Field-scale bromide transport as a function of rainfall amount, intensity and application time delay

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Abstract

Leaching of surface-applied agri-chemicals depends on a variety of factors, especially rainfall amount and intensity, but also the time delay between surface application and subsequent rainfall. It is difficult to study the impacts of these factors in a randomized plot design, especially if leaching of a tracer is quantified based on soil core samples. The objective of this study was to vary important factors periodically in space along a transect. The spatial distribution of leaching depth and its covariance behavior should reveal association to transport-causing factors. Rainfall amount had the strongest effect on leaching depth. Only highest and lowest rainfall intensity treatments showed an obvious inverse effect The longer the time delay between surface application of the tracer and subsequent rainfall, the shallower the leaching depth. The design of this experiment manifests a promising way to quantify how different influences affect leaching, based on spatial association and frequency-domain covariance analysis.

Key Words

Bromide transport, rainfall amount

Introduction

Rainfall events following application of fertilizers and agrochemicals to the land surface can cause rapid leaching of solutes to deep soil layers and pollute ground water. The transport rate and the flow phenomena causing leaching strongly depend on the amount and intensity of a rainfall (Flury *et al.* 1994; Bronswijk *et al.* 1995). Moreover, the time lag after a chemical application to the subsequently occurring rainfall can strongly influence the transport rate of a solute (Ghuman *et al.* 1975). The objective of this study was to quantify bromide transport at the field scale for different rainfall amount, intensity, application time delay and initial soil water content, while amount, intensity and time delay of rainfall were varying at four levels to derive strategies for avoiding rapid leaching of solutes. Another goal of this study was to identify a sampling scheme with a non-random periodically repetitive spatial distribution of treatment intensities along a transect that allows to quantify solute transport at the field scale.

Materials and Methods

The experiment was carried out on a Maury silt loam soil at the Spindletop Research farm of the Agricultural Experiment Station, University of Kentucky, Lexington, KY. The field site was divided into 32 plots, each being 2 m long and 4 m wide. These plots were located next to each other along a 64-m transect. One half of the field (32 plots) was pre-irrigated with water to cause slightly larger initial soil water content than in the other half.

A KBr tracer was applied in October 2008 in a spatial design and time schedule that allowed subsequent rainfall to be applied in groups of four plots with a sprinkler irrigation system. The plots were spatially arranged in a periodic distribution of different treatment intensities at various wavelengths as shown in Figure 1. The two levels of precipitation amount were applied in blocks of eight plots. Four precipitation intensities were established in groups of four plots. Application time delay varied from plot to plot, regularly repeated eight times along the transect. The regularly repeating distribution of treatments in space manifests an experimental design allowing to decompose variability components through Fourier transformation and spectral analysis (Bazza *et al.* 1988; Shumway 1988). The spatial covariance analysis of bromide leaching and the underlying processes should reveal the impact of rainfall amount, intensity and application time delay on transport through crosscorrelation and cospectra (Shumway 1988; Wendroth and Nielsen 2002; Nielsen and Wendroth 2003).

Soil water pressure head was measured at 48 locations (Figure 2). At each of these locations, six tensiometers were installed at 10, 30, 50, 70, 90, and 110 cm depth. The measurements revealed the spatial distribution of soil water pressure head and hydraulic gradients before and during the leaching experiment.

Soil cores were taken after the experiment to measure unsaturated soil hydraulic properties, i.e., the soil water retention curve and the

