in just 8 h. Hamilton and Moreland (1962) found that a cyclic hydroxamate (2,4-dihydroxy-3-keto-7 methoxy-1,4-benzoxazine) was responsible for the conversion of 2-chloro-triazines to their hydroxy analogs in plants.

Akinyemiju and Dickman (1982) demonstrated that several poplar clones could tolerate simazine (2-chloro-4,6-bis(ethyl-amino)-s-trazine) and diuron [3-(3,4-dichloro-phenyl)-1,1-dimethyl urea] at normal field application rates. Akinyemiju et al. (1983) showed that in a tolerant species, a less-phytotoxic dealkylated metabolite of simazine was being accumulated while none was detected in a susceptible clone. Poplar trees grown densely in an experimental plot near Lily Lake, Amana, Iowa, did not display any phytotoxicity to about 1.4 kg/ha of atrazine surface-applied to the plot (Paterson and Schnoor 1992).

OBJECTIVES

The object of this research was to understand the dynamics and possibility for removal of organic pesticides via plant-soil systems. The experiments described were performed to study the influence of poplar plant root systems on enhancing the mineralization, decreasing the mobility by adsorption, and directly uptaking atrazine from soil. The ability of the plant to uptake and translocate the pesticide to various parts of the plant was quantified. The role of the soil to sorb and desorb the pesticide and thus to affect bioavailability for plant uptake and biotransformation was studied via adsorption isotherms.

MATERIALS AND METHODS

Plant Reactor Studies

Two separate studies were conducted on two types of soil media. The first study was conducted with silt-loam soil (Nodeway-Ely series) from Amana, Iowa. The soil was air-dried, pulverized, and passed through a 2 mm sieve. The silt-loam soil was then homogenized and the whole soil (500 g per reactor) were placed in 1 L bioreactors (wide-mouth Erlenmeyer flasks). Table 1 shows the characteristics of this soil. The second set of reactors consisted of a pure silica sand media (800 g per reactor) placed in 1 L bioreactors (wide-mouth jar reactors).

Three poplar-tree cuttings (Imperial Carolina variety), each about 45 cm

TABLE 1. Characteristics of Nodeway-Ely Series Soil from Amana, Iowa

Characteristic (1)	Value or description (2)
(*a*) Site	
Location	Lily Lake, Amana
Horizon	A (0–150 cm)
Texture	Silt-loam
pH (1:1) soil:H_2O	6.3
Organic matter content	2.2%
(*b*) Particle-Size Distribution	
Sand (particle size 0.05–2.0 mm)	1.25%
Silt (particle size 0.002–0.05 mm)	67.5%
Clay (particle size <0.002 mm	20.0%
(*c*) Chemistry	
Total organic carbon	12,500 ppm
Total Kjeldahl Nitrogen	1,182 ppm
Total phosphorus	326 ppm
Calcium	3,100 ppm
Potassium	160 ppm
Magnesium	660 ppm
Sodium	33 ppm
Cation exchange capacity	23.5 meq/100 gm soil
(*d*) Base Saturation	
Ca	66.0%
K	1.7%
Na	0.6%
Mg	23.1%

long by 5 mm stem diameter, were planted in silt-loam soil bioreactor through holes drilled in a neoprene stopper, which was firmly fixed over the reactor mouth and sealed with silicon sealant, as shown in Fig. 2. The gap between the cuttings and stopper was also sealed making the flask airtight. The silica-sand reactors were completed in the same configuration with only one cutting per reactor. The silt-loam soil was treated with 185 μg of ^{14}C uniformly ring-labeled atrazine (specific activity 20.7 μCi/mg) to give a soil concentration of 0.37 μg/g soil. The silica-sand media was treated with lower doses of 48.3 μg of ^{14}C uniformly ring-labeled atrazine for a concentration of 0.06 μg/g media. The silica sand was dosed at the lesser concentration as there was only one cutting in each flask and because less sorption would occur in the silica sand media. Chemical purity of the atrazine was 97.1%, and radiochemical purity was 99.5%. Three replicates and controls (no atrazine added) of the plant bioreactors were prepared in each reactor type. Another set of triplicate controls were prepared with no plants in the bioreactor but with the same atrazine concentrations. Duplicate sterile controls were also prepared using sterilized silt-loam soil. The silt-loam soil for the sterile controls were first autoclaved in trays for 1 h at 121°C and 96.5 kPa (14 psi). The autoclaved soil was then transferred to the flasks, stoppered, and autoclaved again for 15 min each at 121°C and 96.5 kPa (14 psi) (Mihelcic and Luthy 1988). Deionized water was then added to all the

