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Rapid Communication

Short-term ecological risks of depositing contaminated sediment on arable soil

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Abstract

Sediments act as sinks of suspended material from surface water. Dredging of regional waters and subsequent disposal of the sediment on soil may lead to contamination of the soil, in some cases resulting in exceedance of soil quality standards. Soil quality standards are based on total concentrations. Total levels, however, do not always give an indication of adverse effects in soil ecosystems. Instead, truly bioavailable concentrations should be used as indicators. In this study we aim to test a set of suited indicators. We carried out partition and accumulation assays with metals and polycyclic aromatic hydrocarbons (PAHs) in soils and mixtures of soil and sediment, as well as a limited number of toxicity bioassays. We also investigated the rate of disappearance of PAHs from mixtures of sediments and soils. The experiments confirm that total levels indeed are not indicative of truly occurring toxic effects: mixing of highly contaminated sediments with soil hardly gave rise to either additional accumulation of metals and PAHs or excess toxicity. This indicates that the bioavailability of the metals and PAHs present in the sediment is limited. This general finding is confirmed by the low rate of disappearance of PAHs from the mixtures. It is concluded that inclusion of the aspects of bioavailability, mixture toxicity, and degradation, in the way described in this report, will solve the major limitations of the current methodology of classification of contaminated sediments.

Keywords: Metal; PAH; Sediment; Soil; Bioavailability

1. Introduction

Soil standards are usually expressed in terms of total contaminant load per unit of dry material. In daily practice, the relationship between the extent of exceedance of environmental quality standards and the extent of adverse effects on human or ecosystem health is not clear a priori. This may in general be attributed to uncertainties with regard to extrapolation of total contaminant concentrations to actually occurring adverse effects in the field. Important uncertainties in this respect are

- differences in (bio)availability of the chemicals of interest, as related to local soil properties;
- differences in rates of degradation of organic contaminants;
- extrapolation of the results of standard "single species" laboratory tests to "multi species" ecosystems;
- mixture effects of chemicals simultaneously present (see among others Allen, 1997; Peijnenburg et al., 1997; Posthuma et al., 1998a, b).

To assess the link between laboratory-derived standards based on total concentrations and effects actually occurring in the field, it is necessary to relate total

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concentrations of all pollutants present to their combined effect. This could be done on the basis of species sensitivity distributions regarding the toxicity of each of the chemicals present, supplemented with an explicit quantification of the soil-related factors modifying bioavailability, the factors determining mixture toxicity, and the potency for degradation of the organic pollutants present (Posthuma et al., 2002). Accumulation tests and toxicity bioassays are of importance to validate the set of rules thus established. Finally, time is an important parameter. This is not only with regard to removal of organic compounds but also with regard to the observation that sorption tends to increase over time (aging). It is common practice to apply freshly spiked, nonequilibrated soils during toxicity testing. Field soils, on the other hand, are typically in a state of pseudo-equilibrium with regard to the distribution of chemicals among the soil constituents. This induces large difference in bioavailability between soils used for toxicity testing and field soils, and as a consequence results of toxicity tests are not predictive of actual adverse effects occurring in the field. It is the aspect of differences in bioavailability among soils that is crucial within the whole context.

A three-phase bioavailability concept was first proposed by Landrum et al. (1994). In the first phase, partitioning of chemicals between the soil solid phase and the pore water is of importance. This may be operationally quantified by means of partition coefficients. Equilibrium will be established as a consequence of partitioning, thus supplying potentially available pools of contaminants for the biota present. Uptake from one or more of these pools will depend on the relative contribution of the species-specific uptake routes (dermal, ingestion of soil, ingestion of food), and provides the second phase of the concept. Once taken up by an organism or a plant, interactions with specific receptors may induce toxic effects depending on modifying factors such as internal (re)distribution processes and inert storage (third phase).

Sediments act as sinks for suspended material in surface water. Waterways are essential for drainage of excess water and navigation. To safeguard these essential functions, waterways are regularly dredged in order to remove excess sediment. In the Netherlands, regional waters are, for example, dredged with an average frequency of about once every 10 years. Part of the dredged material is deposited on arable soil. This may result in increased levels of organic and inorganic pollutants in the receiving soil, and hence in exceedance of existing maximum contaminant loads. Consequently, adverse effects on the receiving soil ecosystem cannot be ruled out. Exploratory probabilistic modeling studies were carried out on trends in levels of metals and polycyclic aromatic hydrocarbons (PAHs) in sediments of regional Dutch waters and on levels of these pollutants in soils on which dredged sediment is deposited. As Dutch soil standards are modified on the basis of the organic carbon content and the clay content, three soil types were distinguished in these studies: sand, peat, and clay. A realistic dredging scenario was applied in terms of dredging frequency and amounts of sediments typically deposited. The studies showed that dredging of contaminated sediment will lead to exceedance of the maximal tolerable risk levels (MTR, a scientifically derived value used for criteria setting, based on both human and ecological risk) in the receiving soil for several metals (Huiting et al., 1997; Kramer et al., 1997, 1998; Van Dijk et al., 1998).

In this contribution we report on the results of an experimental study aimed at testing the null hypothesis of adverse effects on soil ecosystems not being related to the total burden of pollutants present in the ecosystem. Instead, we hypothesize that adverse effects (to be defined later) are related to

1. Differences in bioavailability (working hypothesis: soil properties determine the extent to which chemicals are available for uptake by organisms, and hence soil properties determine the extent of actually occurring adverse effects to organisms).
2. The rate of degradation of organic micropollutants, as impacted by both compound and soil-related properties (including the presence of a viable population of microorganisms).
3. The combined toxicity of all pollutants present (this requires accumulation of the bioavailable fractions to a joint measure of toxicity).

PAHs and metals (being the contaminants primarily responsible for exceedance of sediment quality standards) in mixtures of freshly dredged sediment and arable soil were used to test our hypotheses. To this end, common deposition procedures for dredged sediments on soil were simulated in terms of relative amounts of sediment and soil. Prior to the selection of the sediments, total concentrations of 16 PAHs (EPA-PAHs) and six metals were determined. The main selection criterion for sediments was the presence of elevated concentrations (i.e., exceeding the MTR) for at least one of the PAHs or metals. This implies that different PAHs or metals may be responsible for any effect observed in the different mixtures. Based on their clay and organic matter content, sediment and soil samples were classified as sand, peat, or clay soils. Similarly classified sediments and soils were mixed (i.e., sandy sediments were, for instance, mixed with sandy soils) and allowed to settle for a fixed period of time. Subsequently, physicochemical soil properties were determined, to assess partitioning of metals and PAHs over the various soil phases. As uptake via the pore water is the dominant route of uptake for many species