

Massachusetts Water Resources Research Center Publication No. 180

**Potential Movement of Pesticides
Related with Dissolved Organic Matter
from Organic Fertilizer Application on Turf**

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June 2006

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Table of Content

| | |
|----------------------------------|----|
| Introduction..... | 3 |
| Materials and methods | 4 |
| Results | 8 |
| Conclusions..... | 12 |
| References | 12 |
| Tables | 15 |
| Figures..... | 18 |
| | |
| Publications..... | 21 |
| Abstracts and presentations..... | 21 |
| Students Supported | 21 |
| Funding | 21 |

Introduction

There is increasing interest in the use of natural organic nitrogen sources in turfgrass management because they provide a number of benefits to soil ecosystems such as improving soil physical, chemical and biological properties, as well as reducing the environmental impacts from applied pesticides and providing a certain degree of disease control (Nelson and Craft, 2000). Deburt (1990) reported that organic matter levels as low as 1.0 to 1.5% in soil reduced pesticide leaching. However, incorporation of organic amendments/fertilizers also introduces soluble organic matter-dissolved organic matter (DOM). Research on agricultural soils showed that addition of organic materials increased the concentration of water-extractable organic carbon (Rochette and Gregorich, 1998; Gregorich et al., 1998). DOM is considered an environmental amphiphile and is similar both structurally and functionally to surfactants. DOM can, therefore, enhance the solubility of poorly water-soluble compounds (Kile and Chiou, 1989; Cho et al., 2002). As such, a potential untold consequence of using organic fertilizers is to enhance chemical transport by DOM. Dunnivant et al. (1992) reported that dissolved organic carbon (DOC) could readily move through soil columns without preferential flow pathways. Therefore, DOM can serve as a carrier in soil solutions that could result in the rapid flow of organic chemicals through soil profiles. Nelson et al. (1998) reported that leaching rates of napropamide from sewage sludge amended soil was twice that of soils without sewage sludge due to enhanced transport by sewage sludge-derived DOM in column experiments. Similar results were reported by Petrovic and his co-workers (Petrovic et al., 1996) in a field lysimeter study that reported with the addition of peat amendments to sand based putting greens, a 55% increase in fungicide (metalaxyl) leaching occurred as compared with sand alone.

Most research on the effect of DOM on pesticide sorption has been done with sewage sludge as a soil amendment to agricultural soils that is practiced to minimize landfill disposal. There are few reports (if any), on turfgrass systems. Currently, the organic fertilizers/amendments used in the turf industry have various sources including bone meal, blood meal, feather meal, soy flour, fish meal, compost, sewage sludge and humic substances, or combination therein. DOC from these organic materials can be as high as 3% (Aoyama, 1985). Furthermore, soil profiles on golf course greens and tees consist of a high percentage of sand with low organic matter contents (UGSA, 1993), yet all are managed with a high frequency of irrigation and fertilization. All these characteristics make turfgrass systems unique compared to other ecosystems.

The primary objective of this research was to evaluate the effect of organic fertilizer derived-DOM on pesticide sorption and leaching in turf soils with an overall goal to help golf course superintendents select and properly use organic fertilizers to minimize environmental impact.

Materials and Methods

Dissolved organic matter extraction

DOM was extracted from two commercial organic fertilizers (Milorganite 6-2-0, Milwaukee Metropolitan Sewerage District, Milwaukee, WI and NatureSafe 8-3-5, Griffin Industries, Inc., Cold Spring, KY) (Table 1) by 0.01 M CaCl₂ solution with a solid to solution ratio of 1:10 (w/v). After mixing for 30 min by a Gyrotory Shaker (New Brunswick Scientific Co., Edison, NJ) at 200 rpm, the samples were centrifuged at 1,500 x g for 30 min to facilitate infiltration. The supernatant was then filtered through nitrocellular filter papers with a pore size of 0.45 µm (Millipore Inc., Bedford, MA). DOM concentration was measured using a Shimadzu

TOC-5000A total organic carbon (TOC) analyzer (Shimadzu Scientific Instruments, Columbia, MD) (Reckhow, 2002). Various dilutions were made prior to subsequent uses.

Surface tension measurements

A du Nouy plate digital tensiometer (Kruss, USA) was used to measure the decrease of surface tension with increasing DOM concentrations (Guetzloff and Rice, 1996). The plate was rinsed with deionized distilled water after each measurement and then held in a flame until glowing red. The average of duplicate measurements is reported.

