# 9 Summary

TNT was more toxic for *F. candida* and *E. crypticus* than any of the other tested explosives Hexyl, Hexogen and Octogen or TAT, the end product of the reductive microbial degradation. Hexyl on the other hand reduced the reproduction of the collembola without causing a mortality up to 4000 mg Hexyl/kg soil (dw). The strong effect on the reproduction was not the effect of a reduced fertility, but of a higher mortality of the more sensitive juveniles. For the enchytraeid, in contrast, Hexyl was lethal, but had a much stronger effect on the reproduction. This can partly be attributed to a reduced cocoon placement and a lower hatching rate. Octogen (HMX) and Hexogen (RDX) showed no toxicity at all up to 8000 mg/kg soil (dw). In soil material TAT was up to 2000 mg/kg soil (dw) only toxic in the reproduction test with the enchytraeid. It did not show any effect on the collembola not even in a contact test or a water test, whereas the enchytraeid was affected at very low concentrations in the water test indicating a strong sorption of TAT to soil. Overall the reproduction test was more sensitive than the mortality test. For the enchytraeid the choice test was even more sensitive than the reproduction test. The collembola on the other hand seems to have no perception of the tested substances, as no choice behaviour could be detected.

In tests with different reference soil materials it was observed that both test species do not reproduce well in lumpy soil materials and that the mortality of the collembola was quite high compared to Lufa 2.2. This change in the soil texture was not the result of a wrong adjustment of the water content. On the contrary, the standardised water content of 60% of the MWC should be reconsidered for different soil types; as it might also be the reason for the very low reproduction of *E. crypticus* in the potting soil. This peaty soil material had a very high MWC and seemed still quite dry after the adjustment of the water content to 60% of the MWC. The reproduction of both test organisms can be affected by unknown factors, as it was extremely low in some uncontaminated soil materials. Overall the determination of the MWC is not very precise and might thus enhance the problems for different soil types.

The reference soil materials differed in their clay and organic carbon content. TNT was the least toxic in the potting soil with the highest content of organic carbon, whereas it was the most toxic in Lufa 2.3 with the lowest $C_{org}$. For the other soil materials (Lufa 2.2, Lufa 3 and Lufa 4) the difference was related with the clay content, but no linear correlation was found either for the clay or the organic carbon content nor for the ratio of the mineral to the $C_{org}$ content.

The toxicity of TNT did also decrease if the spiked soil material was aged. At higher temperatures this effect was stronger due to higher microbial degradation than at lower temperatures. Since so many factors influence the toxicity of TNT in soil, it is very difficult to estimate the toxicity of soils which have been contaminated by use on the bases of the chemical

analysis and the physical properties alone. In the contaminated soil materials tested the test organisms were able to survive and to reproduce in much higher TNT-concentrations than in the spiked soil materials. The order of toxicity for these soil materials depended on their clay and organic matter content. For the decreased toxicity the long ageing period of more than 50 years from the time of contamination during and after World War II until now, has to be taken into account.

Other remediation treatments of munitions contaminated soils than incineration are possible. In a soil washing the amount of soil material, which had to be disposed of by incineration was reduced to 13.6%, whereas the remaining 86.4% were considered to be suitable for a reuse as building material, although they still contained TNT. Biological treatments, too, offer an alternative to incineration. The end product of microbial reduction of TNT is TAT, which is known to bind irreversibly to the soil matrix. Those soils remediated with indigenous microorganisms either by composting or by a windrow-process were not toxic to both test organisms. Even the remediaton of soils highly contaminated with TNT and other explosives seems possible with microorganisms. A complete transformation of TNT is so far only known for white rot fungi. However, a soil material remediated by this procedure was more toxic to both test organisms than before, which might be the effect of the presence of heavy metals or of transformation products. A period of resting could improve the habitat function of this soil material in respect to the transformation products.