Zinc Biofortification on Wheat through Organic Matter Management in Sustainable Agriculture

Final project fact sheet

Zinc deficiency is one of the major global nutrition concerns, particularly in regions where diets are cereal-dominant and soils poor in zinc. This project investigated how short and long-term organic matter application affected soil zinc and its uptake by plants. Leguminous green manure application and long-term organic matter fertilization were found to be a promising approach for increasing zinc and decreasing cadmium, a toxic trace metal, in wheat grains.

Motivation

Zinc deficiency is a global human malnutrition problem. It particularly affects people whose diets are based on wheat and other cereals. In nearly 50% of the soils used for cereal cultivation worldwide zinc availability for plant uptake is very low. The application of organic matter is a potential biofortification approach to increase soil zinc availability to plants and thereby its accumulation in wheat grains. However, organic management may also affect cadmium accumulation, a toxic metal chemically similar to zinc, which is also prominent in agricultural soils. In fact, wheat consumption contributes substantially to human cadmium levels.

Objective

The overall research objective was to understand how short- and long-term organic matter inputs into agricultural soils affect zinc and cadmium accumulation in wheat grains, relating them to soil properties. The project also investigated the potential of inoculation of soils with zinc-solubilizing bacteria to increase availability of soil zinc for plants.

Research Highlights

Researchers first looked at the potential of green manure application to increase zinc concentrations in soil and wheat grains. They grew berseem clover and white mustard, two green manure plants widely used in Switzerland, in pots and plots, mixed them into soil, and grew wheat in the same soil thereafter. In comparison to treatments without green manure or with white mustard, the application of the leguminous clover in soils with sufficient zinc led to higher wheat biomass; soils with more zinc and cadmium available for plant uptake; and wheat grains with higher zinc and cadmium concentrations (see Figure 1). The effect appeared to be due to high soil nitrogen inputs and concurrent pH decrease, and the release of organic molecules able to bind to and mobilize soil zinc and cadmium.

The effect of long-term organic matter application on zinc and cadmium accumulation was investigated by growing wheat in plots of two Swiss long-term field trials which had been fertilized with either organic or mineral fertilizers for the past 36 or 65

Image 1: Doctoral student Benjamin Costerousse and a field assistant harvesting wheat in a field trial

years. In comparison to mineral fertilizers, wheat crops fertilized with farmyard manure had lower yields but grains with more zinc, while compost fertilization led to soils with less cadmium available for plant uptake and wheat grains with less cadmium. The effects of farmyard manure were related to the input of zinc and cadmium with the amendments; the effects of compost application were attributed to the observed increase in soil pH. Despite the different mechanisms, both organic treatments led to higher zinc/cadmium ratios in the wheat grains, indicating a better nutritional quality of the wheat grains.

To understand how certain bacteria solubilize zinc in soil, researchers isolated zinc-solubilizing bacteria from soil around the roots of wheat plants and grew them in microbiological media supplemented with soluble zinc oxide. Results revealed a variety of bacterial pathways leading to the release of zinc into soil pore water, including proton extrusion and the production of different organic acids. Solubilization mechanisms varied among bacteria and were strongly affected by growth conditions. However, inoculation with the zinc-solubilizing bacteria isolated under *in vitro* conditions did not increase zinc availability in real soil under pot conditions.

Relevance to Stakeholders:

The increase in wheat grain zinc concentrations with clover manure suggests that the short-term application of leguminous manure is a promising approach for zinc biofortification, when wheat is grown in zinc sufficient soils or in combination with zinc fertilizer. The study also supports the long-term application of compost as a strategy to reduce wheat grain cadmium concentrations. In contrast, the inoculation of soil with bacteria selected exclusively on their ability to solubilize zinc under *in vitro* conditions does not seem to be a promising approach to biofortify wheat grains with zinc.

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Food System Challenges Addressed Nutrition security, food quality, soil health, human health

www.worldfoodsystem.ethz.ch/research/research-programs/MRP/zomm.html

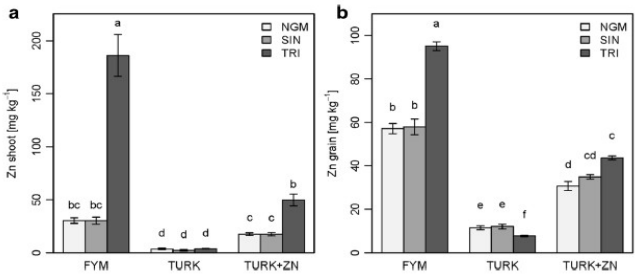

Figure 1: Zinc concentration in shoots and grains of wheat grown with no green manure (NGM), mustard (SIN) or clover (TRI) in soils with high (FYM and TURK+ZN) zinc concentrations (Source: Grüter, R.; Meister, A.; et al. 2018)

Selected Publications

Helfenstein, J.; Müller, I.; Grüter, R.; Bhullar, G.; Mandloi, L.; Papritz, A.; Siegrist, M.; Schulin, R. and Frossard, E. Organic wheat farming improves grain zinc concentration. ***PloS one***. **2016**.11(8), p.e0160729.

Costerousse, B.; Schönholzer-Mauclaire, L.; et al. Identification of heterotrophic zinc mobilization processes among bacterial strains isolated from wheat rhizosphere (Triticum aestivum L.). ***Appl. Environ. Microbiol.*** **2017**, 84 (1): e01715-17.

Grüter, R.; Costerousse, B.; et al. Green manure and long-term fertilization effects on soil zinc and cadmium availability and uptake by wheat (Triticum aestivum L.) at different growth stages. ***Sci. Total Environ.*** **2017**, 599–600: 330-1343.

Grüter, R.; Meister, A.; et al. Green manure effects on zinc and cadmium accumulation in wheat grains (Triticum aestivum L.) on high and low zinc soils. ***Plant Soil.*** **2018**, 422 (1–2): 437–453.

Grüter, R.; Costerousse, B.; et al. Long-term organic matter application reduces cadmium but not zinc concentrations in wheat. ***Sci. Total Environ.*** **2019**, 669: 608–420.

Media

Video Towards solving the zinc crisis. *World Food System Center, ETH Zurich*. **19 April 2019**.

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