Sorption study

Sorbents

A USGA sand sample (0.48% OC) and a mixed soil sample (30% native soil and 70% USGA sand) (0.65% OC) were taken from two different 4-year-old USGA putting greens at the Turfgrass Research Facility, University of Massachusetts at Amherst. The composition of the root zone mixture sand fits USGA specifications for putting green construction (USGA, 1993). A silt loam soil sample (16% sand, 63% silt and 21% clay) was collected from Orchard Hill, Amherst, MA (7.8% OC). Soil samples were air dried and passed through a 2 mm sieve before any experimental use.

Sorbates

Three chemicals were used in this research. [Ring-UL-¹⁴C] 2,4-dichlorophenoxyacetic acid (2,4-D) and the non-radioactive form were obtained from Aldrich Chemical Co. (St. Louis, MO). ¹⁴C Radioactive Dursban (chlorpyrifos) (*O,O-diethyl O-3,5,6-trichloro-2-pyridinyl phosphorothioate*) and the non-radioactive form were obtained from Dow AgroScience, L.L.C. (Indianapolis, IN). These two pesticides are commonly used in golf course management programs for insect and weed control. Chlorpyrifos has low water solubility (1.5 mg l⁻¹) and 2,4-

D is of relatively high water solubility (620 mg l^{-1}). [Ring-UL- ^{14}C]-naphthalene and the non-radioactive chemical were obtained from Aldrich Chemical Co. (St. Louis, MO). Naphthalene is the model compound for sorption study and has a solubility of 31.7 mg l^{-1} (Xing, 1997).

Sorption experiments

All sorption experiments were conducted using a batch equilibration technique (Xing and Pignatello, 1997) in 8-ml screw-cap vials (minimal headspace) with Teflon-lined septa. The background solution (pH 7.0) was 0.01 M CaCl_2 in deionized distilled water containing 200 mg l^{-1} HgCl_2 as a biocide. Mercury chloride has been effectively used to inhibit microbial growth in sorption studies (Xing, 2001). Concentrations ranged from 0.008 to 1 mg l^{-1} for chlorpyrifos; from 0.4 to 450 mg l^{-1} for 2,4-D; and from 0.01 to 15 mg l^{-1} for naphthalene. Due to the low solubility, chlorpyrifos and naphthalene were dissolved in methanol and then added into the background solution (the total methanol concentration in background solution did not exceed 0.1% by volume). 2,4-D was dissolved directly into the background solution. The quantity of sorbents was adjusted to maintain sorption of sorbates between 30 and 80%. Each isotherm consisted of ten concentration points and each point was duplicated. Two blanks without sorbent were run for each concentration point. Chemical suspensions of sorbents and sorbates were shaken in hematology mixers (Fisher Scientific Co., Springfield, NJ) that gave rocking-rotating motions for 5 d at $23 \pm 1 \text{ }^\circ\text{C}$. A preliminary sorption experiment showed that sorption reached apparent equilibrium before 3 d. After 5 d mixing, the vials were centrifuged at $1000 \times g$ for 30 min and 1 ml of supernatant was sampled for liquid scintillation counting (Beckman LS 6500).

Sorption experiments with DOM were performed using the same procedures as the above except with addition of DOM in the background solution. DOM extracted from the organic

fertilizers was diluted with background solution to a final TOC concentration of 120 mg l⁻¹ and 60 mg l⁻¹, respectively.

Data analysis

All sorption equilibrium data were fit using by the log-transformed Freundlich equation:

$$\log S = \log K_F + N \log C_e$$

where S is the solid-phase concentration (mg kg⁻¹), C_e is aqueous-phase solute concentrations (mg l⁻¹), and K_F [(mg kg⁻¹)(mg l⁻¹)^{- N}] and N are constants. The parameters were determined by log-transformed data fitting. Because of nonlinearity (i.e., $N < 1$), K_F cannot be properly compared due to different units (Chen et al., 1999). To facilitate direct comparison of sorption affinities among the samples, organic carbon normalized single concentration point distribution coefficient values [$K_{oc} = (S/C_e)/f_{oc}$] at several equilibrium concentrations (C_e) were calculated. This was done by calculating the S values corresponding to the individual C_e from the respective best-fit Freundlich isotherms (Li et al., 2000).

