Rapid Development of Enhanced Atrazine Degradation in Soil Under Two Cropping Systems: Continuous Corn and Corn-Cotton Rotation

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Introduction

Atrazine [2-chloro-4-(ethylamino)-6-(isopropylamino)-*s*-triazine) is an herbicide used to control annual grasses and broadleaf weeds primarily in corn (*Zea mays* L.) and grain sorghum [*Sorghum bicolor* (L.) Moench]. It is relatively recalcitrant in the environment and is frequently detected in both surface and ground water (Clark and Goolsby, 2000; Kolpin et al. 1996). In the last decade, enhanced degradation of atrazine has been reported for soils with an atrazine history (Barriuso and Houot 1996; Houot et al. 2000). Bacteria able to mineralize *s*-triazine rings have been isolated (Mandelbaum et al. 1995), and genes that encode catabolic mineralization of atrazine, *atzABC*, have been fully sequenced and characterized (de Souza et al. 1995; Boundy-Mills et al. 1997; Sadowsky et al. 1998). Moreover, homologues of the *atzABC* genes have been detected in atrazine-degrading bacteria isolated from geographically distinct regions indicating that these genes are widespread and highly conserved (de Souza et al. 1998). Consequently, the potential for enhanced atrazine degradation in soil with an atrazine history is global. Yet, no study has evaluated the development of enhanced atrazine degradation in a field experiment.

Objective

The objective of this study was to evaluate the development of enhanced atrazine degradation in two Mississippi Delta cropping systems: continuous corn receiving annual applications of atrazine and a corn-cotton rotation receiving an application of atrazine once every two years.

Materials and Methods

Field studies were conducted from 2000 to 2005 at Stoneville, MS on a Dundee silt loam. Treatments consisted of continuous corn, continuous cotton, and corn-cotton rotation. The experimental design was a randomized complete block with 4 replications. Plot size was 45.7-m by 8.2-m, and row spacing was 102 cm. Corn, Pioneer 3223, was planted from March 5th to April 7th, and atrazine + metolachlor was applied pre-plant at 1.8 + 1.4 kg ha^{-1}, respectively. Cotton, Stoneville 474, was planted from April 18th to May 11th, and fluometuron + pendimethalin was applied pre-plant at 1.7 + 1.1 kg ha^{-1}, respectively.

Mineralization experiments were conducted with ^{14}C-ring-labeled atrazine in soil collected in 2000, 2001, 2002, and 2005. Cumulative mineralization data were fitted to the Gompertz growth model (SAS NLIN version 9.1):

$$y = ae^{-e^{(-k(t-ti)}} \quad [1]$$

where a is the plateau or maximum mineralized; k is the mineralization rate constant; t is time, and t_i is the abscissa of the inflexion point or an estimate of the lag phase. For each treatment, k and t_i were determined while constraining a to the cumulative percent mineralized at 30 d.

Field dissipation of atrazine was evaluated in 2003 and 2005. Dissipation data were fitted to the first order kinetics model (SAS NLIN version 9.1):

$$y = ae^{-kt} \quad [2]$$

where a is the percent atrazine remaining; k is the first order rate constant, and t is time.

Results and Discussion

Prior to 2000 field plots had no exposure to atrazine, and cumulative mineralization at 30 d was 9.1% (Figure 1). After one year of atrazine application, cumulative mineralization increased 466% compared to 2000 data, and the estimated lag phase was reduced from 16 d to 3 d (Table 1). Thus, enhanced degradation of atrazine in the Mississippi Delta can occur after one year of herbicide application. In 2005, the kinetics of atrazine mineralization in continuous corn and corn-cotton rotation plots were nearly identical (Figure 2). For both treatments, the lag phase was ≤ 3.3 d, and cumulative mineralization was ≥ 73%. These data indicate that the development of enhanced atrazine degradation is not reduced in a corn-cotton rotation which receives an application of atrazine once every two years.

In 2003 and 2005, field dissipation of atrazine was monitored in continuous corn and corn-cotton rotation plots. In 2005, plots previously established in 4 yrs of cotton were planted in corn to monitor the dissipation of atrazine in a no-atrazine-history soil. For both continuous corn and corn-cotton rotation plots, the 2003 and 2005 data were pooled. Dissipation of atrazine followed first-order kinetics (Figure 3,4). The estimated half-life for atrazine increased in the order of continuous corn (8 d) = corn-cotton rotation (9 d) < no-atrazine history (16 d). Enhanced degradation of atrazine in atrazine history soils may reduce residual weed control but diminish the potential for off-site transport.

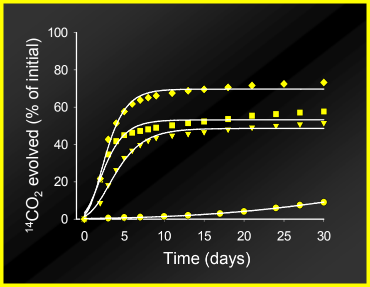

Figure 1. Mineralization kinetics of ^{14}C-ring-labeled atrazine in continuous corn fitted to the Gompertz growth model: 2000 (●), 2001 (▼), 2002 (■), and 2005 (◆). Symbols represent the mean of four replicates.

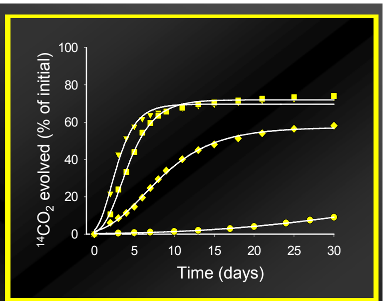

Figure 2. Mineralization kinetics of ^{14}C-ring-labeled atrazine fitted to the Gompertz growth model: 2005 continuous corn (▼), 2005 corn-cotton rotation (■), 2005 no atrazine history (◆), and 2000 baseline (●). Symbols represent the mean of four replicates.

