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# Effect of Intensive Greenhouse Vegetable Cultivation on Selenium Availability in Soil

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## ABSTRACT

Soil properties dramatically change after long-term greenhouse vegetable cultivation, which further affects soil selenium (Se) nutritional status and plant Se uptake. An evaluation of Se availability after long-term greenhouse vegetable cultivation (GVC) can help in better understanding its influential factors under GVC conditions and will also facilitate further regulation of soil Se nutrition in GVC systems. Two typical GVC bases were chosen: one with clayey and acidic soil in Nanjing, southern China, and the other with sandy alkaline soil in Shouguang, northern China. Twenty-seven surface soil samples at the Nanjing base and 61 surface soil samples at the Shouguang base were collected according to cultivation duration and cultivation intensity. Soil properties including soil available Se ($PO_4^{3-}$-Se) and total Se (T-Se) were analyzed. The results showed that soil $PO_4^{3-}$-Se was significantly and negatively correlated with soil Olsen-P, available K (A-K), and electrical conductivity (EC) at the Nanjing base. At the Shouguang base, however, no significant correlation was found between soil $PO_4^{3-}$-Se and Olsen-P and EC, and soil $PO_4^{3-}$-Se increased with increasing soil organic matter (OM). Intensively utilized greenhouse vegetable cultivation caused significant changes in soil properties and further affected soil Se availability. Due to different management practices, the dominant factors affecting Se availability varied between the two GVC bases. At the Nanjing base, the dominant influential factor on soil Se availability was soil nutritional status, especially Olsen-P and A-K status. At the Shouguang base, where organic fertilizers were applied at high rates, soil OM was the dominant influential factor.

*Key Words*: available Se, electrical conductivity, Olsen-P, soil organic matter, soil properties

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## INTRODUCTION

Selenium (Se), a trace element found in most soils, is an essential element for humans and other mammals (McKenzie *et al.*, 1998; Rayman, 2000). Soil Se often occurs in low concentration in China. Due to the concern of Se deficiency, there is a need for evaluating the availability of Se and assessing influential soil factors (Yang *et al.*, 1983, 1984; Tan *et al.*, 2002).

Availability is one of the most important factors that affect soil Se uptake by plants. Soils with similar total Se (T-Se) concentrations could present different available Se concentrations (Antanaitis *et al.*, 2008). Regional studies have shown that factors affecting soil Se availability could be different among various locations. Take China as an example: in northeastern China, the key influential factor on soil Se availability is soil organic matter (OM); while in the Huabei Plain, leaching is the primary factor (Wang and Gao, 2001). Selenium exists in soils in different forms, which also differ in availability. Thus, factors that affect soil Se existence in different forms also indirectly affect its availability. Studies have shown that soil OM, redox condition, pH, and competition ions are all factors that affect Se availability. Soil pH and redox conditions affect soil Se availability through combined effects on Se chemical forms (Fio *et al.*, 1991; Séby *et al.*, 1998; Eich-Greatorex *et al.*, 2007; Keskinen *et al.*, 2011). Ions such as phosphate, sulfate, and carbonate and some organic acids could affect Se sorption-desorption processes through ion exchange mechanisms (Dhillon and Dhillon, 2000; Kaplan and Knox, 2004; Nakamaru and Sekine, 2008). Also, soil OM is shown to have a significant effect on Se sorption in soils (Johnsson, 1991; Gu-

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stafsson and Johnsson, 1992, 1994; Falk Øgaard *et al.*, 2006).