Leaching experiments

USGA sand (0.48% OM) taken from a 4-year old USGA putting green root zone mixture at Turfgrass Research Facility, University of Massachusetts at Amherst, was packed into glass columns (10 cm x 30 cm) with a bulk density about 1.34 kg l⁻¹. The column was pre-saturated with 0.01 M CaCl₂ solution and then eluted with 2 pore volumes of this solution to reach a constant flow rate, about 1.0 ml min⁻¹. ¹⁴C labeled and unlabeled pesticide (chlorpyrifos) was mixed at a ratio 2:1 in 0.5 ml methanol. The solution was uniformly distributed on the top of each soil column and then allowed to air-dry for 2 h to evaporate methanol. A 1 cm layer of acid washed pure sand was then placed on the top of each column to minimize surface disturbance during the experiment. Columns then were eluted with different organic fertilizer extracts: M120

was 120 mg DOC l⁻¹ Milorganite extract, N60 was 60 mg DOC l⁻¹ NatureSafe extract, and the control was 0.01 M CaCl₂ solution only. Column leachates were collected every 20 ml with glass scintillation vials for ¹⁴C activity. Columns were allowed to leach until approximately 1600 ml of (about 8 pore volumes) solution passed through each column (Baskaran et al., 1996).

At the end of the experiment, the column was allowed to drain for 1 day and leachate was collected for ¹⁴C analysis. The soil in each column was divided into 10 cm sections, homogenized, and analyzed for ¹⁴C activity by using acetone extraction for mass balance calculations. All experiments were carried out in duplicate.

Results

Surface tension

The surface tension of deionized distilled water (71.3 mN m⁻¹) did not decrease measurably with addition of 0.01 M CaCl₂. With addition of organic fertilizer extracts (DOM), surface tension was significantly decreased with increasing concentration of DOC (Figure 1). There were some differences in decreasing surface tension between the two fertilizers. Surface tension with Milorganite DOM seems to have an inflection point about 650 mg l⁻¹. This point may be the critical micelle concentration (CMC) of the Milorganite DOM. However, the surface tension continuously decreased for NatureSafe DOM indicating that it may need a much higher DOC concentration to reach its CMC. Nevertheless, the surface tension could be greatly reduced by both Milorganite and NatureSafe DOMs. It has been consistently reported that DOM has similar characters as surfactants and has the ability to lower the surface tension and increase the solubility of hydrophobic organic compounds (HOC) (Chiou et al., 1987; Guetzloff and Rice, 1996; Cho et al., 2002). The apparent solubility of HOC in the presence of micelles is many times that of HOC in water alone (Guetzloff and Rice, 1996).

Sorption experiment

All sorption equilibrium data were fit well by the Freundlich sorption model ($r^2 \geq 0.99$, Tables 2 to 4). The Freundlich isotherms of chlorpyrifos are shown as examples in Figure 2 and the isotherm parameters are given in Table 2. Most isotherms were slightly nonlinear. The N value was 0.955 for USGA sand in 0.01 M CaCl_2 , 0.977 with 60 mg l^{-1} DOC of Milorganite extract, and 0.968 with 120 mg l^{-1} DOC of NatureSafe extract. The N values with and without DOM addition were not significantly different. Chlorpyrifos sorption ($\log K_F$ values and calculated K_{oc} values) for USGA sand decreased in the presence of DOM and decreased with increasing DOM concentration for both organic fertilizer extracts, e.g., K_{oc} values were 5299 for 0.01 M CaCl_2 (control), 2464 for 0.01 M CaCl_2 with 60 mg DOC l^{-1} , and 1796 for 0.01 M CaCl_2 with 120 mg DOC l^{-1} Milorganite extracts at C_e of 0.01 mg l^{-1} in USGA sand (Table 2). This K_{oc} decrease may be due to the surface tension reduction with DOM addition. Similar results were observed on NatureSafe DOM extracts, however, Milorganite DOM extracts reduced sorption capacity more than NatureSafe at any given DOC concentration (Table 2).

Naphthalene (31.7 mg l^{-1}) has a higher solubility than chlorpyrifos (1.5 mg l^{-1}). A mix of 30% native soil (sandy loam) and 70% USGA sand was used for naphthalene isotherms because USGA sand had little sorption. The results are shown in Table 3. Similar to chlorpyrifos results, sorption capacity was reduced with DOM addition. However, there was no significant difference in K_{oc} values between solutions of various DOC concentrations used in this study.

