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Increasing Se concentration in maize grain with soil- or foliar-applied selenite on the Loess Plateau in China

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ABSTRACT

Selenium (Se) is an essential mineral nutrient for animal and human growth. Deficiency in this element is a worldwide nutrition problem. Thus, this study determined the potential of increasing Se content in maize grain by using various Se fertiliser application techniques to improve the nutritional status of local residents. Field experiments were conducted on the Loess Plateau for two growing seasons to investigate the effects of different Se fertiliser application methods and application rates on the Se content in maize grain as well as the Se recovery, yield and status of other nutrients in maize grain under rain-fed conditions. Results show that soil and foliar Se applications exhibited no significant effects on maize biomass and grain yield as well as N, P, K, Ca, Mg, Fe, Mn, Cu and Zn contents in maize grain. However, both foliar and soil Se applications significantly improved the Se content in maize grain. Selenium content in maize grain is found to be linearly correlated with Se application rates, increasing from 0.12 $\mu g\,kg^{-1}$ to 0.33 $\mu g\,kg^{-1}$ by soil application at 1 g of Se ha^{-1} and from 8.23 $\mu g\,kg^{-1}$ to 8.67 $\mu g\,kg^{-1}$ by foliar application at the same rate. Foliar application of Se showed higher Se recoveries in the grain compared with soil Se application: the former exhibited a maximum grain Se recovery rate of 52‰ and 106‰ in maize during the first and second growing seasons, respectively, whereas the latter was only 1.69‰ and 0.95‰, respectively. On the Loess Plateau in China, both soil and foliar Se applications effectively improved the Se content in maize grain. Compared with soil Se application, foliar Se application can improve the grain Se content in maize at reduced costs.

1. Introduction

Selenium (Se) is an essential element for animals and human beings. This element reportedly prevents liver putrescence in mice (Schwarz and Foltz, 1957). Selenium is found to be an essential component of glutathione peroxidise (Rotruck et al., 1973), which can eliminate free radicals and peroxides in organisms to maintain cell membrane integrity. Selenium is also a component of numerous other enzymes (Berry et al., 1991; Pallud et al., 1997; Ramauge et al., 1996) and proteins (Behne et al., 1988, 1997; Gladyshev et al., 1998; Tamura and Stadtman, 1996; Whanger et al., 1997). An adequate dietary intake of Se is necessary to keep humans, livestock and poultry healthy.

Maize is the primary fodder source of livestock and poultry and one of the main food sources in some countries. In 2010, the maize-planted area was 325.18 million hectares, producing 17.75 billion tonnes maize grains in China, preceded only by rice production and second to that in the United States of America worldwide (FAO, 2013). However, low Se content in maize grain affects nutritional quality and cannot meet human, livestock and poultry health requirements. For example, the Se content in maize flour ranged from 16 $\mu g\,kg^{-1}$ to 25 $\mu g\,kg^{-1}$ in Jiangsu Province (Jia, 1999), whereas more than 66% of the maize grain samples were lower than 25 $\mu g\,kg^{-1}$ in Chengdu, Sichuan (Jin et al., 2010). Wang (1982) analysed the Se content in maize grain in China and concluded that the average Se content in 543 maize grain samples was 19.4 $\mu g\,kg^{-1}$, with most of the samples classified as Se-deficient. Therefore, Se deficiency in maize grain is related to human and animal Se deficiency in these areas. Relevant endemic diseases have drawn increasing attention, such as Keshan disease (Peng and Yang, 1991), Kashin–Beck disease (Chen et al., 1980; Ge et al., 1983),

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Behçet's disease (Delilba et al., 1991) and immune system diseases (McKenzie, 1998).

Numerous experiments showed that a Se fertiliser strategy can effectively improve the Se content in edible crop parts. Selenium fertiliser can be applied using four major techniques: seed dressing, seed soaking, soil application and foliar application. The two latter methods are widely used because of their simplicity and practicability. Addition of Se to growth medium increases the Se status in plants. For example, adding Na_2SeO_3 in a germinating solution significantly increased the Se content in chickpea sprouts (Zhang et al., 2011), and adding Se in a hydroponic solution significantly increased the Se content in *Zea mays* (Longchamp et al., 2013). Selenium application to soil, the major growth medium of plants, enhanced the Se content in plants. Selenium application to soil is used widely in Finland to increase the Se content in domestic food and successfully improve the low Se intake of the population (Eurola et al., 2006). In a greenhouse experiment, the Se contents in the upper leaves, roots, stolons and tubers of potatoes increased by Se application to soil (Turakainen, 2007). Similar results were obtained from field experiments in which 20 g Se ha^{-1} of soil applied at the jointing stage increased the Se content in wheat grain from 0.03 mg kg^{-1} in the control samples to 0.39 mg kg^{-1} (Curtin et al., 2006). The same fertiliser application at sowing increased the Se content in maize grain by 21 μg kg^{-1} for each gram of Se applied as Na_2SeO_4 (Chilimba et al., 2012a).

