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# Changes over the Years in Soil Chemical Properties Associated with the Cultivation of Ginseng (*Panax ginseng* Meyer) on Andosol Soil

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**Abstract:** The sowing-to-harvest period for the medicinal plant Ginseng (*Panax ginseng* Meyer) is 4–6 years. Although one of the primary soils used to cultivate ginseng in Japan is Andosol, there have been few studies of the changes in the soil's chemical properties during the cultivation of ginseng in Andosol soil. Here, we investigated the chemical properties of Andosol soil by collecting soil samples from cultivation sites with various numbers of years of ginseng cultivation. A significant negative correlation was observed between the years of cultivation and the soil's pH, indicating that soil acidification increased with an increasing number of years of cultivation. Similarly, exchangeable calcium (Ca) showed a significant negative correlation with the years of cultivation. The soluble aluminum (Al) concentration showed a significant positive correlation with the years of cultivation and was significantly negatively correlated with the exchangeable Ca and magnesium (Mg) contents. These results suggest that a decrease in pH due to Ca absorption by ginseng, increasing Al dissolution, and a further accelerated decrease in pH occur during the cultivation of ginseng in Andosols. The increase in soluble Al with increasing years of cultivation also affected the dynamics of essential trace elements in the soil, showing significant negative correlations with the soil's soluble copper (Cu) and zinc (Zn) contents, indicating that the Cu and Zn contents decreased with increasing Al. Our findings indicate that in the cultivation of ginseng on Andosol soil, the soil's soluble Al content is an essential factor in changes in the soil's chemical properties.

**Keywords:** andosol; calcium; copper; exchangeable cation; ginseng; magnesium; medical plants; Mehlich-3 extraction method; soluble aluminum; zinc

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## 1. Introduction

The root of ginseng (*Panax ginseng* Meyer) has medicinal benefits including nourishing and tonic effects and the promotion of blood circulation, and ginseng root has thus been prized as a staple of Chinese medicine since ancient times [1,2]. The ginseng plants growing wild on Baekdu Mountain on the Korean Peninsula and those in northeastern China and Russia's Primorsky Territory are extremely valuable and have been traded for more than the same weight of gold [3]. However, most of the native ginseng plants are now extinct due to overexploitation, and the cultivation of ginseng has thus been promoted in the Korean peninsula from the 17th century to compensate for this [4].

Ginseng is a perennial herb of the Araliaceae family that thrives in a semi-shady habitat [5]. It does not like direct sunlight, and it was initially cultivated in forests and then shifted to so-called forest sun-covering cultivation, where it is cultivated under a sun-cover [6]. The mass production of ginseng was eventually required for its commercialization, and sun-covered cultivation in fields was then devised. However, forest sun-cover cultivation of ginseng remains common in China and the United States [7–9].

Although the first record of ginseng being introduced to Japan describes ginseng being brought from Korea in the first half of the 8th century, the use of ginseng did not spread to the general population for many years as it was considered a valuable drug [10]. In the 17th century, to improve the administration of medicine, the shogunate made a series of prototypes with the aim of domestic production and later distributed the multiplied seeds to feudal lords to encourage the cultivation of ginseng throughout the country. During the Edo period in Japan (ca. 1603–1867), ginseng was cultivated by more than 20 clans, enriching the finances of each clan; after the Meiji Restoration (1868–1889), due to the influx of Western medicine and changes in social conditions, ginseng cultivation is now continued in only three prefectures: Nagano, Fukushima, and Shimane [10–12].

The basic method used to cultivate ginseng in Japan is to sow in December or in March of the following year, raise the seedlings for 1 or 2 years after germination, and transplant the 1st- or 2nd-year plants to the main field. Generally, flowering occurs after the 3rd or 4th year, and the cultivation system is based on harvesting the 6th-year plants in autumn, making it a crop that takes six years from sowing to harvest [12]. Harvested ginseng is processed for use in Chinese medicine [13]. The root of the ginseng plant contains 30–60 g $kg^{-1}$ of the medicinal constituent saponin glycosides and approx. 50 mg $kg^{-1}$ of essential oil. Ginseng saponin glycosides are classified into ginsenoside Rb and Rg groups, with the Rb group exerting a sedative effect and the Rg group showing an aggravating effect [13,14]. Ginsenosides have attracted attention as a pharmacological ingredient and as a functional ingredient for health promotion, and the demand for ginsenosides as supplements and functional foodstuffs is increasing [3,15]. In Japan each year, 600 tons of ginsenosides are imported from China, but only 15 tons are produced domestically, and it is expected that improved production in Japan will meet the increased demand [12].