Because of the high solubility of 2,4-D (620 mg l^{-1}) and low sorption by USGA sand, Amherst silt loam soil was used for 2,4-D sorption. The isotherm parameters are given in Table 4. A similar sorption trend was found between 2,4-D and chlorpyrifos. The K_{oc} values were

significantly reduced with 120 mg l⁻¹ DOC from organic fertilizers as compared with that in 0.01 M CaCl₂ (Table 4).

Organic fertilizer water extracts (DOM) reduced the sorption of chlorpyrifos, naphthalene, and 2,4-D for the tested soils. These results are consistent with the negative effect of DOM from other organic compound sorption studies that DOM could form a complex with organic chemicals or compete with organic chemicals for sorption sites (Nelson et al., 2000; Grabber et al., 1995; Flores-Cespedes et al., 2002; Celis et al., 1998). In addition, the sorption reduction may be related to the enhanced solubility by DOM as a result of the surface tension reduction (Guetzloff and Rice, 1996).

The sorption process is very complex and is determined by the characteristics of both sorbates and sorbents. In this study, three chemicals with different characteristics (solubility and polarity) showed similar trends for both of the organic fertilizer derived-DOMs. Chlorpyrifos is a very hydrophobic compound, thus it has a high affinity for soils as well as DOM. The differences in sorption reduction between the two fertilizers for this chemical may be due to different chemical structures of DOM in the fertilizers. Similar results for chlorpyrifos sorption were obtained by Huang and Lee (2001) using DOM from poultry, swine, and cow waste - derived lagoon effluents. In contrast to chlorpyrifos, 2,4-D has very high solubility and polarity. Sorption of 2,4-D was also decreased in the presence of DOM in our study. In a study of liquid organic amendments, Cox et al. (2000) reported that DOM and 2,4-D formed a stable complex that facilitated the transport of 2,4-D and also protected herbicide molecules from microbial degradation. Further, Nelson and his co-workers observed greater leaching of napropamid with sewage sludge treated soil than the control soil (Nelson et al., 1998; Nelson et al., 2000; Williams et al., 2000). Celis et al. (1998) reported that the processes occurring at the soil/solution

interface, such as competition of DOM for sorption sites on soil surface, could be important in reducing atrazine sorption in soil. However, sorption of DOM by soil may create additional sites for pesticide molecules and enhance sorption with increasing DOC concentration (Celis et al., 1998; Flores-Cespedes et al., 2002). In our results, we did not observe a significant increase of naphthalene and 2,4-D sorption at higher DOC concentrations as compared with lower DOC concentrations. Nevertheless, the calculated K_{oc} values with DOM addition were still lower than that in 0.01 CaCl₂ only (Tables 2, 3 and 4). These results suggest that DOM complex formation, enhanced solubility, and soil-solution interface competition, or a combination of the three could contribute to reducing sorption in the presence of DOM in this study, but detailed mechanisms need further investigation.

Leaching experiment

Breakthrough curves (BTCs) for chlorpyrifos and 0.01 M CaCl₂ solution are shown in Figure 3. As expected, chlorpyrifos leached out in 0.01 M CaCl₂ solution, but was delayed by about 2 pore volumes compared with BTC of 0.01 M CaCl₂ as measured by electrical conductivity (Fig. 3). This is due to adsorption of the chemical to USGA sand. Chlorpyrifos with DOM had an earlier breakthrough by 0.5 pore volumes and its concentration was also higher in the leachate as compared with the chemical in background solution alone (Fig. 3). The summary of column leaching experiments is presented in Table 5. After 8 pore volumes of effluent, the total percentage of chlorpyrifos leached out was 82.6% for 0.01 M CaCl₂ alone; 93.3% for 0.01 M CaCl₂ with 120 mg DOC l⁻¹ Milorganite extracts; and 94.0% for 0.01 M CaCl₂ with 60 mg DOC l⁻¹ NatureSafe extracts. The maximum concentration of chlorpyrifos in leachate increased approximately 45% from 0.11 mg l⁻¹ to 0.16 mg l⁻¹, indicating that DOM increased chlorpyrifos transport in the USGA sand column. These data are in agreement with observations from other column studies, that is, the presence of DOC enhanced the movement of the pesticides due to interaction between pesticides with DOM (Baskaran et al., 1996; Flores-Cespedes et al., 2002). DOM was reported to be strongly sorbed by soil and not be completely desorbed by DOM-free

solution (Guo and Chorover, 2002). Thus, competition between the pesticide and DOM for sorption sites may also contribute to this enhancement.