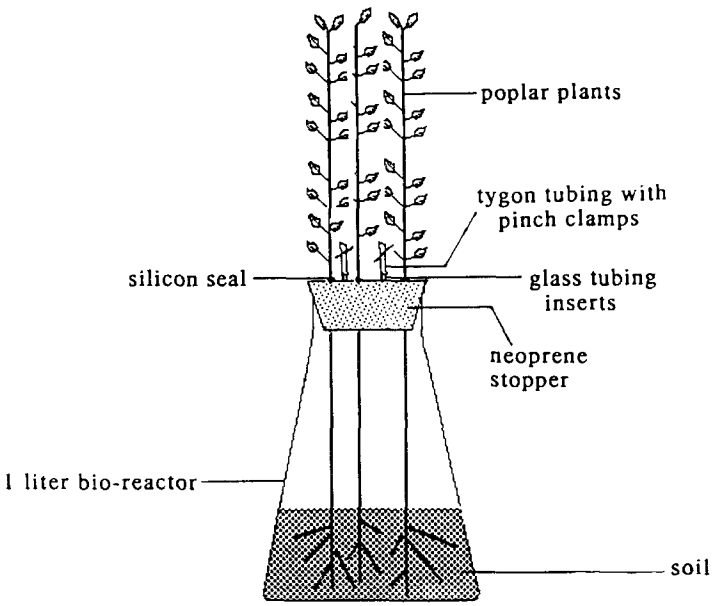

FIG. 2. Plant Bioreactor Used for Experimental Studies

bioreactor sets to completely saturate the soils except for the sterile controls, for which the deionized water was autoclaved and aseptically added to the previously sterilized flasks.

The silt-loam plant reactors were wrapped with aluminum foil to shield off light from the soil, and then placed under growth lights (Sylvania Gro-Lux 40-watt fluorescent tubes) in a walk-in fume hood. The light intensity in the photosynthetic active range (PAR) of 400–700 nm, measured with a LI-COR (model LI-189) quantum sensor at the foliage level ranged from 40–80 $\mu mols/s \cdot m^2$. The lights were operated at 16 h photoperiod with a timer. The temperature and relative humidity in the laboratory was in the range of 20–25°C and 60–70%, respectively. The silt-loam experiments were run for a duration of 126 d. The silica-sand reactors were operated in the same fashion with two deviations. One difference was that the lights (Vita-Lite 40 watt fluorescent tubes) provided 100–120 $\mu mols/s \cdot m^2$ and were operated at 20 h photo period, and the other difference was that the silica-sand experiments were operated for only 22 d, due to more rapid uptake of the pesticide.

At regular intervals, the air in the silt-loam reactors was removed by a Gast vacuum pump from the reactor outlet and fresh gas was passed into the reactors from the reactor inlet. The silica sand reactors were operated in a continuous air-flow system. The gases evacuated from all reactors were collected in CO_2 traps consisting of glass vacuum tubes and 0.2 N NaOH (prepared with CO_2–free deionized water). The fresh gas was passed through a flask of CO_2–free deionized water to moisten the gas before it refilled the silt-loam reactors. Recovery of $^{14}CO_2$ in the CO_2 traps was more than 95%. The samples from the traps were then pipetted into 20 mL polypropylene scintillation vials and a scintillation cocktail, Scintiverse E (Fisher Chemicals), was added at twice the volume of the sample. The vials were

then analyzed using a Beckman Model LS 6000IC liquid scintillation counter. Samples were counted until a fractional error of $\pm 0.5\%$ was obtained at the 95% confidence level, subject to a maximum allowable counting time of 15 m. Counting efficiency for this sample-cocktail mixture was over 90%.