As ginseng has a long cultivation period of 4–6 years, understanding the dynamics of soil nutrients during the cultivation period is critical for improving productivity [16,17]. It was reported that ginseng has been cultivated on Luvisols, brown forest soil, peat soil, red soil, and grey lowland soil in Northeast China, the Korean Peninsula, and from the northern U.S. to Canada [4,13,18,19]. In Japan, although ginseng is cultivated in Nagano and Fukushima Prefectures on various types of soil, including brown forest soil, reddish-yellow soil, and grey lowland soil [11,12,20], it is also often grown on volcanic ash soil (Andosol).

In Shimane Prefecture, ginseng is cultivated only on a 12 km circumference island called Daikonjima (Daikon Island), the surface of which is covered with volcanic ash soil (Andosol) [10,21]. Unlike the circumstances on the Korean Peninsula, in China, the U.S., and Canada, Andosol is one of the main soils for ginseng cultivation in Japan [20]. There have been few studies of changes in soil chemical properties over time when ginseng is cultivated on Andosol. We conducted the present study to investigate the dynamics of soluble elements over time in soil on Daikonjima from the 1st to the 6th year of ginseng cultivation. Experiments were also conducted to clarify the dynamics of soluble elements and the inorganic content of ginseng root with the increase in the number of years of ginseng cultivation (1st–6th year) on Daikonjima to identify the characteristics and problems of ginseng cultivation on Andosol and the element absorption characteristics.

## 2. Materials and Methods

### 2.1. Study Sites and Sampling

The study area for the cultivation of ginseng on Andosol soil was Daikonjima, Yatsuka-cho, Matsue City, Shimane Prefecture, Japan (35°5′ N, 133°2′ E, 4 masl). The normal climatic data for this area is 15.2 °C for the mean annual temperature, 19.7 °C for the mean daily maximum temperature, 11.7 °C for the mean daily minimum temperature, 1705 h of sunshine per year, 12.9 $MJm^{-2}$ of total solar radiation, and 1792 mm of precipitation per year. Daikonjima is a volcanic island with a 12 km circumference; the last eruption occurred ~120,000 years ago, and the surface of the island is covered with a 30–60 cm layer of non-allophenic Andosol [21]. Ginseng cultivation was initiated on the island in the mid-18th century and has continued for ~250 years to the present day, although the area planted has decreased in recent years [10].

We selected cultivation sites A–H in 2016 and 2018, where 1st- to 6th-year ginseng plants were cultivated (Figure 1). Sites A and F were surveyed in 2016, and sites B, C, D, E, G, and H were surveyed in 2018. Site A was planted with 2nd-year plants, site B with 3rd- and 4th-year plants, site C with 5th- and 6th-year plants, site D with 1st- and 2nd-year plants, site E with 3rd-, 4th-, 5th- and 6th-year plants, site F with 1st- to 6th-year plants, site G with 4th-year plants and site H with 6th-year plants. Roots and root zone soils were sampled at the time of harvest at sites A–F in late October in both 2016 and 2018. Only root zone soils were sampled at sites G and H as harvesting had already been completed. The sampling took three plots from each hut row (Figure 2) and composited them to comprise a sub-sample, with three huts sampled for each year of the study at each site.

