The geometric mean of enzyme activities in soil contaminated with heavy metals after the application of the mineral-organic mixture

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In recent years, the quality and health of soil with addition of different organic and mineral materials has been of great interest to a wide range of scientists around the world. Soil microorganisms play a key role in many biochemical processes essential for the environment and for the ecological and production functions of soils, hence they are very important quality indicators (Vithanage *et al.* 2018). Despite the significant number of scientific papers describing the effect of different organic and mineral materials on the soil, only a small proportion of them estimate and quantify the quality parameters of the soil. This probably reflects not only the difficulties in finding appropriate, integrated quantitative indicators for the assessment of soil quality, but also the ability to interpret them. This problem could be solved by aggregating data concerning the chemical, physical, and biological properties of soil in the form of numerical indexes, which include, among other factors, the geometric mean of enzyme activities (*GMea*) (Paz-Ferreiro *et al.* 2012, Mierzwa-Hersztek *et al.* 2019).

The study aimed at evaluating the effect of different additions of the mineral-organic mixtures to the soil contaminated with heavy metals. The pot experiment was carried out in the greenhouse of the University of Agriculture on soil with a loamy sand texture collected from the 0-0.2 m layer. The experiment consisted of 10 treatments carried out in 4 replications: C – soil without fertilisation (contaminated with $CdSO_4 \times 8/3H_2O$, $C_4H_6O_4Pb \times 3H_2O$ and $ZnSO_4 \times 7H_2O$); MF – soil with NPK mineral fertilisers; 3%NaX-Ver_3%WB and 3%NaX-Ver_6%WB – soil with the addition of 3% of a zeolite/vermiculite composite (NaX-Ver) and 3 or 6% of lignite; %NaX-Ver_3%L and 3%NaX-Ver_6%L – soil with the addition of 3% of a zeolite/vermiculite composite (NaX-Ver) and 3 or 6% of leonardite; 3%NaX-C_3%WB and 3%NaX-Ver_6%WB – soil with the addition of 3% of a zeolite/vermiculite composite (NaX-C) and 3 or 6% of lignite; %NaX-C_3%L and 3%NaX-C_6%L – soil with the addition of 3% of a zeolite/vermiculite composite (NaX-C) and 3 or 6% of leonardite. The soil used in the experiment was slightly acidic pH H_2O (5.67) and had a relatively low C total (6.43 g kg^{-1}) and N total (0.54 g kg^{-1}) content.

After the application of the mineral-organic mixtures and mineral salts and mixing them with the soil, the seeds of maize were sown. During the experiment, the humidity of the soils was maintained at a constant level of 45% of the WHC. Soil for biochemical analyses was collected 5 months after of the mineral-organic mixtures application and stored at 4 °C for biological analysis and at 25°C for physicochemical analysis. The evaluation of dehydrogenase (EC 1.1.1.1) activity was performed using the method of Thalmann (1968), urease (EC 3.5.1.5) activity by the Zantua and Bremner (1975) method and acid and alkaline phosphatase (EC 3.1.3.1) activities with the Allef and Nannipieri (1995) method. The geometric mean of enzyme activities (*GMea*) was calculated using a method discussed elsewhere (Paz-Ferreiro et al., 2012) as follows:

$$GMea = \sqrt[4]{DhA \times Ure \times AlP \times AcP}$$

Our results indicate that the interaction of many factors greatly influence the effect of mineral-organic mixtures on the enzymatic activity of the soil (Fig. 1). It was demonstrated that both the type and the dose of the mineral-organic mixtures used had a significant effect on the biochemical activity of the soil. The highest degree of enzyme activity was determined for soil with the addition of 3%NaX-Ver_6%L and the smallest degree in soil with addition of 3%NaX-Ver_3%WB. The values of the geometric mean of enzyme activities indexes showed that the deterioration of soil quality after the use of mineral-organic mixtures compared to treatment C was observed in all treatment except: 3%NaX-Ver_3%WB, 3%NaX-Ver_3%L and 3%NaX-Ver_6%L. Lower GMea values for soils may be due to the lower content of nitrogen, or its lower availability. Further research is necessary to confirm the influence of these mixtures on the enzymatic activity of soil.

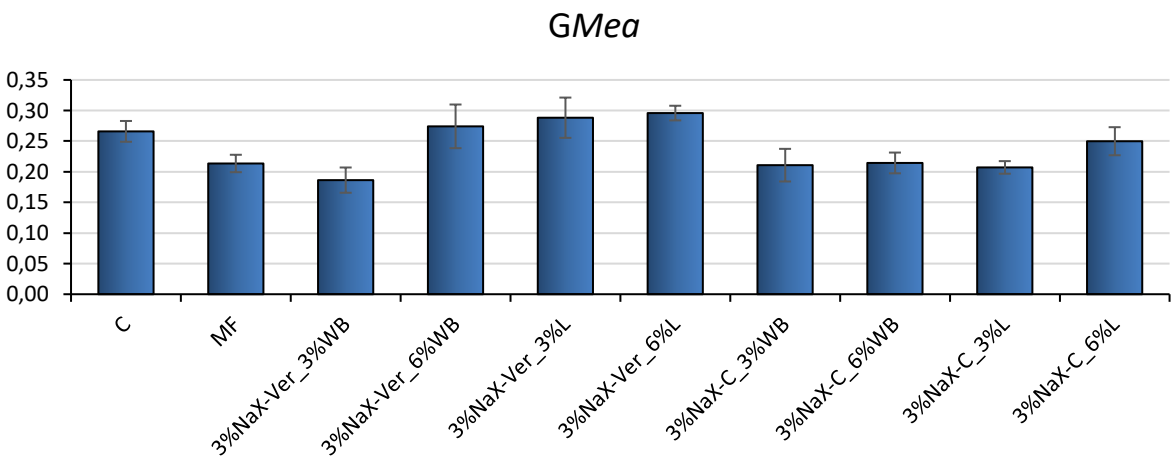

Figure 1. Geometric mean of enzyme activities (GMea)) for different treatments.

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