The silt-loam reactors were sampled regularly, and after each sampling, deionized water was added to the plant bioreactors to compensate for water lost through plant transpiration. All the reactors were refilled with a 60% N_2/40% O_2 gas mixture after each sampling. Throughout the experimental period, no nutrient or plant-growth stimulant was added to the silt-loam bioreactors. The silica sand reactors were fed Hoagland's nutrient solution, a nonorganic nutrient solution, to provide nutrients not available in the silica-sand media. Dead or fallen leaves from the plants were removed and stored for later analysis. Only $^{14}CO_2$ trapped from within the plant bioreactors was measured. Plant respiration of $^{14}CO_2$ from atrazine-ring mineralization was not measured, as research by a coworker (Schwarz 1991), showed that the poplar plants did not volatilize measurable amounts of $^{14}CO_2$.

At the end of each experiment, the fresh leaves, stem, and roots from the plants were harvested separately, dried at 110°C for 24 h, weighed, crushed, and mixed. This was also done for the dead and fallen leaves that were collected and stored for analysis during the period of the experiment. Random samples from each part of the plant were then weighed and wrapped in black paper and placed in a 2 L oxidation flask. The flask was then filled with oxygen gas and then sealed with a glass stopper fitted with a 5 mL holding tube. The apparatus was then placed in a Thomas-OGG Safety Oxygen Flask Igniter, where the sample was ignited by an infrared lamp. After complete combustion, the flask was immersed in a cold bath filled with a mixture of dry ice and acetone to reduce the temperature and vapor pressure. 5 mL of CarboSorb (Packard Chemicals) was placed in the holding tube. The control valve was opened to draw in the CarboSorb and then closed. The flask was kept in the bath for 30 min to allow for complete absorption of carbon dioxide. One mL of the solution in the flask was then pipetted into a 20 mL polypropylene scintillation vial, 10 mL PermaFluor V (Packard Chemicals) scintillation cocktail was added and the sample was counted as described previously.

Soil Sorption-Desorption Studies

Different amounts of ^{14}C ring-labeled atrazine was added to 5 g of silt-loam soil, soil 1 (previously sterilized by gamma radiation of 5 Mrads) in 20 mL glass scintillation vials. Deionized water was then added to saturate the soil to field capacity and the vials were capped and stored in the dark for 21 d at room temperature. After this period, 10 mL of deionized water was added and the vials were shaken on a gyratory shaker for 48 h. Previous work by Nair and Schnoor (1992) show that biological activity in sterile controls is negligible over a 150 d period. After adequate settling, sediment-free aliquots of the water were assayed for ^{14}C activity by liquid scintillation counting.

For the desorption studies, the soil solution was extracted by a vacuum filtration technique. The soil slurry was placed on a Whatman No. 41 filter paper in a Buchner funnel attached to a filtration flask. Vacuum was applied with an air-vacuum pump and the filtrate was assayed for ^{14}C activity. The paper filter with the soil residue was placed back into the vial and 10 mL of deionized water was added again and the procedure was repeated a number of times until only background ^{14}C activity was detected in the filtrate.

TABLE 2. Distribution of ^{14}C in Plant Components for Triplicate Silt-Loam Soil (SLS) and Six Silica Sand Media (SSM) Plant Bioreactors

