Micronutrients for better yields

This case study illustrates collaboration between groups within the Soil Science cluster as well as with research organizations and societal partners outside the cluster. It also demonstrates the use of highly technical research approaches to develop practical products/information that can be used at farm level to improve resource management, food production and livelihoods.

Abstract / Summary

Crop yields in East and Southern Africa are limited by macronutrient or micronutrient deficiencies – which also leads to reduced food quality and micronutrient malnutrition (“hidden hunger”). Effective fertilisation strategies to overcome these problems are hampered by a lack of reliable information on soil nutrient status and bioavailability, as well as crop responsiveness, at field, regional and national scales. The project “Micronutrients for better yields” uses theoretical and practical approaches to understand the aboveground and belowground processes that control bioavailability of plant nutrients. With a combination of field trials, pot experiments, soil characterisation and geochemical multi-surface modelling, the speciation and mobility of micronutrients in soils and bioavailability to plants is described, both at field scale and regionally by applying developed models to existing soil maps. Outcomes consist of improved understanding of micronutrient bioavailability and grain micronutrient concentrations, simple models that can be used to predict micronutrient bioavailability based on easily obtainable soil parameters, and soil maps that can aid the development of (micro)nutrient fertiliser recommendations. The resulting information can be of direct value to farmers and those who depend on their food production.

Case Description

Background

Global food security (Sustainable Development Goal 2) is threatened by macronutrient and micronutrient deficiencies which limit crop yields and/or nutritional quality. Low micronutrient availability not only affects crop yield and grain quality but also human health: particularly in developing countries where micronutrient malnutrition (“hidden hunger”) affects a significant percentage of the population (Sustainable Development Goal 3). Particularly in East and Southern Africa, farmers are facing a decreasing response of crops to regular chemical fertilisers, which is believed to be largely caused by a low availability of micronutrients in the heavily weathered soils. Effective fertilisation strategies to overcome these problems are hampered by a lack of reliable information on soil nutrient status and bioavailability, as well as crop responsiveness, both at the field scale and regional to national scales. A better understanding of the intrinsic capacity of soils in these areas to store and provide nutrients to crops, and of crop response to fertilisation, is sorely needed. This knowledge can then be translated into easily applicable diagnostic tools and spatial data for the relevant soil and agronomic properties, in order to assist stakeholders in providing effective and economically feasible fertiliser recommendations at the field and regional scale.

Research objectives

The project “Micronutrients for better yields” with two PhD students (Soil Chemistry and Soil Biology) is a collaboration between Wageningen University, ISRIC and locally operating partners (International Plant Nutrition Institute, Cascape Ethiopia/WEnR, University of Zimbabwe, AgroCares and IFDC). The project has several objectives. Firstly, to understand the soil chemical processes that control the chemical speciation and availability of micronutrients (i.e. zinc, copper and boron) in soils from various countries in Sub Saharan Africa. This knowledge is used to develop accessible tools and models for predicting soil micronutrient availability. The models will be based on input variables that can be easily obtained through routine soil analysis, and that are available in the form of soil maps. Secondly, we intend to develop a field-scale fertilizer recommendation system that effectively addresses the availability of yield-limiting micronutrients, and digital soil maps of micronutrient availability in Sub-Saharan Africa, including spatially explicit risk assessment of crop micronutrient deficiencies. To develop the field-scale fertilizer recommendation system, the soil fertility tool QUEFTS (QUantitative Evaluation of the Fertility of Tropical Soils) will be used. QUEFTS is currently calibrated for nitrogen (N), phosphorus (P) and potassium (K) and our aim is to extend it with modules for micronutrients. Digital maps can be developed based on existing soil maps and the use of QUEFTS, as well as other tools developed to predict soil micronutrient availability.

Research approach

In Figure 1, a schematic overview of the research on soil fertility in East and Southern Africa is presented. To better understand plant nutrient uptake, the research began with investigating belowground processes that control nutrient availability (the bottom part of the Figure 1.) This requires extensive characterization of soil samples (Figure 1D), including different nutrient fractions, and quantification of the soil reactivity for nutrient adsorption. In addition, micronutrient adsorption to each of the major reactive surfaces in the tropical soils (particularly Fe/Al-(hydr)oxides and soil organic matter) is studied and parameterized using surface-specific ion adsorption models. These models are then combined into geochemical multi-surface models (Figure 1E) that can subsequently be translated into more accessible prediction tools in the form of empirical partition relations. Existing soil maps can be used as input in these partition relations to develop soil maps that predict the nutrient concentration in solution. Figure 1G shows an example of a map for Rwanda with the predicted Zn in solution. The soils maps are developed in collaboration with ISRIC.

