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COMMENTARY

Selenium in cereals: improving the efficiency of agronomic biofortification in the UK

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Abstract Wheat, despite its relatively low selenium (Se) concentration in the UK, is still an important dietary Se source and its biofortification by use of Se fertiliser may be an efficient means to increase the relatively low Se status of the population. We need to know more about the fate of Se applied to the soil and how to ensure the efficiency of Se application, and the three studies reported in this issue of Plant and Soil are timely and informative. Selenium in soil, both globally and locally, is notoriously variable; however, the soils in these studies yielded wheat grain Se concentrations in the narrow range of 16–44 ng/g. The low plant Se levels reported here are not surprising, given that selenite is the dominant Se form in these soils. A regression equation (which used total and extractable Se and extractable S as variables) explained a high proportion of the variance in grain Se concentration. Sulphur application (a common practice on UK wheat growing soils) had variable effects on grain Se concentration, depending on soil S status, pH and possibly other factors. A fertiliser methodology study investigated ways to optimise Se application for the purpose of biofortification. It was calculated that an application of a modest 10 g Se/ha as selenate would increase the grain Se concentration of UK wheat from around 30 ng/g to 300 ng/g. The national Se fertiliser program in Finland shows that this increase would have a large effect on population Se status. However, Se recovery in grain at this application rate is only 14%, and it can be argued that large-scale agronomic biofortification of cereals with Se would be somewhat wasteful of a relatively scarce trace element. Selenium's effects and interactions in soil, plants, animals and humans are complex and often surprising and will keep researchers busy well into the future.

Keywords Agronomic biofortification · Micronutrient · Selenium · Sulphur · Wheat

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Selenium is an essential micronutrient for humans, animals and certain lower plants, and its supply in global food systems is highly variable (Combs 2001). The importance of wheat as a dietary Se source is shown for the UK where it is estimated to supply 22% of dietary Se (Rayman 2000) even though it typically occurs in UK-grown wheat at concentrations of only around 30 ng/g (Adams et al. 2002). Surveys of Se status in humans (Bates et al. 2002) and other studies and reviews (Rayman 2002; Broome et al. 2004; Elia and Stratton 2005) suggest that the Se status of the UK population may be too low for optimum health.

The two studies of Stroud et al and that of Broadley et al in this edition of Plant and Soil serve to increase our understanding of the complex factors which influence the bioavailability of Se in the soil and its uptake by plants. These timely studies follow a review which examined the concept of agronomic biofortification of food crops with Se as a strategy to increase Se status of the human population of the UK (Broadley et al. 2006). If Se agronomic biofortification is to occur, whether locally or nationally, it is sensible to do it as efficiently as possible, especially as Se can be considered as a valuable resource which is difficult to recycle (Haug et al. 2007).

The plant-availability of Se in soil is largely dependent on the predominant Se species and the soil factors controlling their behaviour, such as the quantity of the sorption components (Al and Fe oxides), pH and redox status. Furthermore, the presence of anions competing for the same sorption surfaces (sulphate, phosphate, organic anions, etc.) contributes to the retention of Se (Elrashidi et al. 1987; Neal 1995; Fordyce 2005; Hartikainen 2005). Stroud et al weighted soil profile data according to distribution of wheat roots, a novel method in soil-plant Se research. The authors used multiple regression analysis to help identify soil factors that influence grain Se concentration. Their regression equation (which used total and extractable Se and extractable S as variables) explained a high proportion of the variance in grain Se concentration in this study. The range of total and available soil Se is quite narrow (245–590 and 5–12 μg/kg, respectively), yielding native wheat grain levels mostly in the range 16–44 ng/g. The low plant Se levels are not surprising, given that selenite is the dominant Se form in these soils, with selenate undetectable. As selenite, when taken up by plants, is rapidly converted to organic Se forms which accumulate in roots (Li et al. 2008), it can be speculated that over time, especially under intensive cropping, the ratio of organic Se forms to selenite in such soils would increase.

Whether the equation could apply to some of the more extreme cases of soil Se found elsewhere remains to be seen. In some soils there is a vast difference between total and available Se levels. For example, our group (using ICP analysis following acid digestion) found a grey loamy sand with pH (H_2O) 5.0 from Zimbabwe to contain around 30,000 μg/kg total Se (which could almost class it as seleniferous), yet maize grain grown on it contained only 5 ng/g Se, a deficient level. Conversely, a pH 8.6 brown sandy loam from the west of South Australia containing just 80 μg/kg total Se produced wheat with a grain Se concentration of 720 ng/g (Lyons et al. 2004). The high variability of both total and available soil Se is not confined to different regions: its microspatial variation is just as striking. Wheat grain Se concentration was found to vary 6-fold (110–690 ng/g) in 4 replicated plots of a single wheat cultivar grown together in one field in South Australia (Lyons et al. 2005).