Reactor (1)	^{14}C in plant (μg) (2)	% in leaf (3)	^{14}C in leaf (ppm) (4)	% in root (5)	^{14}C in root (ppm) (6)	% in stem (7)	^{14}C in stem (ppm) (8)
(*a*) Silt Loam Soil Plant Bioreactor							
SLS-1	12.3	61.0%	7.1	3.9%	2.2	35.9%	0.9
SLS-2	22.9	66.0%	10.5	2.7%	4.0	31.3%	1.6
SLS-3	29.6	71.7%	13.7	1.5%	2.2	26.8%	1.5
[Average]	[21.6]	[66.2%]	[10.4]	[2.7%]	[2.8]	[31.3%]	[1.3]
(*b*) Silica Sand Media Plant Bioreactor							
SSM-1	38.0	83.0%	11.9	3.7%	1.0	13.3%	1.0
SSM-2	46.4	89.6%	11.2	2.5%	0.4	7.9%	1.0
SSM-3	45.3	84.6%	12.6	7.2%	0.2	8.2%	0.6
SSM-4	44.2	86.3%	14.3	4.9%	0.9	8.8%	0.8
SSM-5	45.8	84.7%	12.1	6.9%	1.3	8.4%	0.7
SSM-6	43.3	85.0%	13.0	7.1%	1.5	7.9%	0.5
[Average]	[43.8]	[85.5%]	[12.5]	[5.4%]	[0.9]	[9.1%]	[0.8]

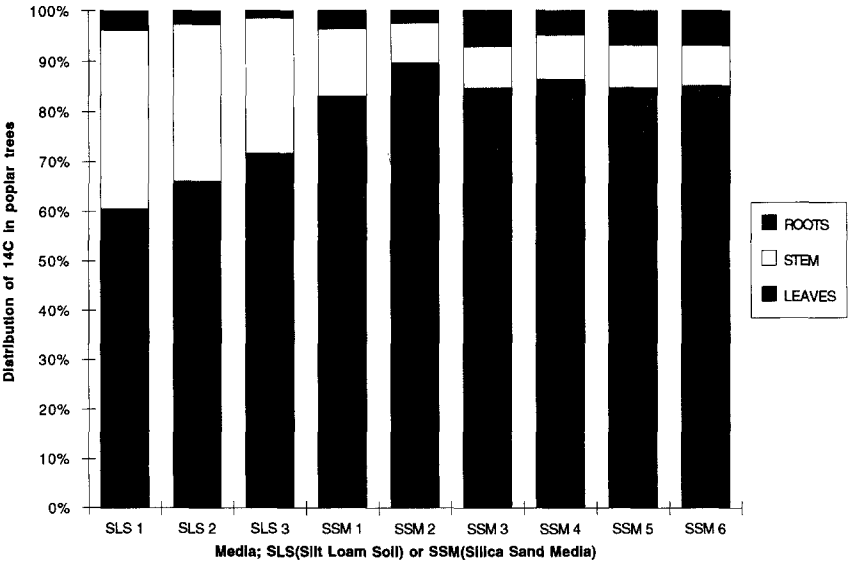

FIG. 3. Distribution of ^{14}C Accumulation in Plant Components for Triplicate Silt-Loam Soil (SLS) and Six Silica Sand Media (SSM) Plant Bioreactor Studies

LABORATORY RESULTS AND DISCUSSION

Poplar Plants

This study demonstrated no phytotoxicity to poplar plants with atrazine soil concentrations of 0.37 μg/g silt-loam soil or 0.06 μg/g silica-sand media. In each experiment, the plants in the bioreactors had very similar survival and growth as the control reactors (no atrazine added) at completion of the

