Seasonal changes in soil acidity and related properties in ginseng artificial bed soils under a plastic shade

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Abstract

Background: In Changbai Mountains, Panax ginseng (ginseng) was cultivated in a mixture of the humus and albic horizons of albic luvisol in a raised garden with plastic shade. This study aimed to evaluate the impact of ginseng planting on soil characteristics.

Methods: The mixed-bed soils were seasonally collected at intervals of 0–5 cm, 5–10 cm, and 10–15 cm for different-aged ginsengs. Soil physico-chemical characteristics were studied using general methods. Aluminum was extracted from the soil solids with NH₄Cl (exchangeable Al) and Na-pyrophosphate (organic Al) and was measured with an atomic absorption spectrophotometer.

Results: A remarkable decrease in the pH, concentrations of exchangeable calcium, NH₄⁺, total organic carbon (TOC), and organic Al, as well as a pronounced increase in the bulk density were observed in the different-aged ginseng soils from one spring to the next. The decrease in pH in the ginseng soils was positively correlated with the NH₄⁺ (r = 0.463, p < 0.01), exchangeable calcium (r = 0.325, p < 0.01) and TOC (r = 0.292, p < 0.05) concentrations. The NO₃ showed remarkable surface accumulation (0–5 cm) in the summer and even more in the autumn but declined considerably the next spring. The exchangeable Al fluctuated from 0.10 mg g⁻¹ to 0.50 mg g⁻¹ for dry soils, which was positively correlated with the NO₃ (r = 0.401, p < 0.01) and negatively correlated with the TOC (r = −0.329, p < 0.05). The Al saturation varied from 10% to 41% and was higher in the summer and autumn, especially in the 0–5 cm and 5–10 cm layers.

Conclusion: Taken together, our study revealed a seasonal shift in soil characteristics in ginseng beds with plastic shade.

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1. Introduction

Panax ginseng Meyer (ginseng, Araliaceae) is a perennial herb cultivated for its highly valued root. Ginseng prefers a cool and temperate climate and is widely planted in the mountainous region of Northeast China. Its cultivation is difficult because of its long cultivation period and its demand for deep shade and nutrient-rich, slightly acidic, deep, and well-drained soils. Replantation in old fields usually fails, and it takes up to 30 yrs for previously cultivated fields to recover. The following factors may contribute to the problem: deteriorated soil conditions [1–5]; plant diseases (soil sickness) [6]; and autotoxicity [7]. This study primarily focuses on soil conditions.

The Changbai Mountains are famous for ginseng production, with their fertile soils with good water permeability and aeration. People have collected wild ginseng here for 17 centuries and have been planting ginseng by simulating natural conditions since the Yuan dynasty. Today, the ginseng supply relies mainly on intensive field cultivation under artificial-shade structures. Floating plastic mulch is positioned above the ginseng bed, except during the winter, to create shade, enhance photoselectivity, and defend against strong rain. The semi-protective cultivation mode has the potential to affect the bed soil conditions.

Albic luvisol is one of the main soil types used for ginseng cultivation in the Changbai Mountains, which is derived from loess and characterized by high clay and organic-matter content. After
the land was cleared, a binary mixture of the humus and albic horizons (generally 1:1) was created in an elevated bed [8]. Ginseng bed soils from albic luvisols have been shown in our research, as well as others', to be acidic [4,9]. Soil pH has a large influence on ginseng growth and development. Producing American ginseng (Panax quinquefolius L) at a pH of 5.5 doubled its yield when compared with a pH of 4.4 [10]. A low pH, low calcium (Ca), and high exchangeable aluminum (Al) reportedly led to the development of red skin and rusty roots in ginseng [11]. Impacts related to soil acidity, such as Al toxicity, might contribute to ginseng replant disease in albic ginseng garden soils. Systematic and comprehensive investigation is necessary to understand the development of acidity and related characteristics in ginseng planting soils. In this study, the soil conditions were investigated seasonally at a ginseng farm located in the Changbai Mountains in Northeast China.