Table 1. Kinetic parameters derived from the Gompertz growth model for 2000 base line (BL), 2001 continuous corn (CC), 2002 CC, and 2005 CC. Kinetic parameters *a*, *k*, and *ti* represent atrazine mineralized at 30 d (%), rate of mineralization (d^{-1}), and lag phase (d), respectively.

Treatment	*a*	*k*	*ti*
2000BL	9.1 (5.3)[a]	0.13 (± 0.04)[b]	16.4 (± 2.02)[b]
2001CC	51.5 (1.9)	0.34 (± 0.06)	3.2 (± 0.41)
2002CC	57.7 (1.8)	0.39 (± 0.11)	1.9 (± 0.66)
2005CC	73.3 (1.2)	0.43 (± 0.10)	2.0 (± 0.49)

[a] Standard deviation of four replicates.
[b] Ninety-five-percent confidence interval.

Table 2. Kinetic parameters derived from the Gompertz growth model for 2005 continuous corn (CC), 2005 corn-cotton rotation (CCR), 2005 no atrazine history (NAH), and 2000 base line (BL). Kinetic parameters *a*, *k*, and *ti* represent atrazine mineralized at 30 d (%), mineralization rate constant (d^{-1}), and lag phase (d), respectively.

Treatment	*a*	*k*	*ti*
2005 CC	73.3 (1.2)[a]	0.43 (± 0.10)[b]	2.0 (± 0.49)[b]
2005 CCR	74.1 (3.5)	0.41 (± 0.04)	3.3 (± 0.19)
2005 NAH	56.8 (8.5)	0.20 (± 0.01)	6.3 (± 0.18)
2000 BL	9.1 (5.3)	0.13 (±0.04)	16.4 (± 2.02)

[a] Standard deviation of four replicates.
[b] Ninety-five-percent confidence interval.

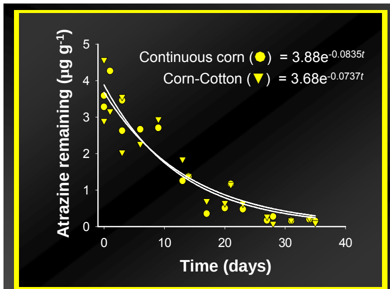

Figure 1. First-order dissipation kinetics of atrazine in continuous corn (●) and corn-cotton rotation (▼) combined over 2003 and 2005. Symbols represent the mean of four replicates.

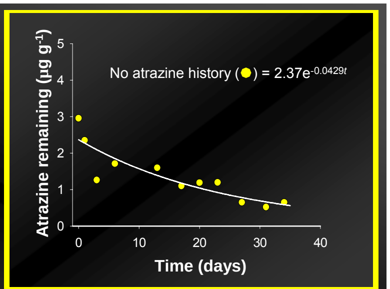

Figure 2. First-order dissipation kinetics of atrazine in soil with no history of atrazine use. Symbols represent the mean of 4 replicates.

Conclusions

- Enhanced degradation of atrazine in the Mississippi Delta can occur after one application
- A corn-cotton rotation does not impede the development of enhanced atrazine degradation
- Enhanced degradation of atrazine in atrazine history soils may reduce residual weed control and the potential for non-point source pollution

Future Research

- The Long-term impact of corn-cotton rotation on soil properties, soil microbial populations, weed population shifts, and crop yield will be compared to mono-cropping systems
- Management strategies for controlling the development of enhanced atrazine degradation will be evaluated in cotton and sugarcane production systems

References

Barriuso, E. and S. Houot. 1996. Rapid mineralization of the *s*-triazine ring of atrazine in soils in relation to soil management. Soil. Biol. Biochem. 28:1341-1348.

Boundy-Mills, K., M.L. De Souza, R.M. Mandelbaum, L.P. Wackett, and M.J. Sadowsky. 1997. The *atzB* gene of *Pseudomonas* sp. Strain ADP encodes the second enzyme of a novel atrazine degradation pathway. Appl. Environ. Microbiol. 63:916-923.

Clark, G. and D. Goolsby. 2000. Occurrence and load of selected herbicides and metabolites in the lower Mississippi River. Sci. Total Environ. 248:101-113.

de Souza, M.L., J. Sefernick, B. Martinez, M.J. Sadowsky, and L.P. Wackett. 1998. The atrazine catabolism genes *atzABC* are widespread and highly conserved. J. Bacteriol. 180:1951-1954.

de Souza, M.L., L.P. Wackett, K.L. Bound-Mills, R.T. Mandelbaum, and M.J. Sadowsky. 1995. Cloning, characterization, and expression of a gene region from *Pseudomonas* sp. strain ADP involved in the dechlorination of atrazine. Appl. Environ. Microbiol. 61:3373-3378.

Houot, S., E. Topp, A. Yassir, G. Soulas. 2000. Dependence of accelerated degradation of atrazine on soil pH in French and Canadian soils. Soil. Biol. Biochem. 32:615-625.

Kolpin, D., E. Thurman, and D. Goolsby. 1996. Occurrence of selected pesticides and their metabolites in near-surface aquifers of the Midwestern United States. Environ. Sci. Technol. 30:335-340.

Mandelbaum, R.T., D.L. Allan, and L.P. Wackett. 1995. Isolation and characterization of a *Pseudomonas* sp. That mineralizes the *s*-triazine herbicide atrazine.

Sadowsky, M.J., Z. Tong, M.L. de Souza, L.P. Wackett. 1998. *AtzC* is a new member of the amidohydrolase protein superfamily and is homologous to other atrazine-metabolizing enzymes. J. Bacteriol. 180:152-158.

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