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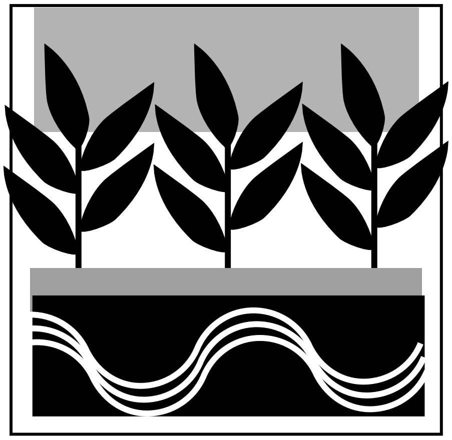

# How soil properties affect groundwater vulnerability to pesticide contamination

J.H. Huddleston

Four factors govern the potential for groundwater contamination by pesticides passing through the soil:

- Properties of the soil
- Properties of the pesticide
- Hydraulic loading on the soil
- Crop management practices

This publication focuses mainly on soil properties. Interactions among all four factors must be considered to fully assess groundwater vulnerability.

Soils whose properties allow rapid transmission of a pesticide to groundwater are called *sensitive* soils. Just because a soil is sensitive, however, does not necessarily mean there is a high risk of groundwater contamination. Good water management, low application rates, proper timing of applications, and careful handling of pesticides all compensate for sensitive soils and reduce the risk of groundwater contamination. The opposite of these conditions can increase the risk even on soils that are not particularly sensitive.

## Soil sensitivity factors

Soil sensitivity depends on four soil properties:

- Permeability
- Water table conditions
- Organic matter content
- Clay content

Permeability and water table conditions together control the *leaching potential.* Soils with high leaching potentials are more sensitive than soils with low leaching potentials.

Organic matter and clay content together control the *sorption potential.* Soils with low sorption potentials are more sensitive to groundwater contamination than soils with high sorption potentials.

Interactions between leaching potential and sorption potential govern the overall sensitivity of the soil. A soil that has both a high leaching potential and a low sorption potential is the most sensitive. A soil that has both a low leaching potential and a high sorption potential is the least sensitive.

## Assessment of leaching potential

*Leaching* refers to the removal of soluble materials by water passing through soil. Naturally occurring salts, chemical fertilizers, and pesticides are subject to leaching. Whether leaching actually occurs depends on the amount of water passing through the soil and the rate of water movement.

*Leaching potential* refers to the risk that soluble pesticides will be transmitted through the soil to the groundwater reservoir. Leaching potential depends on soil permeability, water table conditions, and hydraulic loading.

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**Permeability** refers to the rate at which water moves through soil. Permeability is controlled by the size and continuity of the soil pores.

Factors that influence soil permeability include:

- Texture
- Organic matter
- Structure
- Root and animal activity
- Density

Soil texture refers to the proportions of sand, silt, and clay in a soil. A "loam" is a balanced mixture of sand, silt, and clay. Unbalanced mixtures dominated by increasing amounts of sand are called sandy loam, loamy sand, and just plain sand. If clay dominates, the texture is called clay loam, or, with more clay, just plain clay. Silty soils that contain little or no sand are called, in order of increasing clay content, silt loams, silty clay loams, or silty clays.

Coarse-textured sandy and gravelly soils have the largest pores and the most rapid permeabilities. Fine-textured clayey soils have very tiny pores and very slow permeability rates. Medium-textured loams, silt loams, and clay loams have intermediate rates of soil permeability.

Organic matter helps create and stabilize aggregates of the grains of sand, silt, and clay. These aggregates, or units of soil structure, have relatively large spaces between them, permitting more rapid water movement.

Roots and burrowing insects and animals create large voids, or "macropores," that can transmit water very rapidly under saturated conditions. Macropores also are common in very coarse-textured soils and in soils that crack extensively upon drying.

Macropores are especially important where they are connected to the soil surface. Heavy rainfall or irrigation events may create temporarily saturated surface soil, which can lead to rapid flow through macropores. If soluble pesticides also are present, they can be carried deep into the soil in a short time. If pesticides are bound tightly to soil particles, however, macropore flow may reduce groundwater vulnerability because water moving through macropores does not have a chance to react with the pesticides and remove them from the soil. Tillage generally reduces the number of macropores that are open to the soil surface.

Dense, compact, or cemented soil layers have very slow rates of permeability.

Permeability of soil in its natural setting is highly variable and extremely difficult to measure. Soil permeability can be determined in a laboratory by measuring the rate of flow through a column of soil under a constant head of water.

Permeability rates are given in inches per hour. Typical rates are 0.01 inches per hour for compact clay, 0.5 inches per hour for a loam with good structure, and 15 inches per hour for a loamy sand.

Soil permeability rates are published in each county soil survey report. These rates are mostly estimates based on soil properties, rather than the results of actual measurements, but they are useful for evaluating leaching potentials of different soils.

**Water table conditions** refers to the height and duration of water tables in the soil. Shallow water tables that persist for long periods increase the risk of groundwater contamination.