Conclusions

The increasing interest of using organic fertilizers/amendments on turf is a critical part of integrated pest management programs. Results from this study indicate that addition of DOM extracted from organic fertilizers (Milorganite and NatureSafe) applied on turf may reduce sorption of chlorpyrifos, naphthalene and 2,4-D by soils. Higher concentrations of DOC in solution resulted in reduced chlorpyrifos sorption. BTC results with or without DOM agree with the batch equilibrium sorption data. These results support the idea that DOM can interact with pesticides and enhance their transport. Frequent fertilizer and pesticide applications and irrigation are a regular practice for high maintenance turfgrass, especially golf greens where a high percentage of sand is usually incorporated into the soil profile. We recommend that organic fertilizers should not be applied on turf immediately after pesticide application, which would reduce the impact of organic fertilizer-derived DOM facilitated transport of applied pesticides. Appropriate application rates of different organic fertilizers and the rates of DOM release in the field need further investigations.

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Table 1. Characteristics of the two organic fertilizers

| Parameter | Organic fertilizer | |
|-----------------------------------|--------------------|------------|
| | Milorganite | NatureSafe |
| pH (1:10) | 6.2 | 6.3 |
| Organic carbon (%) | 35.5 | 32 |
| DOC (%) | 2.4 | 0.9 |
| N (%) | 6.0 | 8.0 |
| P ₂ O ₅ (%) | 2.0 | 3.0 |
| K ₂ O (%) | 0 | 5.0 |

Table 2. Chlorpyrifos sorption isotherm parameters of USGA sand

| Sorbent | Sorption | | | K_{oc} (ml g ⁻¹ of OC) | | |
|---------------------------------|-----------------------------|----------------|-------|-------------------------------------|------------------------------------|-----------------------------------|
| | log K_F | N | r^2 | $C_e = 0.001$ mg l ⁻¹ | $C_e = 0.01$ mg l ⁻¹ | $C_e = 0.1$ mg l ⁻¹ |
| USGA Sand | 1.40 (0.03) ^b | 0.96 (0.02) | 0.996 | 5357 | 5299 | 5240 |
| USGA sand + M60 ^a | 1.03 (0.02) | 0.98 (0.01) | 0.997 | 2601 | 2464 | 2335 |
| USGA sand + M120 | 0.937 (0.03) | 1.00 (0.04) | 0.993 | 1752 | 1796 | 1785 |
| USGA sand + M240 | 0.898 (0.03) | 0.99 (0.02) | 0.993 | 1791 | 1741 | 1693 |
| USGA sand + N60 | 1.03 (0.02) | 0.92 (0.02) | 0.991 | 4025 | 3317 | 2734 |
| USGA sand + N120 | 1.13 (0.03) | 0.97 (0.02) | 0.994 | 3487 | 3238 | 3007 |

K_{oc} is organic carbon normalized sorption capacity, OC = organic carbon. C_e is equilibrium solution concentration. ^aM240, M120 and M60 are 240, 120 and 60 mg DOC l⁻¹ extracts from Milorganite, respectively; N120 and N60 are 120 and 60 mg DOC l⁻¹ extracts from NatureSafe, respectively. ^bThe values shown in parentheses are 95% confidence intervals.

Table 3. Naphthalene sorption isotherm parameters of mixed soil (70% USGA sand and 30% native soil)

| Sorbent | Sorption | | | K_{oc} (ml g ⁻¹ of OC) | | |
|------------------------|------------------------------|----------------|-------|-------------------------------------|------------------------------------|-----------------------------------|
| | log K_F | N | r^2 | $C_e = 0.001$ mg l ⁻¹ | $C_e = 0.01$ mg l ⁻¹ | $C_e = 0.1$ mg l ⁻¹ |
| Mix | 0.888 (0.02) ^b | 0.83 (0.02) | 0.996 | 2249 | 1736 | 1339 |
| Mix + M60 ^a | 0.780 (0.02) | 0.90 (0.02) | 0.996 | 1832 | 1460 | 1164 |
| Mix + M120 | 0.790 (0.02) | 0.91 (0.01) | 0.998 | 1809 | 1458 | 1175 |
| Mix + N60 | 0.749 (0.02) | 0.90 (0.01) | 0.998 | 1724 | 1368 | 1086 |
| Mix + N120 | 0.769 (0.01) | 0.90 (0.01) | 0.998 | 1865 | 1465 | 1151 |

K_{oc} is organic carbon normalized sorption capacity, OC = organic carbon. C_e is equilibrium solution concentration. ^aM120 and M60 are 120 and 60 mg DOC l⁻¹ extracts from Milorganite, respectively; N120 and N60 are 120 and 60 mg DOC l⁻¹ extracts from NatureSafe, respectively.