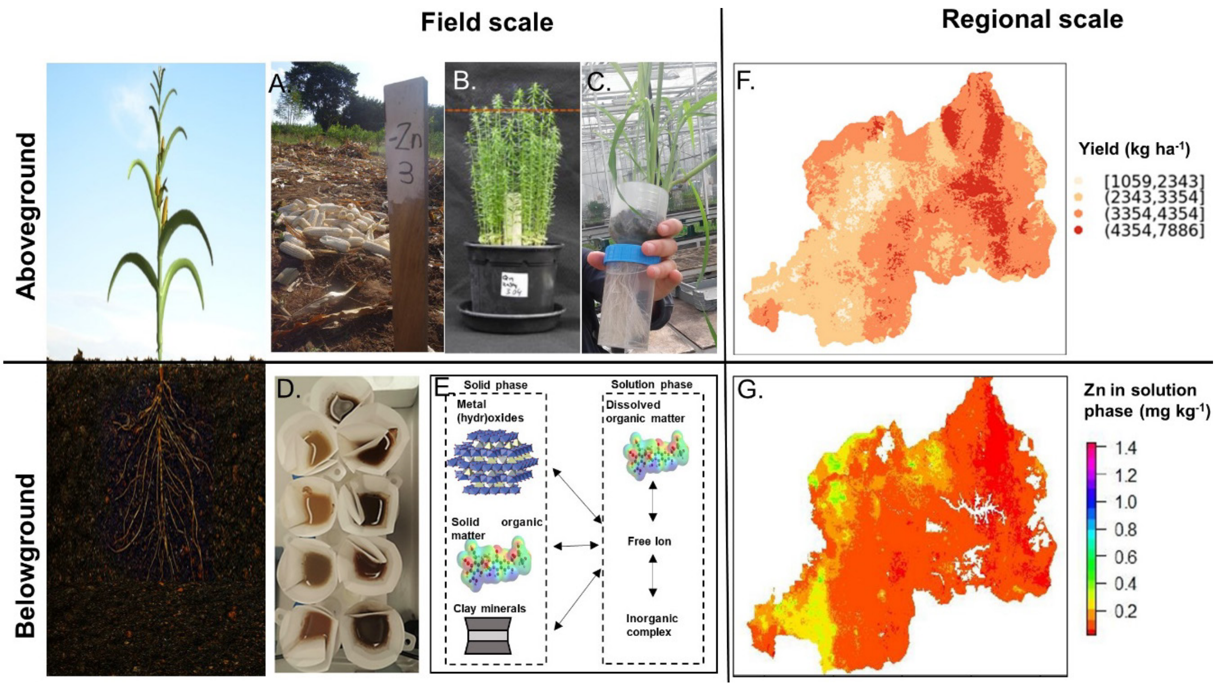

Figure 1: A schematic overview of the research on soil fertility in East and Southern Africa

Moving aboveground, the nutrient uptake by the crop is used as an indicator for bioavailability of nutrients in soils. To this end, nutrient omission field trials are executed in which yields are compared between treatments that receive complete fertilization compared with treatments in which zinc and boron micronutrient fertilisers are left out, in order to assess whether they are growth limiting for maize (Figure 1A). Field experiments were set up in Kenya, Zambia, Zimbabwe and Ethiopia, in collaboration with Wageningen Environmental Research (CASCAPE project), The Plant Production Systems group at Wageningen University, The International Plant Nutrition Institute and local partners such as the University of Zimbabwe. Next to field experiments, pot experiments are conducted to better understand the soil properties that affect zinc availability for plant uptake in a controlled environment (Figure 1B). Next to the regular pot experiments, a double pot experiment has been set-up in collaboration with AgroCares Research, in which a nutrient solution in the lower pot is used next to the soil sample in the upper pot (Figure 1C).

Knowledge derived from the field trials and greenhouse experiments, is used to extend the QUEFTS model by developing micronutrient modules. To move to the regional scale, maps of aboveground parameters can be developed with QUEFTS for fertiliser recommendations. Figure 1F shows a preliminary map of predicted maize yield in Rwanda, developed using QUEFTS (based on N, K and K). This map can be further elaborated and serve as a baseline reference once QUEFTS is extended with micronutrient modules.