2. Materials and methods

2.1. Description of sites and mode of ginseng cultivation

The study was carried out in a field (41°32’N, 128°09’E) on the first ginseng farm in Malugou County, Jilin province, China. It is located on the lava plateau of the Changbai Mountains. Different-aged ginseng seedlings are grown here. This area is characterized

Fig. 1. The seasonal variation of major cations in different aged ginseng bed soils. Soil were collected from beds with different-aged ginseng at depths of 0–5 cm (upper roots), 5–10 cm (root zone), and 10–15 cm (down root) in April (spring), July (summer), September (autumn), and the next April (the next spring). The exchangeable Na⁺ (A, B, C, D, and E), exchangeable K⁺ (F, G, H, I, and J), exchangeable Ca²⁺ (K, L, M, N, and O) and exchangeable Mg²⁺ (P, Q, R, S, and T) were measured. Data are means ± standard deviation (n = 3).
by a mountainous climate with a dry and windy spring, rainy summer, cool and foggy autumn, and cold and long winter. The mean annual temperature varies between 3.3 °C and 7.3 °C, with a mean summer temperature ranging from 8.7 °C to 19.3 °C and a mean winter temperature ranging from −23.3 °C to −16.1 °C. The annual solar radiation is 124 MJ m⁻². The annual mean precipitation is over 1,400 mm, which is the highest in North-Eastern China [12,13].

A mixed hardwood forest was located in this area prior to ginseng cultivation. Albic luvisols were developed from the parent material of loess. After deforestation, a binary mixture of the humus and albic horizons (generally 1:1) was used to create an elevated bed for growing ginseng. Prior to seed sowing and/or seedling transplantation in the spring, the soils were fertilized with composted manure. The bed width was approximately 170 m and was separated by 40-cm walkways. Local farmers constructed artificial plastic shades approximately 80 cm above the ginseng bed. The plastic covers were used from May through to September. Ginseng is a tender perennial. The first frost kills the leafy top, but a new top emerges the following spring from an underground bud on the

Fig. 2. Seasonal variations in NH₄⁺, NO₃⁻, water content and bulk density of different aged ginseng bed soils. Soil were collected from beds with different-aged ginseng at depths of 0–5 cm (upper roots), 5–10 cm (root zone), and 10–15 cm (down root) in April (spring), July (summer), September (autumn), and the next April (the next spring). The concentration of NH₄⁺ (A, B, C, D, and E), NO₃⁻ (F, G, H, I, and J), and water content (K, L, M, N, and O) were measured. The bulk density was measured from a soil samples taken from a nearby site (P, Q, R, S and T). Data are means ± standard deviation (n = 3).
perennial root. It takes 5 yrs or 6 yrs of ginseng cultivation to grow into a mature product. Ginseng was planted on the same land for 3 yrs, then the root tissues were replanted into the newly-mixed bed soils for another 2 yrs or 3 yrs prior to harvest.

2.2. Soil sampling procedures

Soil samples were collected from beds with different-aged ginseng plants in April (spring) of 2009 before the plastic shades were put into place. A 0.01 m² area was plotted, and the ginseng was carefully removed. The soil was sampled at 0–5 cm (upper roots), 5–10 cm (root zone), and 10–15 cm (down root) in April (spring), July (summer), September (autumn), and the next April (the next spring). The pH level (A, B, C, D, and E), exchangeable Al³⁺ (F, G, H, I, and J), total organic carbon (K, L, M, N, and O) and Na-pyrophosphate extractable Al (P, Q, R, S, and T) were measured. Data are means ± standard deviation (n = 3).

Fig. 3. Seasonal variation in pH, exchangeable Al total organic carbon and organic Al soils from in different aged ginseng bed. Soil were collected from beds with different-aged ginseng at depths of 0–5 cm (upper roots), 5–10 cm (root zone), and 10–15 cm (down root) in April (spring), July (summer), September (autumn), and the next April (the next spring). The pH level (A, B, C, D, and E), exchangeable Al³⁺ (F, G, H, I, and J), total organic carbon (K, L, M, N, and O) and Na-pyrophosphate extractable Al (P, Q, R, S, and T) were measured. Data are means ± standard deviation (n = 3).
determine nitrate content. The remainder were air-dried and sieved through a 2-mm screen for laboratory analysis. Winter sampling was not conducted because of the difficulty of sampling frozen soils.