^bThe values shown in parentheses are 95% confidence intervals.

Table 4. 2,4-D sorption isotherm parameters of soil

| Sorbent | Sorption | | | K_{oc} (ml g ⁻¹ of OC) | | |
|-------------------------|------------------------------|----------------|-------|-------------------------------------|------------------------------------|-----------------------------------|
| | log K_F | N | r^2 | $C_e = 0.001$ mg l ⁻¹ | $C_e = 0.01$ mg l ⁻¹ | $C_e = 0.1$ mg l ⁻¹ |
| Soil | 0.889 (0.01) ^b | 0.88 (0.01) | 0.999 | 235 | 177 | 132 |
| soil + M60 ^a | 0.767 (0.01) | 0.86 (0.01) | 0.999 | 199 | 143 | 103 |
| soil + M120 | 0.822 (0.02) | 0.89 (0.01) | 0.998 | 184 | 143 | 110 |
| soil + N60 | 0.786 (0.02) | 0.86 (0.01) | 0.998 | 202 | 147 | 107 |
| soil + N120 | 0.635 (0.01) | 0.87 (0.01) | 0.999 | 136 | 100 | 75 |

K_{oc} is organic carbon normalized sorption capacity, OC = organic carbon. C_e is equilibrium solution concentration. ^aM120 and M60 are 120 and 60 mg DOC l⁻¹ extracts from Milorganite, respectively; N120 and N60 are 120 and 60 mg DOC l⁻¹ extracts from NatureSafe, respectively. ^bThe values shown in parentheses are 95% confidence intervals.

Table 5. Results of column leaching experiments with chlorpyrifos and USGA sand

| Treatment | Total leaching out % | Max. concentration mg l ⁻¹ | Total recovery % ^c |
|---|----------------------------|--|----------------------------------|
| 0.01 M CaCl ₂ | 82.6 (1.0) ^a | 0.11 | 98 |
| 0.01 M CaCl ₂ + M120 ^b | 93.3 (4.2) | 0.16 | 101 |
| 0.01 M CaCl ₂ + N60 | 94.0 (3.6) | 0.16 | 101 |

^aThe values shown in parentheses are 95% confidence intervals. ^bM120 and N60 are 120 and 60 mg DOC l⁻¹ extracts from Milorganite and NatureSafe, respectively. ^cAverage values of two columns data.