Foliar Se application is another commonly used technique for increasing the Se content in edible parts of crops. Foliar Se application of selenite or selenate solutions significantly promoted the Se content in carrot roots and leaves (Kápolna et al., 2009), garlic bulbs (Põldma et al., 2011), onion bulbs and leaves (Kápolna et al., 2012) as well as radish flowers and leaves (Hladun et al., 2013). In addition to vegetables, the nutritional status of cereal crops, particularly the edible parts was improved by foliar Se application. Selenium content in wheat grain increased from 0.03 mg kg^{-1} in the control samples to 0.45 mg kg^{-1} when Se was added at 20 g ha^{-1} by using foliar spray (Curtin et al., 2006).

Selenite and selenate are the main forms of Se fertilizer. Selenate is more effective than selenite for Se application to soil for the purpose of biofortification (Duma et al., 2011), although it is more easily leached to deep soil by the water from irrigation and rainfall due to its higher mobility (Wang et al., 2010). Furthermore, in edible parts of crops, Se in organic forms is more effective to human and animals than that in inorganic forms (Rider et al., 2010). Selenium in the leek was found with 79% in organic forms when selenite was applied to soil, while it was only 45% when selenate was applied (Lavu et al., 2012). Kápolna et al. (2012) also showed foliar application of selenite enhanced bio-synthesis of organic Se species compared to selenate. On the Loess Plateau in China, more than 65% of rainfall is received between July and September, when are right the maize growing season, and the leaching of soil applied Se and its subsequently environmental risks should not be neglected. Hence, Se in the form of selenite should be a more rational choice for Se biofortification of maize in this area.

Studies on addressing human Se deficiency by Se fertilisation are rarely reported in the Loess Plateau areas. This study conducted field experiments on the Loess Plateau to investigate (1) the effect of both Se foliar and soil applications in the form of selenite on maize grain yield and Se content; (2) the efficiency of soil and foliar applications; (3) the relationship between Se content in maize grain and Se application rate; and (4) the effect of Se fertiliser on macronutrients and other micronutrients in maize grain. This study was conducted to provide a more efficient method and determine the proper Se fertiliser application rate for improving the Se content in maize grain and alleviating Se deficiency in humans.

Table 1
Main characteristics of soils from four experimental fields sampled before the experiment.

Soil property	Soil field		Foliar field	
	2009	2010	2009	2010
pH (H_2O)	8.17	8.12	8.17	8.17
Organic matter (g kg^{-1})	13.0	14.1	12.9	13.1
Total N (g kg^{-1})	0.91	0.93	0.87	0.87
Nitrate-N (mg kg^{-1})	14.7	17.2	3.77	3.71
Ammonium-N (mg kg^{-1})	6.34	12.2	4.13	4.13
Available P (mg kg^{-1})	16.5	12.5	6.51	6.63
Available K (mg kg^{-1})	122	169	99.3	97.3
Total Zn (mg kg^{-1})	65.3	62.8	66.2	64.3
Available Zn (mg kg^{-1})	0.80	0.98	0.65	0.60
Total Fe (g kg^{-1})	2.04	2.04	2.04	2.04
Available Fe (mg kg^{-1})	5.08	6.39	7.22	5.08
Total Mn (g kg^{-1})	0.59	0.62	0.60	0.61
Available Mn (mg kg^{-1})	14.9	23.2	20.0	15.4
Total Cu (mg kg^{-1})	20.8	21.2	20.8	20.0
Available Cu (mg kg^{-1})	1.35	1.24	1.58	1.29
Total Se (μg kg^{-1})	142	100	170	93.0
Available Se (μg kg^{-1})	2.16	0.98	1.12	0.93

2. Materials and methods

2.1. Experiment location

Two-year field experiments were conducted under rain-fed conditions in four plots in Yangmazhuang Village, Yongshou County (34°49′ N 108°11′ E, elevation = 1127.76 m), Shaanxi Province, China. The annual on-site precipitation is approximately 600 mm, and more than 65% of rainfall is received between July and September.

The soil in the experiment fields is loessal sandy loam. The main characteristics of the soil in each field prior to any treatment application are shown in Table 1.

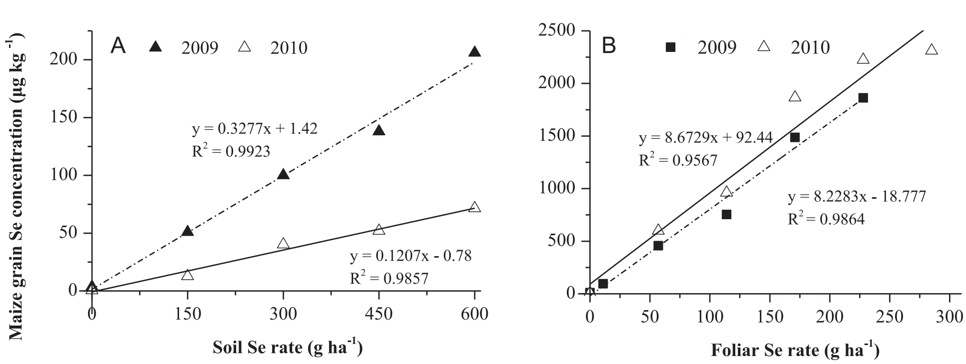

Fig. 1. Relationship between the Se content in maize grain and soil (A) and foliar (B) Se application rates.