2.3. Analysis of soil properties

The bulk density and moisture content of the soil was determined using general methods in the laboratory. The pH in water (w/v, 1:2.5) was measured with a pH meter (PHS-3C; Shanghai Precision Scientific Instrument Co., Ltd., Shanghai, China). The total organic carbon (TOC) was determined using a dry-combustion method. The soil nitrate was extracted using a 1M KCl solution and was analyzed using dual-wavelength UV spectrophotometry (Shimadzu UV-2450; Shimadzu Corporation, Kyoto, Japan) according to Norman et al [14]. Exchangeable cations were extracted with a 1M NH₄Cl (Soil: extractant, 1:50) solution and were determined by atomic absorption (Ca, Mg, and Al) and flame photometer (FP640; Shanghai Jingxue Scientific Instrument Co, Shanghai, China) (Na and K). The effective cation exchange capacity was calculated as a molar ratio of exchangeable Al (Ex-Al³⁺) to the sum of exchangeable Ca (Ex-Ca²⁺), exchangeable Mg²⁺, exchangeable sodium (Ex-Na⁺), Ex-K⁺, and Ex-Al³⁺ [15]. The Al saturation was calculated as Al/effective cation exchange capacity. The soils were also extracted using 0.1M Na-pyrophosphate (pH 10.0; soil ratio: extractant: 1:100, with shaking for 16 h) for organic Al (Al₃p) [16]. The Al in the extract solution was measured in duplicates using an atomic absorption spectrophotometry equipped with graphite furnace atomizer (PerkiElmer Analyst 700; PerkinElmer Inc., Norwalk, CT, USA).

The data were statistically evaluated using the Data Processing System 11.0 edition for Windows [17] (Zhejiang University, Hangzhou, China). Data are presented as the mean ± standard deviation. Analysis of correlation was performed with three replicates.

3. Results

3.1. Seasonal changes in major cations

Some studies have indicated that unbalanced cations and nutrition disorders have contributed to a decline in ginseng garden soil conditions [1,18]. A measurement of the major cations was carried out seasonally. Both concentrations of Ex-Na⁺ and Ex-K⁺ stayed relatively constant without obvious spatial variation during 2009; however, they sharply increased in the 0–5 cm depth in the spring of 2010 (Fig. 1A–J). The exception was the decrease in both the Ex-Na⁺ and Ex-K⁺ in transplanted 1-yr-old ginseng soils in the spring, which might be driven by individual factors.

The Ex-Ca²⁺ concentration showed a decrease within a 1-yr cycle of investigation (Fig. 1K–O). For transplanted 1-yr-old ginseng soils particularly, the Ex-Ca²⁺ concentration sharply decreased in the three depths after the spring of 2009 (Fig. 1N). Although the Ex-Ca²⁺ concentrations in the transplanted 2-yr-old ginseng soil were constant, a value of approximately 0.4 was the lowest of the detected Ex-Ca²⁺ concentration data (Fig. 10).

The exchangeable Mg²⁺ concentrations were kept relatively constant at the three soil depths for the different aged ginsengs within a 1-yr cycle (Fig. 1P–T).

3.2. Seasonal changes in concentrations of NH₄⁺ and NO₃⁻, soil moisture and bulk density

The NH₄⁺ concentrations showed sharp decreases at all three depths from the spring of 2009 (Fig. 2A–E). The decrease was more remarkable in the summer and autumn. There were two obvious exceptions: the increase of NH₄⁺ in the 0–5 cm layer for the 1- and 3-yr-old ginseng soils during the next spring (Fig. 2A,C), which might have been driven by individual factors.

The surface (0–5 cm) NO₃⁻ concentration exhibited a remarkable increase in the summer and autumn, and then sharply decreased to the original level by the next spring (Fig. 2F–L). The NO₃⁻ concentrations in the 0–5 cm layer peaked in the autumn and were over 10-fold greater than those in the spring (Fig. 2F–I). In the transplanted 2-yr-old ginseng soils, the NO₃⁻ concentration reached 826.26 mg kg⁻¹ of dry soil in the autumn of 2009 (Fig. 2I). The NO₃⁻ concentrations at the 5–10 cm and 10–15 cm depths exhibited minor variations between seasons. Different yr-old ginseng exhibited similar seasonal trends for NO₃⁻ concentrations.