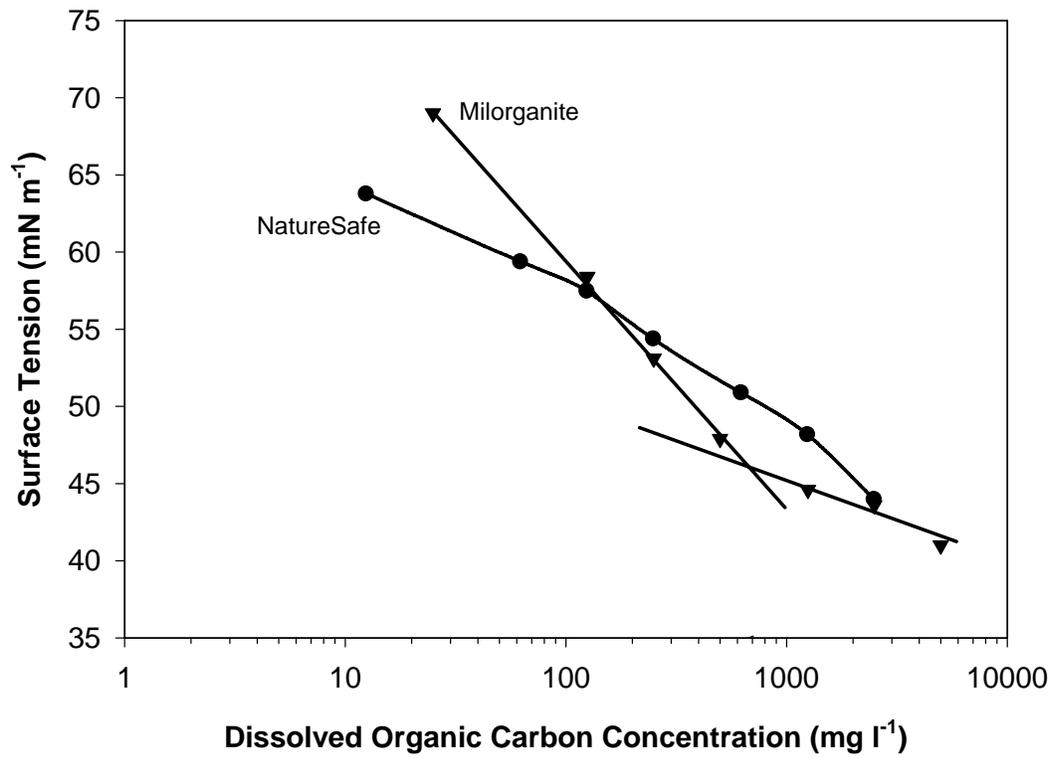


Figure 1. Effects of organic fertilizer derived dissolved organic matter (DOM) on surface tension (solid circles for NatureSafe DOC and solid triangles for Milorganite DOC).

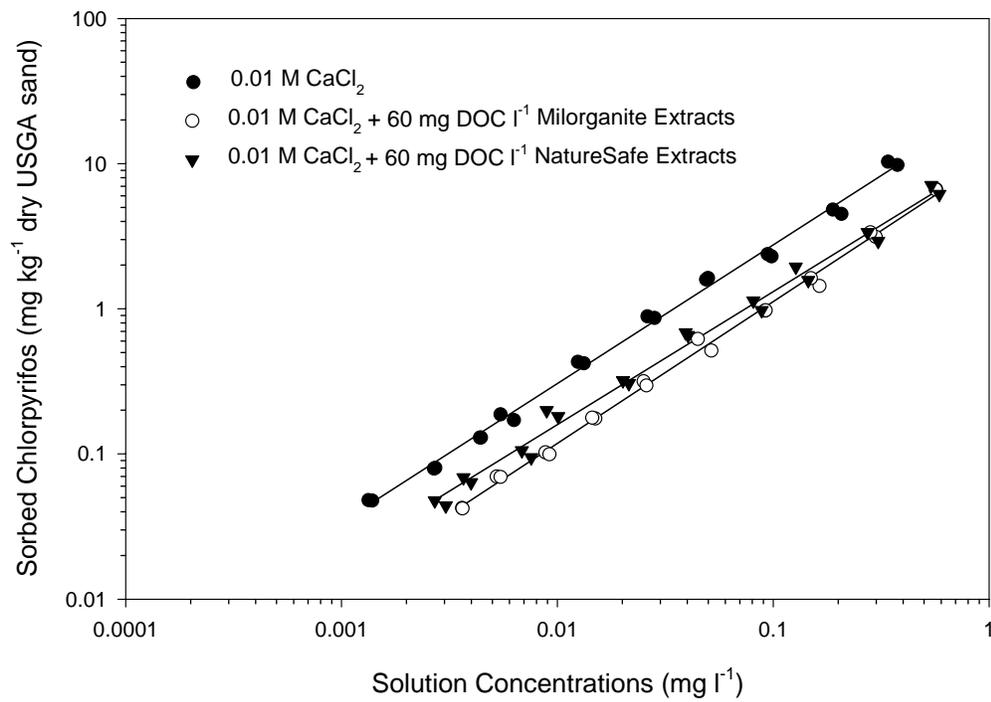


Figure 2. Sorption isotherms of chlorpyrifos without/with organic fertilizer derived-DOM (on USGA sands).