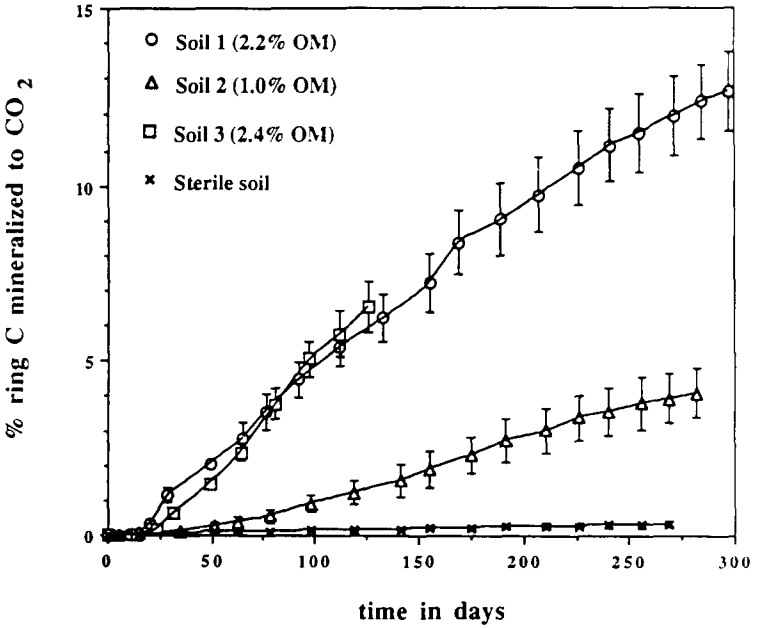

FIG. 4. Mineralization of Atrazine Ring ^{14}C from Bioreactors with Soils Having Different Organic Matter (OM) Content

experiment. The plant leaves did not show any visual symptoms of injury due to photosynthetic inhibition. Leaf coloration was normal and the leaves did not show any sign of chlorosis. Chlorosis is the only visible symptom of photosynthetic inhibition by triazine herbicides in plants (Ebert and Dumford 1976).

Table 2 shows the comparative results of ^{14}C atrazine plant uptake in the two different soil types. Poplars grown in the silica sand showed greater uptake than those grown in the silt-loam soil. Trees in the silica sand in the 22 d growing period accumulated over 91% of the ^{14}C atrazine applied to the reactor. The total uptake on a mass basis was 44 μg of ^{14}C labeled atrazine at the rate of 2.0 μg/d. Plant accumulation of the ^{14}C atrazine in the silt-loam reactors was 11% at the completion of the 126 d growing period with a total uptake equaling 20 μg of ^{14}C labeled atrazine at a rate of 0.16 μg/d. Differences in uptake can be explained by three variables in the experiments: (1) The poplars grown in the silt-loam soil had slightly less light; (2) the poplars grown in the silica sand had a much higher transpiration rate; and (3) the lower sorption of atrazine to the mineral and organic fractions in the silica sand allowed more uptake.

Fig. 3 shows the distribution of radioactivity in the plants. The leaves of the plants on the average accounted for 66% of the total ^{14}C activity in the plants in the silt-loam soil reactors and 85% for the silica-sand reactors. The stem and roots accounted for 31.3% and 2.7% of the total ^{14}C activity in the plants of the silt-loam soil reactors, respectively. The stem and root of the plants in silica sand reactors accumulated 9.1% and 5.4%, respectively. Accumulation of ^{14}C in the plants, per mg of dry matter was greatest in the leaves and smallest in the stem. The roots had a high concentration

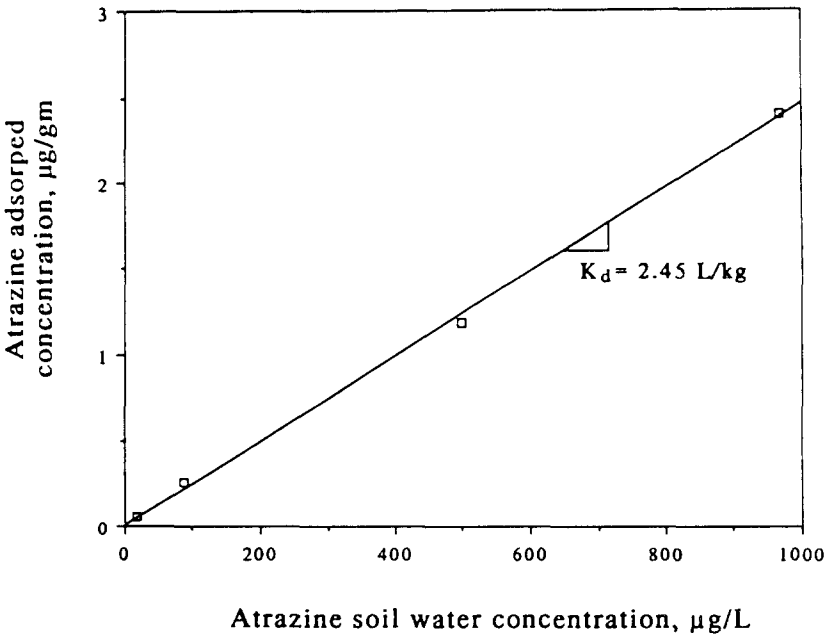

FIG. 5. Absorption Isotherm for Atrazine-Ring ^{14}C in Nodeway-Ely Soil from Amana, Iowa (*foc* = 0.022)