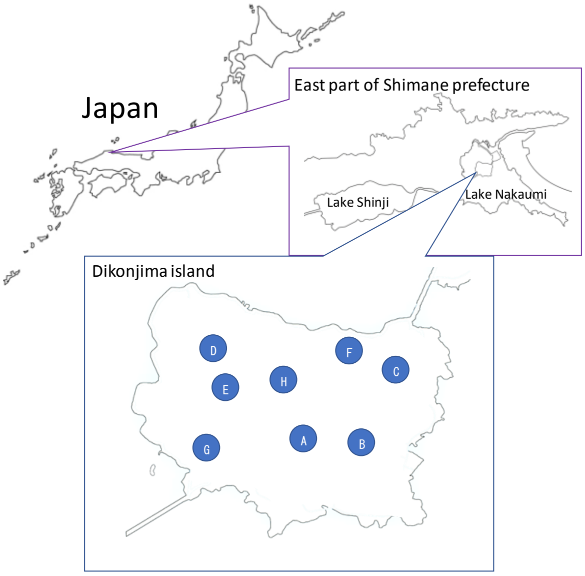

**Figure 1.** Study sites and location of sampling farms.

**Figure 2.** Covered hut for the cultivation of ginseng made of chestnut posts and a wheat straw roof.

### *2.2. Soil Analyses*

For the chemical analyses, the soil samples were air-dried and passed through a 2 mm mesh sieve. The soil pH was measured in a 2.5:1 suspension of deionized water and soil using a pH meter (pH meter F-52, Horiba Advanced Techno, Kyoto, Japan). Similarly, the soil electrical conductivity (EC) was measured in a 5:1 suspension of deionized water and soil using an electrical conductometer (Cond meter DS-71, Horiba Advanced Techno). The

Mehlich-3 extraction method was used to extract available nutrients [22–24], allowing the simultaneous measurement of multiple elements. These extracts were diluted accordingly with 5% nitrate. The concentrations of elements in the extracts were determined by an inductively coupled plasma mass spectrometry (ICP-MS) system (Agilent 8800, Agilent, Hanover, Germany).

It has been shown that the calcium (Ca), magnesium (Mg), and potassium (K) extracted by the Mehlich-3 extraction method correspond to the exchangeable Ca, Mg, and K. The concentrations of phosphorus (P), manganese (Mn), zinc (Zn), iron (Fe), copper (Cu), and boron (B) extracted by the Mehlich-3 extraction method have been shown to correspond to the respective available forms. We therefore considered these elements available nutrients in the present study. Aluminum (Al) extracted by the Mehlich-3 extraction method corresponds to soluble Al and is therefore referred to as soluble Al.

### 2.3. Plant Analyses

The ginseng roots were measured for fresh weight and then dried in an oven at 70 °C. The dried samples were finely ground by a rapid pulverizer (Multi-beads Shocker MB3000, Yasui Kikai, Osaka, Japan) to make a powder sample. The powder sample (0.5 g) was decomposed in a circulating acid decomposition system (Ecopre Sample Digestion System, Aqtac, Tokyo) by adding a 5:1 mixture of nitrate and hydrogen peroxide [25]. The decomposed solution was diluted with 5% nitrate, and the concentration in the extracted solution was measured by ICP-MS with the Agilent 8800 system.

### 2.4. Statistical Analyses

Regression analyses were performed for the number of years of cultivation and available nutrients and soluble Al in the soil, and the significance of the correlations was tested using BellCurve for Excel (Social Survey Research Information Co., Ltd., Tokyo, Japan). The significance of differences showing a probability ($p$)-value $< 0.05$ or $< 0.10$ was examined.

## 3. Results

### 3.1. Changes over Cultivation Years in Fresh Root Weights and Mineral Concentrations in the Ginseng

The roots of the ginseng plants showed marked enlargement from the 3rd year, with a fresh root weight of approx. 33 g per plant in the 4th year, 63 g in the 5th year, and 90 g at harvest in the 6th year (Figure 3). The mineral concentrations in the roots from the 2nd to 6th year are shown in Table 1. No constant trend with the year of cultivation was observed for the major elements, which ranged from 15.3 to 20.9 g kg$^{-1}$ for K, 0.9–1.0 g kg$^{-1}$ for P, 2.1–3.0 g kg$^{-1}$ for Ca, and 1.4–1.9 g kg$^{-1}$ for Mg per dry matter. The trends of trace elements other than Zn were not constant throughout the number of growing years, with Fe ranging from 95.6 to 190.9 mg kg$^{-1}$, Mn from 37.1 to 45.9 mg kg$^{-1}$, Cu from 4.4 to 6.3 mg kg$^{-1}$, and B from 9.2 to 12.6 mg kg$^{-1}$. In contrast, Zn showed a tendency to decrease with the increase in the number of years of cultivation, with the highest value of 31.6 mg kg$^{-1}$ in the 2nd year, decreasing to 18.3 mg kg$^{-1}$ in the 6th year of harvest.