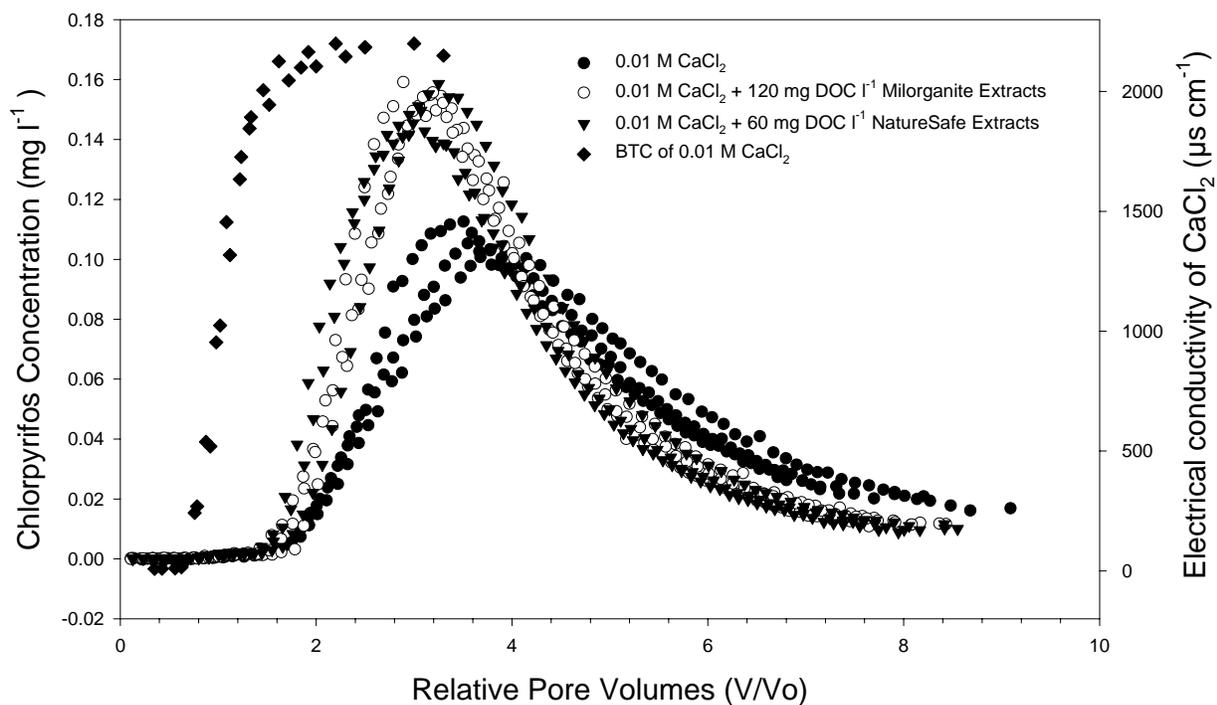


Figure 3. Breakthrough curves of chlorpyrifos on USGA sand. Electrical conductivity of 0.01 M CaCl_2 is $2146 \mu\text{s cm}^{-1}$. Solid diamonds are the breakthrough curve (BTC) of 0.01 M CaCl_2 solution as detected by electrical conductivity, solid circles are the BTC of chlorpyrifos in 0.01 M CaCl_2 solution, open circles are the BTC of chlorpyrifos in $120 \text{ mg DOC l}^{-1}$ Milorganite extract, and solid triangles are the BTC of chlorpyrifos in 60 mg DOC l^{-1} NatureSafe extract.

Publications:

- 1) Li, K., B. Xing, and W.A. Torello. 2005. Effect of organic fertilizers derived dissolved organic matter on pesticide sorption and leaching. *Environ. Pollut.* 134: 187-194.
- 2) Heymann, K., H. Mashayekhi, and B. Xing. 2005. Spectroscopic analysis of sequentially extracted humic acid from compost. *Spectroscopy Letters*, 39(3): 293-302.
- 3) Li, K. 2004. Evaluation of organic turfgrass management and its environmental impact by dissolved organic matter. Ph.D. dissertation, University of Massachusetts at Amherst, pp. 101.

Abstracts and presentations:

- 1) Li, K., W.A. Torello, and B. Xing. 2003. Effect of dissolved organic matter on pesticide leaching in a USGA sand column experiment. *Agronomy Abstracts*, Denver, CO. Nov. 2-6. 2003.
- 2) Xing, B. and L. Kun. 2003. Pesticide movement and organic fertilizer application on turf. *Water Resources in the Northeast Science and Policy Conference*; Dec. 5, 2003; University of Massachusetts; p. 18 of the Final Program book.
- 3) Heymann, K., S. Ebdon, D. Reckhow and B. Xing. 2005. Characterization of dissolved organic matter and its effect on sorption of organic chemicals. *Annual SSSA meetings*, Nov. 6-10, Salt Lake City, USA. Abstract #: 119-13.

Students Supported:

One M.Sc. student
One Ph.D. student
Three undergraduate students

Funding:

One competitive grant was awarded.

Another proposal was submitted.