of ^{14}C per mg dry weight, however roots accounted for such a small amount of the accumulated ^{14}C label due to the limited mass of the roots. The configuration of the bioreactor did not allow any $^{14}CO_2$ mineralized from the soil, to be sequestered by the plant leaves. Related work by a coworker (Schwarz 1991), showed that the poplar plants did not volatilize measurable amounts of $^{14}CO_2$. So, all the ^{14}C activity in the plant was due to plant uptake through the roots only, and translocation to the leaves was the major fate pathway. Fletcher et al. (1990) showed that a water-soluble chemical nitrobenzene could translocate from the root to the shoot without being engaged by the enzyme complements of living cells. Atrazine-tolerant plants have detoxification mechanisms, which convert atrazine to nonphytotoxic hydroxyatrazine, dealkylated metabolites, or conjugates with plant material (Lamoureux et al. 1970). At this stage, the identity of the constituents contributing to the ^{14}C activity in the plants is not known.

The plant roots by themselves, increased the organic matter mass in the soil by slightly greater than 2%, even though root growth was limited due to the restricted space in the reactor. Nair (1991) showed that mineralization rates of atrazine-ring and isopropyl-side-chain carbons were directly proportional to soil organic matter content as shown in Fig. 4. All reactor sets were treated with ^{14}C–labeled atrazine at 0.77 ppm soil concentration. Data points show average results for replicate reactors. Error bars show standard error for data. However, addition of organic acids (formic, acetic, and oxalic acids) as surrogate plant exudates did not stimulate atrazine mineralization, except for oxalic acid, which stimulated atrazine-ring mineralization only slightly. The organic-acid concentrations used were relatively high (0.22 mM or less), but microbial activity for atrazine mineralization itself was not

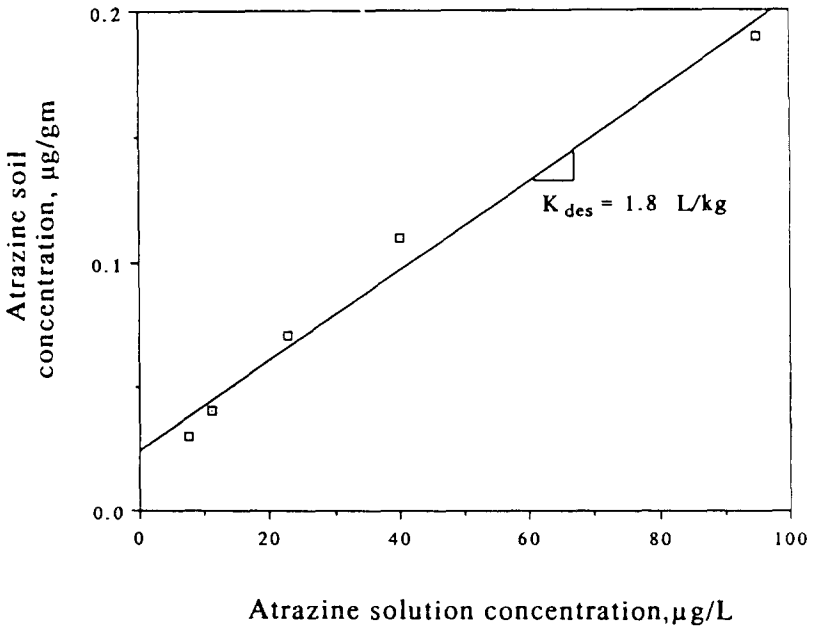

FIG. 6. Desorption Isotherm Demonstrating Hysteresis for Atrazine in Nodeway-Ely Soil from Amana, Iowa (*foc* = 0.022)

enhanced (Nair 1991). It can also be assumed that dead roots and exudates from the plants helped to enhance binding of some of the atrazine or metabolites irreversibly to soil organic matter. The silt-loam soil used for the experiments described here had an organic matter content of 2.2% and a clay content of 20%, and sorption to these soil fractions made less atrazine available for plant uptake. The organic and clay content in the silica sand media was less than 1%. The enhancement of the sorption mechanism coupled with plant uptake made less atrazine or metabolites available for microbial consumption, and thus resulted in less mineralization of atrazine by soil microbes in either media type. This was most evident in the silt-loam soil.