The second study of Stroud et al, which investigated the interaction of Se and S fertilisation and its effect on grain Se concentration, found that applied S decreased grain Se concentration in controls at both sites, in accordance with numerous previous studies. However, when S and Se were applied together, grain Se was increased on the low pH, S-sufficient soil but decreased on the high pH, S-deficient soil. The incubation trial, where added S increased the availability of selenate Se, agreed with the finding at the S-sufficient field site, but not at the other site. At the S-deficient site, the authors explain that S addition would be expected to reduce selenate uptake due to down-regulation of sulphate transporters (Terry et al. 2000; White et al. 2004). However, selenate is at very low levels in both soils, and the plant uptake of selenite, the main Se form present, is more likely to be affected by influences on phosphate transporters (Li et al. 2008). Moreover, the low-pH site, with total C in topsoil of 2.43%, would be expected to contain a significant proportion of total Se bound to organic matter (Kang et al. 1993). Clearly there is ample scope for further field studies of interactions of Se with other minerals in the soil.

Broadley et al compared the fate of Se applied in either granular or liquid form. It was found that all selenate applications were effective; spring application was more effective than winter; considerable Se remains in straw (and thus could be beneficial if it is used in animal feed), and percent Se recovery increases with application rate. A feature of this study is the projection of trial findings to a national level. It is calculated, for example, that an application of a modest 10 g Se/ha as selenate would increase the grain Se concentration of UK wheat from around 30 ng/g to 300 ng/g. This is especially impressive considering the usually high yields of UK-grown wheat. There is no more suitable micronutrient than Se for agronomic biofortification of food crops...a little goes a long way! Nevertheless, recovery of Se in grain at this application rate is only 14%, so it can be argued that if the world's low-Se areas, which include much of the UK, Europe, China and Africa, were biofortified agronomically with Se, a sizeable proportion of the world's available Se resource would be spent and not be available for future use (Haug et al. 2007). Biofortification of Se during germination/sprouting, can result in complete bioconversion from inorganic to organic Se forms within five days with 100% Se recovery (Bryszewska et al. 2005); however this method is unlikely to increase the Se status of whole populations.

We know from the Finland national Se biofortification program (which represents a true "food system" approach to improving human nutrition) which commenced in 1985, that this method is remarkably effective for increasing the Se status of food crops and the human and animal population. In Finland Se is currently supplied at the rate of 10,000 μg/kg in NPK fertiliser (Hartikainen 2005). Of course, further research is needed to improve our knowledge of the fate of Se in the soil and in the food chain. It is reassuring that in Finland, where environmental parameters have been closely monitored since the Se program began, minimal negative effects are evident (Makela et al. 2005).

The moon goddess Selene appears to have conferred not only her name, but also her nature on this micronutrient. Selenium is intriguing, enigmatic and challenging (even capricious), especially for researchers. The studies reported in this issue increase our knowledge of Se in soil and plant and also raise further questions for researchers to try to answer.

On a cautionary note, Broadley et al mention the small gap between deficient and toxic Se intakes for humans…in pharmacological/medical terms, its narrow therapeutic index, although it is not unusual for trace elements (e.g. Fe, Cu, Zn). Some researchers consider that the upper safe limit of Se intake in humans may be even lower than previously thought (Vinceti et al. 2009). Equivocal findings for Se's roles in human health are common. Conflicting evidence for Se and risk factors for cardiovascular disease, for example, is provided by recent surveys: a study in the UK found higher Se status to be associated with higher LDL-cholesterol levels (Stranges et al. 2009), while a study of women in Spain found the opposite (Llaneza et al. 2009).

Such is the complexity of action and effect of Se, especially in human nutrition, that there is no certainty that, even were UK food crops to be universally Se-biofortified to achieve a hypothetical ideal population Se status, there would be any measurable population-level health benefits. And this despite findings in France and Italy (with similar Se levels to those in the UK) that low blood Se in people over 65 years is a strong predictor of mortality in the ensuing 6–9 years (Akbaraly et al. 2005; Lauretani et al. 2008).

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