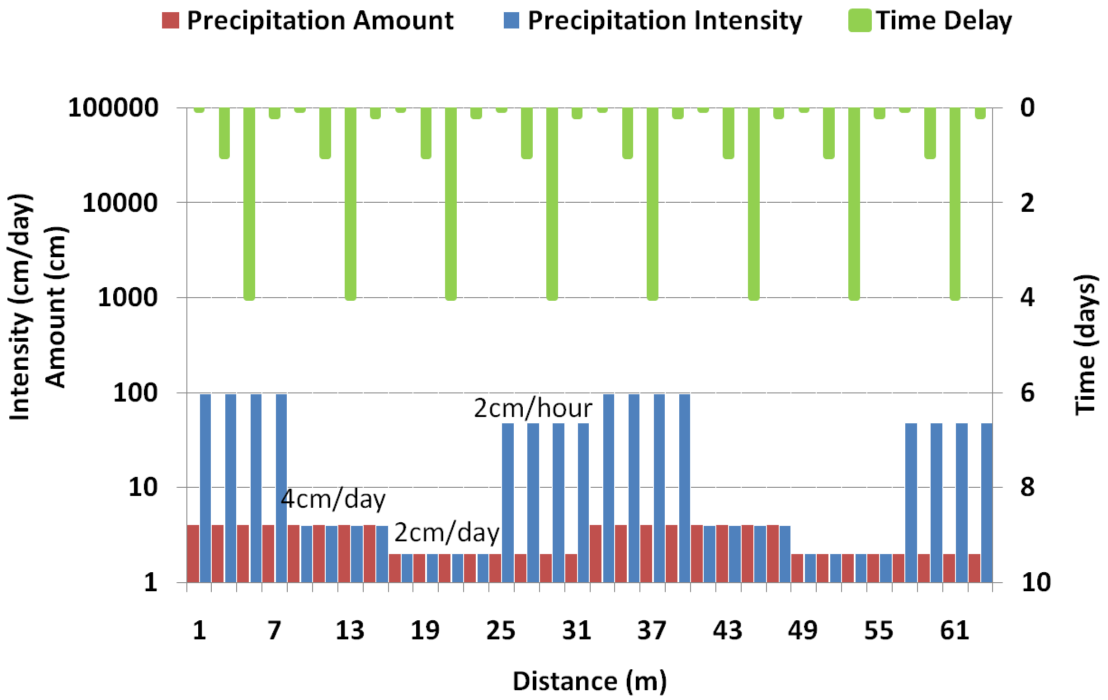

Figure 1. Experimental design and spatial arrangement of plots receiving rainfall at different total amount, intensity, and delay after solute application.

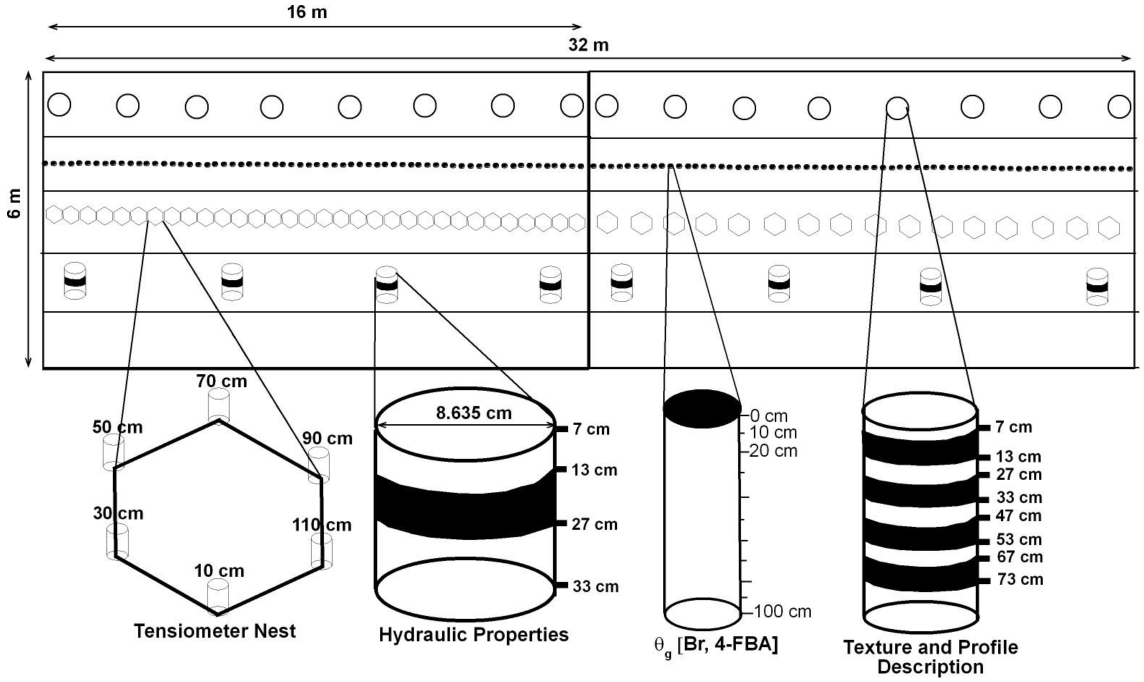

Figure 2. Layout of spatial soil sampling design for soil water pressure head, solute concentration and tracer concentration.

hydraulic conductivity – pressure head relationship. After the tracer application and subsequent irrigation events, a soil core was taken between 0 and 100 cm depth at spatial intervals of 50 cm along the transect resulting in four cores per plot (Figure 2). Each 100-cm soil core was separated in 10-cm depth increments and those samples obtained from each depth interval analyzed for soil water content and bromide concentration. Bromide was only measured for the upper five depth intervals, i.e., to a depth of 50 cm.