The soil moisture at the 10–15 cm depth remained constant; however, in the 0–5 cm and 5–10 cm depths it decreased in summer and autumn and increased the following spring for all of the ginseng bed soils (Fig. 2K–O). Soil bulk density was always < 1 g cm⁻³ and increased by 30–40% during a 1-yr cycle for the different aged ginseng fields (Fig. 2P–T). Although the soil bulk density in the 3-yr-old ginseng beds was kept relatively constant, a value of approximately 0.85 g cm⁻³ was higher than all of the other data, consistent with the proposal that ginseng planting resulted in soil compaction and loss of air and water.

3.3. Seasonal changes in the pH, Ex-Al³⁺, TOC, and Al₃p contents

Soil pH fluctuated from 3.8 to 5.2 throughout the three depths and tended to decrease within seasons in the different aged ginseng beds (Fig. 3A–E). Correlation analysis showed a soil pH that was significantly correlated with concentrations of NH₄⁺ (r = 0.465, p < 0.01, n = 60) and Ex-Ca²⁺ (r = 0.325, p < 0.01, n = 60).

The Ex-Al³⁺ concentrations fluctuated from 0.10 mg g⁻¹ to 0.50 mg g⁻¹ for dry soils and showed significant correlation with NO₃⁻ (r = 0.401, n = 60, p < 0.01). The Ex-Al³⁺ concentrations increased in the summer and further increased in the autumn; then, there was a decrease in the different aged ginseng beds the following spring (Fig. 3F–I). The Ex-Al³⁺ concentrations at the three depths of the ginseng bed planted 2 yrs previously were higher compared to those in the same depths of the different-aged ginseng bed (Fig. 3L).

The ginseng bed soils contained higher TOC concentrations that fluctuated from 50.1 mg kg⁻¹ to 94.8 mg kg⁻¹ of dry soil (Fig. 3K–O), which was positively correlated with the pH (r = 0.293, p < 0.05, n = 60) and negatively correlated with the Ex-Al³⁺ (r = −0.329, n = 60, p < 0.05) content. The TOC concentrations had no obvious spatial variation, tended to decrease within a 1-yr cycle and reached their lowest levels in the 3-yr-old and transplanted 2-yr-ginseng bed (Fig. 3M,O). This was consistent with the view that ginseng growth will decrease the organic matter content of bed soils [1].

Al that is extracted with Na-pyrophosphate (Al₃p) is used as a proxy for Al in organic complexes. The Al₃p tended to decrease within a 1-yr cycle and was positively correlated with TOC concentrations (r = 0.425, p < 0.01, n = 60), NH₄⁺ concentrations (r = 0.34, p < 0.01, n = 60) and pH (r = 0.370, p < 0.01, n = 60; Fig. 3P–T). For the transplanted 2-yr-old ginseng beds, the Al₃p was constant, but the values were the lowest of all the soil samples (Fig. 3T).

The Al saturation was calculated in the present study as an indicator of soil acidification and Al toxicity levels (Table 1). The Al saturation fluctuated from 10% to 41% in the different aged ginseng beds. In the spring, the Al saturations tended to increase with the deepening layers. The Al saturations at 0–5 cm and 5–10 cm depths increased obviously in the summer and autumn. The highest Al saturation of all the beds at three depths was found in the transplanted 2-yr-old ginseng beds.
capillary action (Fig. 2K).

In the summer and autumn, the potential difference in the amount of capillary water resulted in NO$_3^-$ surface accumulation and the melted snow resulted in NO$_3^-$ leaching (Fig. 2F–J).

Most of the proton-generating processes are associated with the cultivation-induced changes in organic-matter cycles, typically the loss of organic matter from the soil owing to the increased organic-matter decomposition and product removal. In this study, the ginseng planting obviously reduced the TOC concentrations of ginseng soils, which is positively correlated with the pH ($r = 0.293$, $p < 0.05$, $n = 60$). The decrease in the TOC is one of the causes of the decreased pH.