The plant transpiration rate in the silt-loam soil experiment was approximately 13.0 mL/d for the first 30 d period and 5 mL/d for the rest of the experimental period. The reduced transpiration was due to nonsurvival of some plant cuttings in each of the plant reactors including control plant reactors. The plants in the silica sand reactors had an average transpiration rate of 69 mL/d and had a 100% survival rate. This is believed to be a cause of the greater than tenfold increase in the daily rate of atrazine uptake in the silica sand compared to the silt-loam soil reactors.

Soil Sorption-Desorption

Fig. 5 shows the adsorption isotherm obtained for ^{14}C ring-labeled atrazine in silt-loam soil. The fit was linear for the concentration range used for this study, and this indicates that the sorption capacity of the soil for atrazine was not reached. The soil was incubated for three weeks to allow for additional sorption. Ring cleavage due to biotransformation, if any in sterilized

soil, during this short period will be insignificant [less than 0.1% based on previous studies (Nair and Schnoor 1992)]. The K_d (distribution coefficient) value obtained was 2.45 L/kg, which is typical for silt-loam soil with an organic matter content of 2.2%. The K_{oc} value obtained was 111 L/kg, using this K_d value and a f_{oc} (fraction organic carbon) value of 0.022.

Fig. 6 shows the desorption isotherm obtained for the same soil. The K_{des} (desorption distribution coefficient) was 1.8 L/kg, which is less than the K_d value obtained previously. Some hysteresis of the sorption-desorption process was observed, and this agrees with research literature observations (Swanson and Dutt 1973; Di Toro and Horzempa 1982). The desorption of the atrazine ring was not completely reversible, and this may be due to formation of bound residues (about 7%). A more-vigorous extraction procedure was not used, as the objective for the sorption-desorption studies were to determine how much of the atrazine ring C will be available in solution for plant uptake.

PRACTICAL APPLICATIONS

Potential application of this low-cost, innovative, and environmentally acceptable technology for removing pesticide residues in soil would be for pesticide-mixing areas in agricultural fields, spills at storage areas, along water courses next to agricultural fields to intercept tile drainage, and shallow ground-water infiltration. Pesticide transport through tile drainage and shallow ground-water infiltration into streams can potentially be intercepted by an engineered buffer system.

SUMMARY

The experiments described show that poplar plants have a good ability to uptake atrazine from a silt-loam soil and even better potential in a porous sandy soil. The respective accumulation of over 11% and 91% of the atrazine ring ^{14}C in the plant, mostly in the leaves, is much greater than reported in previous studies [less than 2.5%, (Andreux et al. 1990)]. The plants did not display any phytotoxic effect to atrazine at the applied rate, as high as 0.37 μg/g soil, and it is presently not known what the detoxification mechanisms are in poplar-plant species.

The sorption-desorption experiments show a hysteresis effect and that some of the pesticide was bound to the soil and could not be extracted using a water-extraction technique. The implication is that a higher proportion of pesticide may be bound by soil particles and may not be available to be desorbed into solution for plant uptake. Standard assumptions of instantaneous equilibrium for sorption-desorption processes used in pesticide fate and transport models for the unsaturated zone may not be applicable under actual field conditions.

The poplar-tree systems show potential to retard the transport and reduce the amount of pesticides entering streams along agricultural fields. If planted densely and deeply along both sides of streams, the trees could be used to takeup and bind pesticides moving laterally with the soil water to the stream. They also have the potential to retard surface runoff and intercept eroded sediments from agricultural fields.

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