Based on the bromide concentration depth profiles, for each of the 128 sampling locations, the bromide leaching depth was characterized with the center of mass COM, defined by

$$\mathrm{COM} = \frac{1}{M}\sum_{i=1}^{n} m_i r_i$$

where M was the total bromide mass recovery at a given location over $i = 1 \ldots n$ depth compartments, m_i was the bromide mass in a specific depth compartment i, and r_i was the center of depth in the specific soil layer. Bromide concentration data, COM and the spatial distribution of rainfall amount, intensity and application time delay were statistically analyzed with respect to auto and crosscovariance, i.e., auto- and crosscorrelation, semi- and cross-semivariance, power spectrum, cross- and quad spectrum and coherency.

Results

Results are focused here on the center of Bromide mass distribution along the transect under the cyclically repeating pattern of treatments. Increasing the amount of precipitation generally increased the leaching of depth bromide as expected (Figure 3). However, for the same rainfall amount, leaching was the more effective the lower the rainfall intensity. In other words, a high intensity rainfall may not cause as much leaching as the same amount of rainfall occurring at a slower rate which would therefore last longer.

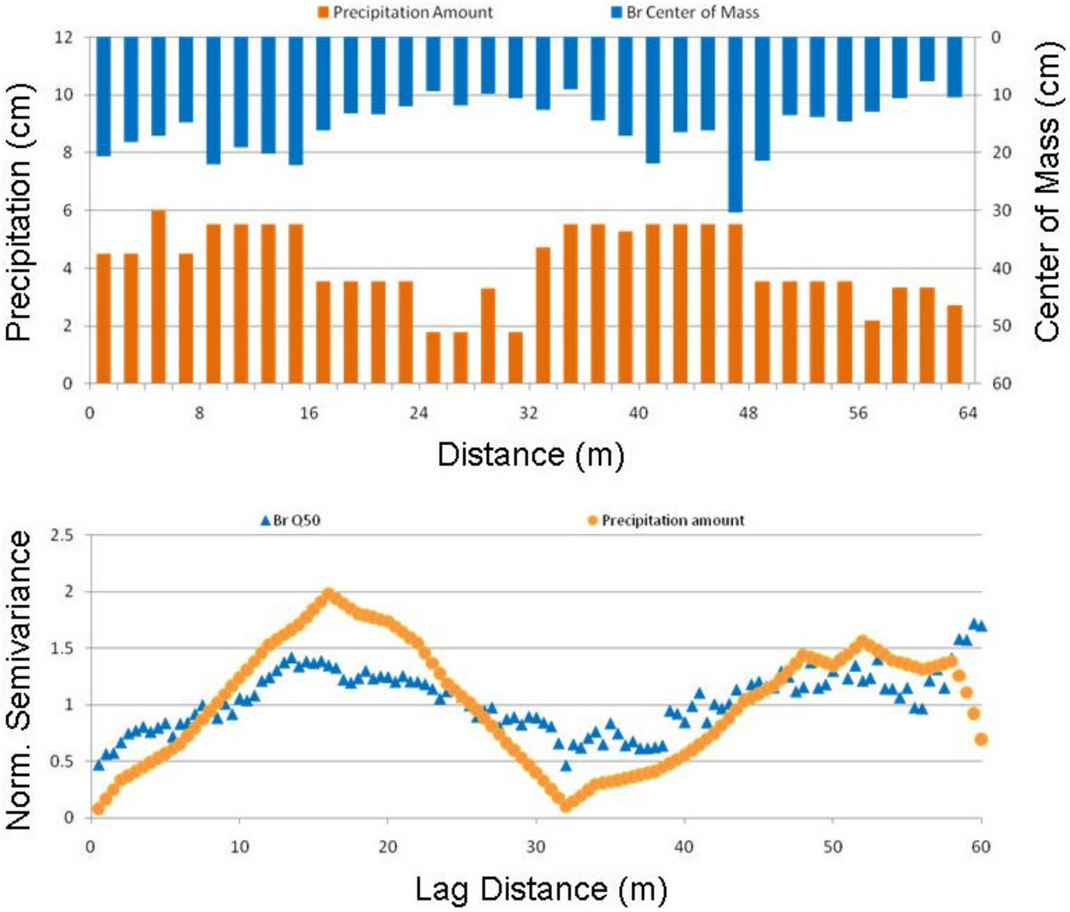

Figure 3. Spatial distribution of precipitation amount and center of mass of Bromide along the 64-m-transect (top) and normalized semivariograms for both variables (bottom).