Base cations were investigated seasonally (Fig. 1A–T). Ginseng planting had negligible effects on the concentrations of Ex-Na$^+$, Ex-K$^+$, and exchangeable Mg$^{2+}$. The elevated concentrations of Ex-Na$^+$ and Ex-K$^+$ in the next spring may have been derived from the release of exchangeable metal ions bound to strong cation-exchange sites on the surface of soil minerals left by frost. There was, however, a remarkable decrease in the concentration of Ex-Ca$^{2+}$ (Fig. 1A–T). Considering the vegetation age and temporal variation, we propose that ginseng might require more Ca to grow. Konsler and Shelton [10] found that ginseng plants took up Ca more readily in soils. Ca deficiencies can be seen in stunted ginseng that lack general vigor and have smaller and more fragile growth buds [21]. Soil Ca can also be proposed as a key element in the success of American ginseng crops in forest soils [22]. Wild populations of American ginseng in the United States are found in a wide range of soil pHs but always in Ca-rich soils [23]. Beyfuss even found that healthy populations of wild ginseng grew in soil conditions with very low pH and very high levels of Ca [24], which is abnormal in mineral soils. In this study, the decrease in Ex-Ca$^{2+}$ in the bed soils added new evidence that Asian ginseng needs more Ca to grow and that Ca is the key factor for successfully planting Asian ginseng. Furthermore, the Ex-Ca$^{2+}$ concentrations positively correlated with the pH ($r = 0.325$, $p < 0.01$, $n = 60$) within the ginseng bed. The decrease in Ex-Ca$^{2+}$ concentrations might be one of the factors resulting in pH decreases in bed soils (Fig. 1F–J, 3A–E).

It is well known that the soil pH has a large influence on ginseng growth and development [10,11]. Red skin indices of ginseng were reported to agree well with the Al$^{3+}$–H$^+$, Al$^{3+}$ levels [11]. In acidic soils, most plants become stressed as a result of a toxic concentration of Al$^{3+}$ [25]. Both low Ca and high Al concentrations were measured in the soils of American ginseng fields, and Ca deficiency and Al toxicity were proposed to have resulted in the higher susceptibility of American ginseng to abiotic and biotic stresses [22].

A risk assessment for Al toxicity in forests has also been based on different methods using soil- and/or plant-based indices [26]. In this study, the Al toxicity evaluation focused on the Ex-Al$^{3+}$ and the Al saturation, based on dry soils. The Ex-Al$^{3+}$ concentrations fluctuated from 100 mg/kg to 500 mg/kg, which increased in the summer, further increased in the autumn, and decreased the next spring (Fig. 3F–J). The Ex-Al$^{3+}$ was positively correlated with NO$_3^-$ ($r = 0.401$, $p < 0.01$, $n = 60$) and negatively correlated with TOC ($r = -0.329$, $p < 0.05$, $n = 60$). Umemura et al. [27] also showed that there were remarkable increases in NO$_3^-$ and Al$^{3+}$ contents in the summer season in the soil solution of a Japanese cedar forest. Ohte et al. [28] also reported that the seasonal NO$_3^-$ variation was in agreement with that of the free Al. NO$_3^-$ might be the most important factor in solubilizing Al in this study.

Al$_p$ was used as a proxy for Al in organic complexes, which tended to decrease from one spring to the next (Fig. 3P–T). Al$_p$ in bed soils corresponds well with the TOC concentrations ($r = 0.425$, $p < 0.01$, $n = 60$; Fig. 3P–T). The stabilizing effect of soil organic matter on Al appears to be a complication of Al in the soil solution and subsequent precipitation of insoluble Al–organic-matter complexes, which suppress microbial enzyme activity and substrate-degradation rates [29]. A positive impact of organic

