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Soil microbial biomass and community structure affected by repeated additions of sewage sludge in four Swedish long-term field experiments

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Soil organic matter is a key attribute of soil fertility. The pool of soil organic C can be increased, either by mineral fertilisers or by adding organic amendments such as sewage sludge. Sewage sludge has positive effects on agricultural soils through the supply of organic matter and essential plant nutrients, but sludge may also contain unwanted heavy metals, xenobiotic substances and pathogens. One obvious effect of long-term sewage sludge addition is a decrease in soil pH, caused by N mineralisation followed by nitrification, sulphate formation and presence of organic acids with the organic matter added. The objective of this study was to investigate the effect of sewage sludge on the microbial biomass and community structure.

Materials and methods
We analysed soil samples from four sites where sewage sludge has been repeatedly applied in long-term field experiments situated in different parts of Sweden; Ultuna (59°49'N, 17°39'E, started 1956), Lanna (58°21'N, 13°06'E, started 1997-98), Petersborg (55°32'N, 13°00'E, started 1981) and Igelösa (55°45'N, 13°18'E, started 1981). In these four experiments, at least one sewage sludge treatment is included in the experimental design.
In the Ultuna experiment, all organic fertilisers, including sewage sludge, are applied every second year, corresponding to 4 ton C ha-1. The Lanna experiment has a similar design, with 8 ton dry matter ha-1 applied every second year. Lanna also has an additional treatment in which metal salts (Cd, Cu, Ni and Zn) are added together with sewage sludge. At Petersborg and Igelösa, two levels of sewage sludge (4 or 12 ton dry matter ha-1 every 4th year) are compared with three levels of NPK fertiliser (0 N, $\frac{1}{2}$ normal N and normal N).
Topsoil samples (0-20 cm depth) from the four sites were analysed for total C, total N, pH and PLFAs (phospholipid fatty acids). In addition, crop yields were recorded.

Results
At all four sites, sewage sludge has had a positive effect on crop yields and soil organic matter levels. Correlations between soil organic matter and total PLFA contents showed highly positive correlations at all sites (with R-values between 0.72 and 0.88). To find out whether sewage sludge through its metal impurities could impose stress on the microbial biomass, we compared the correlations between all different fertilisers used and PLFAs. The slopes of these comparisons revealed that sludge did not differ from other fertiliser treatments, which means that our results contrast earlier reports on negative effects of metals in sludge on soil microbes.
The microbial community structure, studied with principal component analysis of individual PLFAs, was strongly affected by changes in soil pH, and at those sites where sewage sludge had caused a low pH, Gram-positive bacteria were more dominant than in the other treatments. However, differences in community structure were larger between sites than between the treatments investigated in this study, thus indicating that the original soil properties were more important for the microbial community structure than the fertiliser treatments.