Increasing Grain Zn in Wheat by the Application of Sewage Sludge

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INTRODUCTION

Sewage sludges (biosolids) are a useful source of nutrients including N and P, and organic matter. There is now increased urgency to improve the recycling of N and P due to both environmental and resource use concerns. Sewage sludge also contains a number of metals at varying concentrations, depending on the source, and commonly zinc (Zn). There is also a need to improve the Zn status of staple cereal grains for human health reasons (Kutman et al., 2011).

Nine field experiments were originally set up to examine the effects of Zn, Cu and Cd on soil microbial activity and long-term soil fertility in 1994-7. This paper highlights results from three of the sites in England at which three different sources of Zn were added and measurements were made of Zn in grain of bread wheat (*Triticum aestivum* L.) between 1999 and 2005.

METHODS

Nine long-term field experiments were established to evaluate the effects of heavy metal additions to soil from sewage sludge on soil microbial activity and long-term soil fertility (Gibbs et al., 2006a). Three sites (Woburn, Watlington, Rosemaund) were chosen that were in arable/grass annual rotation. Over a four year period (1994-97), a Zn-rich **sludge cake** from a public wastewater treatment plant was applied to establish Zn dose-response treatments aiming to extend from background up to and slightly exceeding current maximum permitted limit values in the UK (300 mg Zn kg^{-1}) for soils in the pH range 6-7. Zinc-rich sludge cake was applied at four rates of application, and low-metal sludge cake additions were also made to balance organic matter additions on all the treatments, so all the sludge treatments received the same amounts of organic matter. On the same field as the above, we also compared the effects of Zn additions as Zn-amended **liquid sludge** (Zn sulphate was added to low-metal liquid sludge and incubated anaerobically for 6-9 months; Gibbs et al., 2006b). Liquid Zn-amended sludge was applied over a three-year period (1995-97) to cover the same range of Zn concentrations in soil as the sludge cake experiments. **$ZnCO_3$** powder was added in a further experiment on the same fields during 1995-7 and 2000, again to cover the same range of Zn concentrations in the surface soil (0-25cm) as the cake and liquid sludge experiments.

In the above experiments, the treatments selected were 1. **Cake** experiment: a no sludge control, a low-metal digested cake as a low Zn sludge treatment and four Zn treatments with increasing amounts of a Zn-rich sludge 2. **Liquid** sludge experiment: a no sludge control, the low-metal liquid sludge as a low Zn sludge treatment and three Zn treatments using the same liquid sludge with increasing amounts of Zn and 3. **Salt** experiment: no treatment or three amounts of $ZnCO_3$. All treatments were replicated threefold in randomised blocks and were thoroughly cultivated between 1997 and 1999 to mix the materials added into the soil. Spring wheat var. Chablis was grown at all sites in 1999, 2001, 2003 and 2005 with the exception of Rosemaund site in 1999 and 2001 (winter wheat cv. Riband). All sites had N and other fertilisers added each year at amounts required for optimum yields.

To examine the effects of increasing soil Zn from the three different sources of Zn, we used simple regression of whole grain Zn against total (*aqua regia*) or 1M NH_4NO_3-extractable soil Zn. Soil Zn measurements were normalised by log transformation. In addition, measurements of soil pH (1:2.5 in H_2O) and % soil organic C (SOC) were available for all the plots. These were used in multiple linear regressions with pH and % SOC as secondary explanatory variates to the measurements of Zn status.

RESULTS AND DISCUSSION

There were no effects of soil Zn on grain yields (data not shown), and the sites were not low in Zn status as all grain contained > 20 mg Zn kg^{-1}. There was some variation between the harvest years included in the analysis (1999, 2001, 2003, 2005) but this year-to-year variation was not consistent across the sites, and indicated no trend of increasing or decreasing Zn availability with time. Averaged across the 6-year period, a simple log-linear regression including all 3 sites and experiments showed a good relationship with soil total Zn (Table 1), particularly for the liquid and salt experiments. The smaller R^2 for the cake experiments may be due to greater variability of the Zn in the soil, despite the cultivations. When extractable Zn was examined, the R^2 for the liquid and salt experiments did not increase, but there was some improvement for the cake experiments. Taking the slope of the relationship with total Zn as an indicator of bioavailability, this decreased in the order liquid>salt>cake. Lower bioavailability may partly explain why the extractable Zn improved the relationship for the cakes.

Including pH and SOC in the multiple regressions did not improve these relationships. This may partly by due to the small range of pH and SOC in the experiments (6-7 and 1-3%, respectively). The linear relationships with log total Zn can be used to determine the effect that building up any particular concentration of Zn in soil will have on grain Zn. For example, 200 mg kg^{-1} Zn in soil on average would result in 78, 77 and 71 mg Zn kg^{-1} grain in the liquid, salt and cake experiments.

Table 1. Linear regressions of soil total Zn or extractable Zn as predictors of grain Zn concentrations across a 6-year period. Grain Zn (mg kg^{-1}) = constant + (slope x Log total or Log extractable Zn). Ranges indicated are 95% confidence intervals. All R^2 and parameters were significant (P <0.001).

Log total Zn	**Constant**	**Slope**	**R^2 adj**	**Log extr Zn**	**Constant**	**Slope**	**R^2 adj**
Cake n=216	-58.9 -77.1- -40.7	56.3 48.1-64.5	46.0	**Cake n=216**	60.3 58.0-62.6	23.3 20.5-26.1	56.3
Liquid n=180	-120 -137- - 103.5	86.3 78.4-94.2	74.0	**Liquid n=180**	57.0 54.5-59.5	27.6 24.9-30.3	71.0
Salt n=144	-109.1 -137- -81.4	81.0 68.9-93.1	64.9	**Salt n=144**	61.0 56.5-65.5	25.2 21.2-29.1	62.6

CONCLUSIONS

Sludge cake Zn can increase grain Zn concentrations for at least 2 to 8 years after application to soil at three sites, but the differences detected between sources of Zn were small in practical terms.

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