### Table 1

The seasonal variations of Al saturations (%) in different aged ginseng bed soils

| Ginseng age | Depth (cm) | April | July | September | Next April |
|-------------|------------|-------|------|-----------|------------|
| 1 yr old    | 0–5        | 13.6±2.1 | 20.1±2.5 | 20.0±0.6 | 9.5±0.2    |
|             | 5–10       | 16.8±2.0 | 18.8±3.1 | 20.6±1.1 | 16.9±1.4  |
|             | 10–15      | 20.2±0.8 | 17.3±6.7 | 20.6±0.1 | 18.0±5.3  |
| 2 yrs old   | 0–5        | 16.2±1.7 | 21.9±1.2 | 26.2±2.9 | 11.6±3.3  |
|             | 5–10       | 24.7±0.8 | 27.4±2.4 | 36.3±1.2 | 19.7±2.1  |
|             | 10–15      | 26.8±1.7 | 25.8±2.3 | 27.0±1.0 | 23.5±3.0  |
| 3 yrs old   | 0–5        | 18.7±0.7 | 25.4±0.8 | 27.1±0.7 | 10.5±0.4  |
|             | 5–10       | 23.6±3.9 | 32.2±1.3 | 25.3±1.7 | 14.9±1.4  |
|             | 10–15      | 29.4±3.6 | 20.7±2.4 | 22.8±0.9 | 18.7±3.1  |
| Transplant, | 0–5        | 18.7±0.7 | 32.3±2.9 | 22.2±2.0 | 19.3±2.6  |
| 1 yr old    | 5–10       | 20.5±0.2 | 29.4±3.4 | 29.6±0.5 | 26.6±2.1  |
|             | 10–15      | 22.6±8.3 | 32.0±2.2 | 30.1±1.2 | 30.2±1.4  |
| Transplant, | 0–5        | 29.5±0.8 | 40.6±3.7 | 38.3±2.1 | 24.2±1.3  |
| 2 yrs old   | 5–10       | 38.2±3.8 | 38.9±1.3 | 38.9±1.6 | 29.3±2.3  |
|             | 10–15      | 40.5±0.9 | 40.8±1.6 | 40.1±0.9 | 35.9±2.6  |
fertilization on American ginseng survival and growth has also been noted [30]. The decrease in the TOC concentrations in garden soils might prompt the transformation of Alp into inorganic Al, such as Ex-Al$^{3+}$(Fig. 3P).

Accordingly, the dissolution of Ex-Al$^{3+}$ might have resulted from the following factors: (1) the pH has important implications with regards to the geochemical behavior of Al because the Al dynamics might be strongly affected by seasonality via hydrological processes; (2) NO$_3^-$ was the main anion of the Al$^{3+}$ counterions and seasonal nitrate variation played a major role in controlling the dissolution of Al into the soil solution; and (3) the decrease in soil organic carbon also decreased the concentrations of organic Alp, which were transformed into Ex-Al$^{3+}$.

Al saturation in soils is widely used to assess the risk of Al toxicity. In this study, there was considerable variation in Al saturations, which fluctuated from 10% to 41% (Table 1). The transplanted 2-yr-old ginseng beds had the highest Al saturation. The Al saturation of most soil samples in the summer and autumn was > 20% (Table 1), which was considered to be the maximum amount acceptable for the development of species sensitive to Al [31]. Al toxicity might be one of the important factors in limiting ginseng growth in the bed under a plastic cover.

**5. Conclusion**

A 1-yr field investigation was conducted at a ginseng farm growing different aged ginseng plants in the Changbai Mountains of China. A model was proposed to describe the process of soil acidiﬁcation and Ex-Al$^{3+}$ dissolution (Fig. 4). The over-uptake of exchangeable Ca$^{2+}$ and NH$_4^+$ by ginseng roots and the nitrification process will release a large amount of protons, resulting in a decreased pH. A plastic canopy reduced nutrient leaching and resulted in upward water capillary domination, which promoted NO$_3^-$ surface accumulation. Ginseng planting decreased the TOC concentrations and, subsequently, the Alp concentrations. The increase in the exchangeable Al (Ex-Al$^{3+}$) in the summer and autumn might result from a decreased pH, NO$_3^-$ surface accumulation, and the transformation of Alp to Ex-Al$^{3+}$.

**Conflicts of interest**

All authors declare no conflicts of interest.

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