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SCIENCE DIRECT
Geoderma 129 (2005) 147–166
GEODERMA
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Quantification of physical properties of dredged sediments during physical ripening

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Received 11 February 2003; received in revised form 6 December 2004; accepted 17 December 2004
Available online 2 February 2005

Abstract

The soil formation process ripening can be used as a bioremediation technique for dredged sediments that are polluted with organic chemicals. Currently, data are lacking that quantify the effects of physical ripening on parameters that affect aerobic bioremediation. We quantified the effects of physical ripening on shrinkage, swelling, moisture retention, hydraulic conductivity, and oxygen diffusion for three freshly dredged sediments using specially designed pressure chambers. We also quantified the effect of physical ripening on structure development by measuring aggregate size distributions for four half-ripe and four ripe sediment samples that were collected from field sediment disposal sites. The course of physical ripening and the aerobic bioremediation process for sediments at above ground (upland) disposal sites can be predicted using the data and information developed in this study when using a combination of existing water and oxygen transport and ripening models.

Keywords: Hydraulic conductivity; Moisture retention; Oxygen diffusion; Physical ripening; Shrinkage; Structure development; Swelling

1. Introduction

Large amounts of sediments are dredged for both maintenance and environmental reasons worldwide. For example, 400 million m^3 of sediment are dredged annually by the United States Army Corps of Engineers or their permit recipients (Linkov et al., 2002), and about 40 million m^3 of sediment are dredged annually in the Netherlands (Vermeulen et al., 2003). A substantial proportion of these dredged sediments is held temporarily at an above ground (upland) disposal facility. Upland disposal is a relatively easy, cost-effective alternative for dredged materials, and is therefore a widely adopted sediment management practice.

Following the application of clayey dredged sediments to a temporary upland disposal site, the compaction processes of consolidation and ripening are initiated. Consolidation is caused by the ‘overburden pressure’

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doi:10.1016/j.geoderma.2004.12.040

resulting from the weight of overlying sediment (Terzaghi and Peck, 1967). Ripening is a soil formation process that irreversibly converts waterlogged *sediments* into *soil* by desiccation and structure development (Pons and van der Molen, 1973; Vermeulen et al., 2003). Due to desiccation of the top layer, the water table in the dredged sediments drops and causes an increase of the effective 'overburden pressure', which enhances the consolidation process (Terzaghi and Peck, 1967). The soil profile that results from ripening, roughly exists of four zones with different extents of structure development: (i) unripe consolidated soil below the water table, (ii) half-ripe soil with a coarse to very coarse prismatic structure, (iii) nearly ripe soil with coarse aggregates, and (iv) ripe soil with medium to fine aggregates at the top (Vermeulen et al., 2003).

Ripening of dredged sediments consists of physical, chemical, and biological processes. Vermeulen et al. (2003) described these three sub-processes extensively and concluded that ripening plays a key role in bioremediation of temporarily disposed dredgings that are polluted with organic pollutants like Polycyclic Aromatic Hydrocarbons (PAH) and mineral oil (Total Petroleum Hydrocarbons (TPH)). It is known that ripening of a 1-m-thick layer of dredgings can take up to 3 to 6 years. (Harmsen, 2001). However, it is currently not possible to predict the exact course of simultaneous ripening and bioremediation of dredged material during temporary disposal because of the complex relationships (coupling effects) between ripening and biodegradation of organic pollutants (Vermeulen et al., 2003). Therefore, the development of a mathematical model that describes the different processes and their coupling effects would be useful. Such a combined model would need sediment-specific input data. Because the different coupling effects have been studied only rarely (Vulliet et al., 2002; Horn, 2003), sufficient data on parameters that affect aerobic bioremediation are lacking.

Therefore, we carried out this study to quantify: (i) the shrinkage and swelling behavior of dredged sediments, (ii) the effect of physical ripening on the moisture retention and hydraulic conductivity characteristics, (iii) the oxygen diffusion coefficients of desiccating dredged sediments, and (iv) the effect of physical ripening on structure development. We quantified (i)–(iii) with three freshly dredged clayey sediments that were artificially ripened in the laboratory. For (iv) we used samples of sediments that had been subjected to natural ripening at field disposal sites.

In this study, we only consider the physical aspects of ripening. Biological and chemical processes typically play an important role in structure development (Dexter, 1988; Horn et al., 1994; Vermeulen et al., 2003); however, we consider physical ripening to be the most important and the driving mechanism of the whole ripening process.

2. Quantification and modeling of physical ripening

The n-value as defined by Pons and van der Molen (1973) can be used as an empirical measure of the degree of desiccation of dredged sediments (Vermeulen et al., 2003):

$$n_{\mathrm{rip}} = \frac{A_{\mathrm{sat}} - 0.2R}{L + 3H} \tag{1}$$

where: n_{rip}=n-value (g water g^{-1} clay); A_{sat}=saturated moisture ratio in (g moisture (100 g)$^{-1}$ dry matter (D.M.)); L=clay content (g clay (100 g)$^{-1}$ D.M.); H=organic matter content (g organic matter (100 g)$^{-1}$ D.M.); R=sand+silt content (g sand+silt (100 g)$^{-1}$ D.M.).

Using n_{rip}, Pons and van der Molen (1973) defined five classes of physical ripening (Table 1). Structure development cannot be described directly by Eq. (1) because this process is not only governed by desiccation but also by the intensity and number of wet/dry cycles (Vermeulen et al., 2003). However, in general, low values of n_{rip} correspond with a high degree of structure development.

Table 1
Classification of sediment material according to the degree of physical ripening

n_{rip} (g g^{-1})	Designation
3.0–2.0	Unripe, recently deposited *sediment*
2.0–1.4	Consolidated, but practically unripe
1.4–1.0	Half ripe
1.0–0.7	Nearly ripe
<0.7	Ripe, normal *soil*