Decreased Zn Concentrations in Wheat Grain Is Due to Increased Yield and Harvest Index

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INTRODUCTION

Zinc is an essential micronutrient for plants and animals, and there is evidence of deficiency effects on human health (WHO 2002). Crops are a major source of many micronutrients in the diet, especially in developing countries. It has been suggested that modern crops have inherently lower micronutrient contents, and that modern intensive farming methods may decrease the amount of elements, such as Zn, in the soil over time. However, proof of these conjectures is lacking to date (Graham et al. 1990, McGrath 1985, Garvin et al. 2006).

We investigated these ideas using the unique sample archive at Rothamsted and the Broadbalk long-term experiment. On this site, wheat has continuously been grown with contrasting nutrient treatments since 1843.

METHODS

The Broadbalk experiment (Johnston 1997) occupies 5 ha, and was originally divided into 20 parallel plots (0.24 ha each, later reduced to 0.19 ha with the introduction of 1.5 m paths between plots) for different fertilizer treatments. Winter wheat is usually sown in October and harvested in early August of the following year. Wheat grain and soil samples from the experiment have been air-dried and stored in sealed containers in the archive since 1843. The soil is a moderately drained Aquic Paleudalf with flinty silty clay loam topsoil on clay-with-flints overlying chalk parent material. The topsoil contains approx. 25% clay, 57% silt and 15% sand. We recently sub-sampled and ground archived grain and soil in preparation for digestion. Grain samples were digested with ultra-pure HNO_3 and H_2O_2 in microwave vessels and soil with ultra-pure HNO_3 and $HClO_4$. Concentrations of Ca, Mg, K, P, S, Na, Zn, Fe, Cu and Mn were determined by Inductively-Coupled Plasma Atomic Emission Spectrometry (ICP-AES). Previously recorded results were available for yields and the calculation of harvest index (HI = proportion of grain to grain+straw). In this paper, we show results from plots that received the following treatments: Control (no inputs), N-P-K-M-g-Na-S-inorganic fertiliser, and farmyard manure (FYM).

RESULTS AND DISCUSSION

Soil Mineral Concentrations

There was no evidence of any depletion of the analyzed elements in the soil. Total concentrations of the elements studied remained constant or increased significantly over the last 160 years. The increase in P and Mg can be attributed to the inputs from inorganic fertilizers, Zn and Cu from FYM, and from atmospheric deposition in the case of Zn in the control plot. Only the data for Zn are shown here (Figure 1a).

Grain Yield and Mineral Concentrations

Grain yields increased dramatically with the introduction of short-straw varieties from the mid 1960s onwards (data not shown). This was accompanied by a decrease in Zn-grain concentrations (Figure 1b). This decline was seen in all treatments, even in treatments with increasing soil-Zn concentrations (Figure 1a). We examined the relationships between the concentrations of four micronutrients and yield and HI by linear regression analysis. Highly significant ($P < 0.001$) negative slopes were found for each element with yield and HI, except for Fe which was not significantly related with yield.

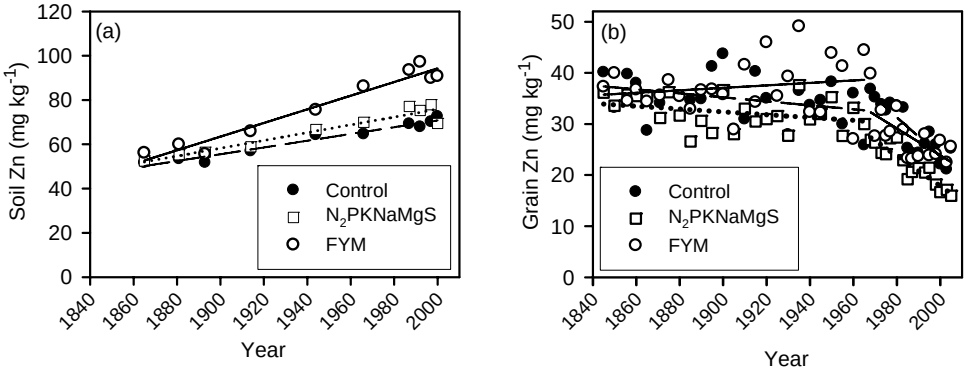

Fig. 1. Concentrations of Zn in (a) Broadbalk soils and (b) the corresponding wheat grain over time.

CONCLUSIONS

It appears that the introduction of short-straw varieties in the 1960s after the "Green Revolution" coincided with a decrease in Zn concentrations in grain despite increasing soil-Zn concentrations. This was supported by separate experiments, in which long- and short-straw varieties were grown in adjacent subplots in 1988-1990 (data not shown). Yield and HI of wheat increased during the experiment, but the uptake and/or translocation of micronutrients, such as Zn, into the grain did not, leading to decreased grain concentrations in grain. Similar effects were seen by Garvin et al. (2006) who grew varieties with different release dates in two locations in Kansas in 1999. Modern varieties have been selected more for high yield rather than nutritional quality (Morris and Sands 2006). This study indicates the urgent need for a breeding program which promotes higher concentrations of micronutrients, such as Zn, in wheat and other staple crops.

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