Cospectral analysis revealed a strong covariance and spatial association between Bromide center of mass and all three factors investigated here (Figure 4). The time delay effect on Bromide leaching depth was manifested in cross- and quadspectra at frequencies corresponding to wavelengths of 32 and 8 m, respectively. The long wave variation was caused by amount and intensity of rainfall. The signal at 8 m wavelength indicates an invers relationship between application time delay and center of mass (Figure 4). This implies, that the longer the delay between Bromide surface application and subsequent rainfall, the less effective is the leaching. In other words, the sooner a rainfall occurs after a surface application of a chemical, the larger is the leaching depth.

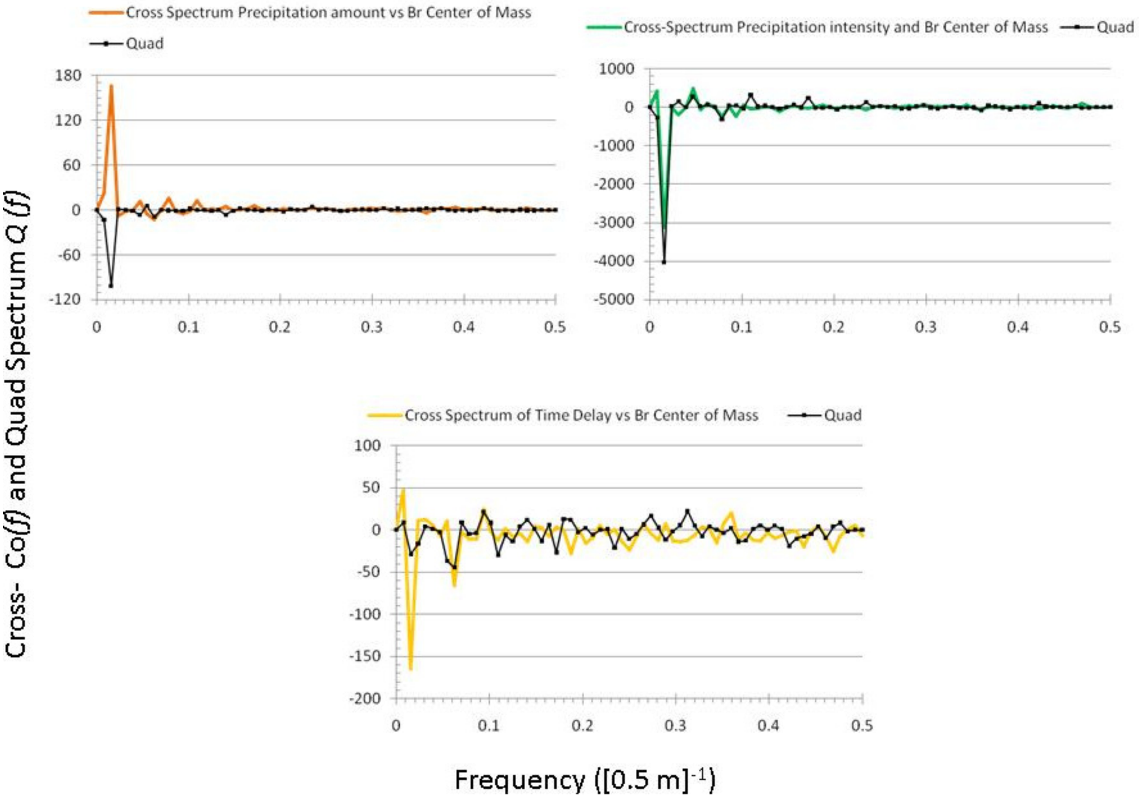

Figure 4. Cross-and quadspectra for the spatial distribution and cyclic variation of Bromide center of mass versus precipitation amount (upper left panel), precipitation intensity (upper right panel) and time delay (lower panel).

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