Well-drained soils rarely have water tables that persist for long periods above a depth of 6 feet. They are much less sensitive than poorly drained soils, which may have water tables at or near the surface for several months.

Two types of water tables occur in soils: perched and apparent. A perched water table is the top of a zone of saturation that is separated from permanent groundwater by a soil layer of very slow permeability. An apparent water table is the top of a zone of saturation in a soil in which there are no dense or confining layers.

Perched water tables do not increase the risk of groundwater contamination as much as apparent water tables do. The soil layer that perches water acts as a barrier to prevent contaminants from moving to the permanent groundwater supply. Perched water, however, is more likely to move into a surface water source, creating a concern for surface water quality.

Soil survey reports contain information on water table conditions in soils. The depth to the water table, the months during which it persists, and whether it is perched or apparent all are given in tabular format. This information is very useful in assessing soil sensitivity.

**Hydraulic loading** refers to the total amount of water applied to the soil. No matter how permeable the soil, the leaching potential remains low if there is insufficient water to move completely through the soil.

Where rainfall exceeds both plant consumptive use and the soil's ability to store water, leaching occurs. Water moving below the root zone ultimately reaches groundwater, carrying with it soluble soil constituents. In these soils, the leaching potential is highly correlated with soil permeability.

Irrigation compensates for water deficits in dry areas. Most irrigation water is taken up by plants, but some usually passes through the soil out of the root zone. Thus irrigation can increase groundwater vulnerability. Careful management of the amount and timing of irrigation water applications can be very effective in reducing the risk of groundwater contamination.

The position of a soil in the landscape also influences its hydraulic loading. Soils near a hilltop often shed water, either by runoff over the surface or by lateral flow within the soil. Soils lower on the hillside and where the slope begins to flatten out often receive excess water from the higher positions. These soils are more susceptible to leaching from the added hydraulic loading.

## Assessment of sorption potential

Sorption refers to the binding of chemicals to particles of organic matter and clay in the soil. Sorption retains chemicals in the soil, where they can be degraded. Thus the higher the sorption potential, the lower the risk of groundwater contamination. Sorption potential depends on organic matter content and clay content.

**Organic matter content** is the most important variable affecting sorption of pesticides. Organic matter provides the greatest number of binding sites because it has an extremely large surface area and is very reactive chemically.

Organic matter content in soil depends on climate, vegetation, position in the landscape, soil texture, and farming practices. Abundant rainfall, combined with lush natural vegetation, gives rise to soils with high organic matter contents. Desert soils have very low organic matter contents. Grassland vegetation generally produces more organic matter deeper in the soil than forest vegetation.

Organic matter decomposes more slowly in wet soils. As a result, poorly drained soils in low-lying areas tend to have more organic matter than better drained soils higher in the landscape.

Sandy and gravelly soils tend to be droughty soils that support less vegetation. Under similar climatic conditions, these coarse-textured soils have less organic matter than medium- and fine-textured soils. The difference is particularly marked where rainfall is limiting for plant growth.

Farming practices that return crop residues and animal wastes to soils help maintain soil organic matter content. Practices that harvest or destroy residues tend to reduce soil organic matter.

Data on organic matter content and distribution in soils are too few to permit evaluation of sorption potential for all soils. Instead, we use knowledge of soil properties and their relationships with climate, vegetation, and landscape to rate soil organic matter content from very low to very high.

**Clay content** refers to the percentage of microscopic plate-shaped grains in the soil. These tiny, flat particles have a tremendous amount of surface area per unit weight of soil, and their surfaces are chemically reactive. The higher the clay content, the greater the number of binding sites for pesticide retention. Clay content is particularly important in the subsoil, where the organic matter content is generally much lower than in the surface soil.

Data on clay content are readily available in soil survey reports. For evaluation of sorption potential, it is sufficient to classify soils in generalized groups ranging from low sorption for the coarse-textured sands and gravels to high sorption for the fine-textured silty clays and clays.

## Assessment of overall sensitivity

The combined effects of leaching potential and sorption potential determine a soil's sensitivity with respect to groundwater vulnerability. The *most sensitive soil* is an irrigated sandy soil with very low organic matter content. The *least sensitive soil* is a well-drained clayey soil with high organic matter content.

Fine-textured soils—silty clays and clays—generally have low sensitivities because they have slow or very slow permeabilities and high sorption potentials. Macropore flow in large cracks may be a problem, however.

Medium-textured soils—silt loams, silty clay loams, loams, and clay loams—generally have low to moderate sensitivities, even in humid areas, because they have relatively slow permeabilities and relatively high sorption potentials.

Coarse-textured soils—sands, loamy sands, and sandy loams—generally have moderate to high sensitivities because they are more permeable and tend to have lower sorption potentials. Small differences in hydraulic loading and organic matter content in these soils impact sensitivity much more than in loamy and clayey soils.

Organic soils—those that consist almost entirely of decomposed plant material—have extremely high sorption potentials. Though these soils have naturally high water tables, cultivated organic soils have been artificially drained, which lowers the water table. Thus the cultivated organic soils have low sensitivities.

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