Greenhouse vegetable cultivation (GVC) is a special agriculture system that has attracted increased public attention due to its role in the supply of vegetables as well as environmental deterioration problems resulting from intensive management practices (Chen *et al.*, 2004; Ju *et al.*, 2006, 2007; Xu *et al.*, 2007; Shi *et al.*, 2009; Liang *et al.*, 2013). To obtain higher economic profits from extra yields, farmers use large amounts of fertilizers and grow two or more crops each year (Zhu *et al.*, 2005). Direct results of these practices include the intensive accumulation of macronutrients. For instance, soil Olsen-P and available K (A-K) contents in greenhouses could be up to 5.7 and 2.9 times higher than those in open fields (Xu *et al.*, 2007; Cao *et al.*, 2012). Significant increases in soil OM were also observed in GVC due to high organic fertilizer application rates (Ju *et al.*, 2007; Qiu *et al.*, 2010). Changes in soil properties may also affect the availability and uptake of other nutrients (Gustafsson and Johnsson, 1992, 1994; Bañuelos and Ajwa, 1999).

Most of the studies on factors that affect Se availability in soils have been conducted under specific laboratory conditions, with only particular factors considered. There is little information on soil Se availability under intensive greenhouse cultivation conditions and studies on vegetable nutritional balance are needed as it relates to human health. In this study, the objective was to reveal the factors that affect soil Se availability under intensively cultivated conditions and provide basic information for further soil Se regulation in agriculture system.

## MATERIALS AND METHODS

### *Study sites*

This research was conducted at two typical GVC bases: one was in Nanjing, Jiangsu Province in southern China, and the other in Shouguang, Shandong Province in northern China. The bases represented two typical greenhouse types in southern and northern China, respectively. Soil type difference was also considered when selecting the study sites. Soils at the Nanjing base were generally Stagnic Anthrosols developed from clayey Quaternary loess (Gong *et al.*, 2003). Soils at the Shouguang base were generally Ustic Cambosols derived from loamy alluvium (Gong *et al.*, 2003). The soils were acidic to neutral at the Nanjing base, and alkaline at the Shouguang base. Both of the bases are under typical monsoon climate, with average annual temperatures of 15.4 and 12.4 °C, and annual precipitation of 1 100 and 593.8 mm for the Nanjing and Shouguang bases, respectively.

The Nanjing base is located near the perimeter of Nanjing City, and is a major vegetable supplier for Nanjing City. This area has a long-term history of rice cultivation. However, in the most recent decade, greenhouses have began to flourish, and are mainly distributed in the east and northwest parts due to convenient traffic patterns and access to irrigation water (Fig. 1). In 2006, the base was constructed and operated as cooperative. As time progressed, the GVC area was further expanded. Hence, greenhouses distributed in the east and northwest parts have been under cultivation for longer periods of time and under higher cultivation intensities than the greenhouses in other parts of the Nanjing base. The Shouguang base is a well-known GVC base in China, operated as a small-family business. Vegetable greenhouses in the base feature different cultivation durations due to continuing expansion, some of which have gone on for more than 20 years. Farmers at the Shouguang base are local people, so they know the greenhouse cultivation durations precisely.

### *Household survey*

A household survey was conducted to investigate fertilizer management practices at the two GVC bases. Large amounts of fertilizers were applied to increase vegetable output at both of the bases. The application rates of compound fertilizers, such as N-$P_2O_5$-$K_2O$ (15-15-15) could be up to 3–4 t $ha^{-1}$ $year^{-1}$. Potassium sulphate fertilizer was also used in some greenhouses to supply potassium. Higher rates of fermented chicken manure and other organic fertilizers were used at the Shouguang base (446 and 62 t $ha^{-1}$ $year^{-1}$) compared with the Nanjing base (15 and 4 t $ha^{-1}$ $year^{-1}$) (Yang *et al.*, 2013).

### *Soil sampling*

In order to evaluate the effect of cultivation intensity on soil Se availability, a series of topsoil samples were collected at the Nanjing and Shouguang bases in the fall of 2011 and the spring of 2012, respectively, based on cultivation duration information supplied by local farmers. At the Shouguang base, farmers are mostly local people, so the cultivation duration information was supplied precisely. At the Nanjing base, however, farmers are mostly from other provinces; thus, greenhouse cultivation duration information was not precisely available. As such, the cultivation intensity was based on both the cultivation duration information supplied by the farmers and the macronutrient