Mapping and interpreting soil textural layers to assess agri-chemical movement at several scales along the eastern seaboard (USA)

Tammo Steenhuis1, Kathy Vandenheuvel1, Kirk W. Weiler1, Jan Boll1, Jayaram Daliparthy2, Stephen Herbert2 & K.-J. Samuel Kung3

1Department of Agricultural and Biological Engineering Riley-Robb Hall Cornell University Ithaca, NY 14853 USA; 2Department of Plant and Soil Sciences University of Massachusetts Amherst, MA 01003 USA; 3Department of Soil Science University of Wisconsin Madison, WI 53708, USA (*corresponding author: phone: (607)255-2489, fax:(607)255-4080, email:tss1@cornell.edu)

Key words: funnel flow, unsaturated flow, layered soils, preferential flow, ground penetrating radar, groundwater contamination

Abstract

Despite numerous cases of groundwater contamination with agricultural chemicals on layered sandy soils, monitoring and prediction of the fate of these chemicals in the vadose zone has eluded researchers and bureaucrats alike so far. To aid in a better understanding of this phenomena, the movement and fate of agricultural chemicals were assessed at different scales for the (sandy and layered) floodplain soil occurring along the Eastern Seaboard. At the point and field scale ground penetrating radar was used to locate the coarse sand lenses and tracer experiments were initiated to study the flow pattern of the chemicals. Results show that water and solutes moved over the coarse layers and were funneled into fingers bypassing most of the soil matrix and reaching the groundwater much faster than when the solute would move evenly through the vadose zone. At field scale a computer simulation indicated that the exact location of the layers does not have to be known for calculating travel times, indicating that pedo-transfer functions could be developed for calculating groundwater pollution potential for different combinations of soil and chemicals. In the future, groundwater pollution on a regional scale can be predicted by using these pedo-transfer functions in a Geographic Information System.

Introduction

Soil surveys have been completed in many countries and can be reliably used for qualitative interpretations of the suitability of a site for different land uses. Relying on soil survey data to assess the danger of groundwater pollution, however, is more complicated and requires a quantitative approach based, in part, on the soil survey data [2]. This quantitative approach can vary in scale and complexity. The scales, as defined by Hoosbeek and Bryant [8] vary from molecular scale (-5) to the continental scale (+5). Scale 0 is the pedon or plot. The complexity ranges from relatively simple assessments (level 1), expert knowledge (level 2), to simulation methods of various degrees (levels 3, 4, and 5). Groundwater contamination can be transient and, thus, a variable for time needs to be included in the quantitative approach. Although groundwater models introduce time varying values, these changing parameter values can also be obtained by monitoring. Whereas the latter is a more direct way of obtaining these values, monitoring is not without complication either as we will see later from the field site in Massachusetts where we measured solute concentrations.

The case study for this paper is groundwater pollution from agricultural chemicals in the region along the Eastern Seaboard of the United States where much of the productive agricultural land can be found. Scales of interest are point or horizon (−1), plot or pedon (0), polypedon or field (1), watershed or catena (2), county (3), or regional (4). The spatial terminology we will use throughout the paper (i.e., point, plot, and field) has been chosen because it is more consistent with the terminology in other solute movement studies. In the next sections we will discuss the groundwater quality findings in the Eastern Seaboard region followed
Regional scale problem definition and scale selection

The soils along the Eastern Seaboard are deposited by post-glacial rivers and have a texture ranging mostly from sand to sandy loam. As a result of the deposition process, these soils are characterized by layers of coarse and fine sand. Many primary aquifers are located in this area and some, such as on Long Island, can serve as the sole water supply of some 10 million people. In the rural areas many farm wells directly extract water from the aquifer without any pretreatment. The contamination of groundwater in this region is, therefore, a subject of great concern.

Many cases of groundwater pollution with agricultural chemicals have been reported in the Eastern Seaboard region. The first publicized occurrence of the pesticide aldicarb (and other carbamates) in groundwater occurred in the sandy soils of Long Island. Since that time, researchers from the Northeastern United States have reported that sandy (and gravelly) deposits are the most vulnerable soils to the leaching of pesticides, nitrates and other substances to the groundwater: Massachusetts [3, 6]; Connecticut [7, 19]; New Jersey [15]; New York [17]; New Brunswick [16]; and in the Delmarva Peninsula [11]. Interestingly, the depth of contaminant detection was positively correlated with the historical land use pattern. Nitrates, which use clearly predate that of pesticides, were found deepest in the aquifers [11].

Selection of scale for fate of agricultural pollutants

For studying the fate of agricultural chemicals, a scale size of the field or smaller is the most appropriate. In almost all cases, the groundwater pollution can be traced back to a specific location or field in the landscape. An excellent example of this relation between origin of contamination and the present location of the plume is the TCE pollution from dry cleaning stores on Long Island. By obtaining the location and the dates of operation of the dry cleaning store from old air photographs and knowing the velocity and the direction of the groundwater, the contaminant plume can usually be found without difficulty. Another example is where the Army dumped toxics in the 1950’s with the thought: out of sight out of mind. Thirty years later, by tracking the movement of the chemicals, the culprits were identified.

Unlike the Army’s dumping of chemicals or the TCE added from dry cleaning stores, models (levels 3, 4, and 5) that rely on the convective-dispersive equation have shown that application of agricultural chemicals to agricultural land should not cause any groundwater problems. However, as we have seen above, expert knowledge (level 2) based on monitoring at plot and field scales (0 & 1) has shown quite the opposite along the Eastern Seaboard region.

Problem definition at the field (and smaller) scales

At the field, plot, and point scales there are two issues in groundwater contamination: The first is how the contamination is measured and the second is prediction of the degree of contamination at the various scales. These two issues will be illustrated for the Massachusetts site.

Massachusetts site

The location of the experimental site is on the banks of the Connecticut River in Deerfield, MA at the University of Massachusetts Research Farm, and is typical for other sites in river valleys and along the coast. The experimental site is positioned on a primary high yielding aquifer surrounded by an area of intensive farming activity. The soil at the site is classified as a fine sandy loam (coarse, mixed, mesic Fluventic Dystrochrept) whose description, according to the soil survey, is given in Table 1. Its upper 0.6 m is homogeneous, overlaying inclined layers of coarse and fine material until a depth of approximately 2 m where the profile becomes more silt. It should be noted that the soil survey data was based on one pit. We found considerable variance, especially in the depth of the silt layer throughout the field.

Initial experiment

To determine the effect of nitrate leaching under manured alfalfa plots, an experiment was initiated in 1990 with the surface application of liquid dairy manure on a one-year-old alfalfa stand. Treatments for alfalfa consisted of a control (zero N), low manure-N (112 kg N ha⁻¹ yr⁻¹), high manure-N (336 kg N ha⁻¹ yr⁻¹), low fertilizer N (112 kg N ha⁻¹ yr⁻¹ from \( \text{NH}_4\text{N} \cdot 12\text{NO}_3\)), and high fertilizer N (336 kg N ha⁻¹...