Research Highlights

Availability of boron for plant uptake is generally considered to be controlled by adsorption of boron to reactive minerals such as ferrihydrite (i.e., Fe(hydr)oxide with the highest reactive surface area). This adsorption process has not been described previously. We were able to study the interaction of boron with ferrihydrite nanoparticles which are omnipresent in soil systems, and have the data interpreted with state-of-the-art surface complexation modelling.[1] We confirmed that the presence of phosphate reduces the adsorption of boron and changes the surface speciation (Figure 2).

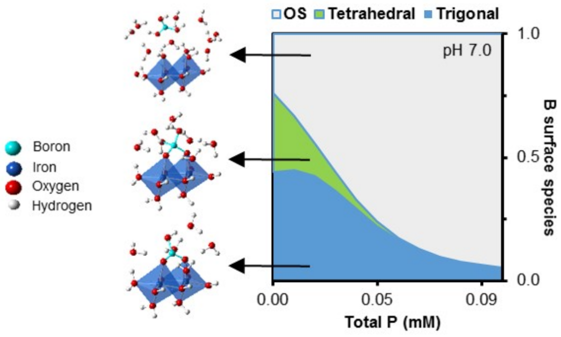

Figure 2: Effect of phosphate on boron adsorption and surface speciation on ferrihydrite

The surface complexation parameters that were derived based on adsorption experiments were applied to soils in a multi-surface geochemical model to understand which surfaces are most important for boron adsorption, and to test the boron speciation in various extraction methods that have been proposed for assessment of boron availability in soils (Figure 3).[2] Our modelling approach has enabled, compared to previous attempts, a strongly improved mechanistic understanding of boron speciation in soils.

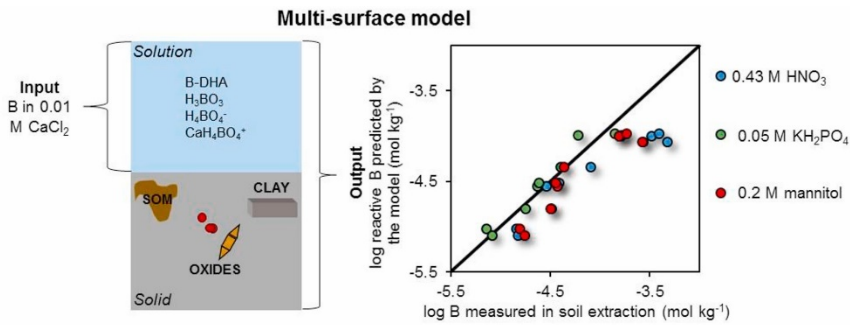

Figure 3: *left*: The multi-surface model with adsorption to solid and dissolved humic acids (SOM, B-DHA), oxides and clay. *Right*: comparison between boron measured in soil extractions and the labile boron calculated by the model

Impact

During the course of this project, transfer functions have been developed for phosphorus and potassium soil tests[3]. QUEFTS requires four input parameters, of which two (pH and organic carbon) are routinely measured. For the other two parameters (phosphorus and potassium availability) several soil tests are employed, giving varying results depending on the method. In order to apply QUEFTS to existing soil maps, transfer functions were needed, so that available phosphorus and potassium data could be translated into the input that QUEFTS requires. These functions greatly increase the applicability of QUEFTS. Besides the potential use by local researchers, ISRIC currently uses the transfer functions to develop soil and yield maps.

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[1] Van Eynde, E., Mendez, J. C., Hiemstra, T., & Comans, R. N. (2020). Boron adsorption to ferrihydrite with implications for surface speciation in soils: Experiments and modeling. ACS Earth and Space Chemistry, 4(8), 1269-1280.

[2] Van Eynde, Elise, Liping Weng, and Rob NJ Comans. "Boron speciation and extractability in temperate and tropical soils: A multi-surface modeling approach." Applied Geochemistry 123 (2020): 104797.

[3] Mirjam S Breure, Elise Van Eynde, Bas Kempen, Rob NJ Comans and Ellis Hoffland. "Transfer functions for phosphorus and potassium soil tests and implications for the QUEFTS model". Under review.

The more accessible tools for predicting soil micronutrient availability developed in this project are expected to have a great impact as well. Currently, assessing micronutrient bioavailability is analytically challenging, especially given the extremely low concentrations in African soils. These tools that are supported and validated by the mechanistic geochemical models developed in this project, can be used to develop maps on a regional and national scale. These maps will enable the identification of regions at risk of micronutrient induced growth-limitations and consequently the development of effective fertilizer recommendations, which are indispensable for increasing yields and resource management in Sub Saharan Africa, as well as for human health and livelihoods.