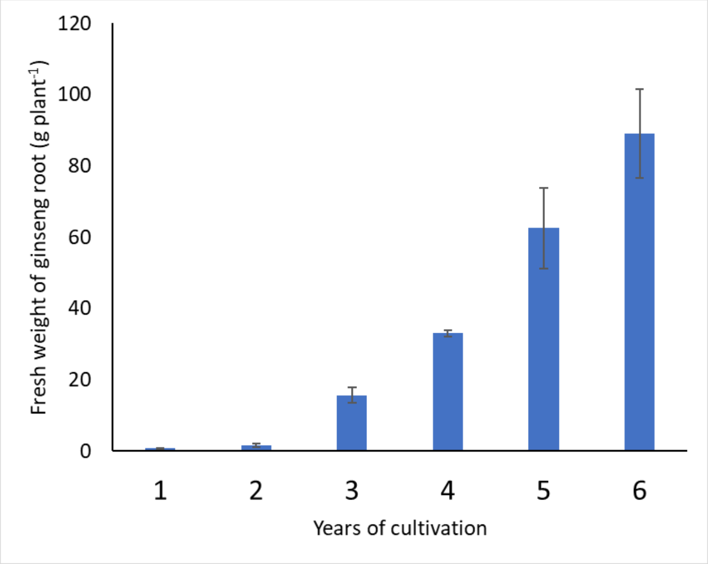

**Figure 3.** Changes over cultivation years in fresh weights of ginseng roots. Mean values ± standard errors (*n* = 3).

**Table 1.** Changes over cultivation years in mineral concentrations (dry-weight basis) in the ginseng roots.

| **Years of Cultivation** | **K (g kg$^{-1}$)** | **P (g kg$^{-1}$)** | **Ca (g kg$^{-1}$)** | **Mg (g kg$^{-1}$)** | **Fe (mg kg$^{-1}$)** | **Mn (mg kg$^{-1}$)** | **Zn (mg kg$^{-1}$)** | **Cu (mg kg$^{-1}$)** | **B (mg kg$^{-1}$)** |
|---|---|---|---|---|---|---|---|---|---|
| 2 | 20.9±1.3 | 1.0 ± 0.1 | 2.9 ± 0.2 | 1.9 ± 0.3 | 190.9 ± 57.1 | 47.2 ± 9.1 | 31.6 ± 8.4 | 5.6 ± 0.7 | 12.6 ± 1.0 |
| 3 | 16.1±2.7 | 1.0 ± 0.1 | 2.3 ± 0.3 | 1.3 ± 0.3 | 95.6 ± 69.0 | 37.1 ± 8.3 | 23.6 ± 8.7 | 5.5 ± 0.7 | 9.2 ± 0.1 |
| 4 | 15.3 ± 2.6 | 0.7 ± 0.1 | 2.1 ± 0.3 | 1.4 ± 0.1 | 109.3 ± 27.8 | 39.4 ± 7.4 | 19.7 ± 9.9 | 5.6 ± 0.5 | 9.8 ± 0.5 |
| 5 | 15.7 ± 2.0 | 1.0 ± 0.1 | 2.3 ± 0.2 | 1.5 ± 0.1 | 112.9 ± 17.1 | 41.0 ± 4.7 | 15.7 ± 5.6 | 4.4 ± 0.3 | 11.0 ± 0.2 |
| 6 | 18.9 ± 2.5 | 0.9 ± 0.2 | 3.0 ± 0.2 | 1.4 ± 0.1 | 141.6 ± 16.5 | 45.9 ± 4.9 | 18.3 ± 6.5 | 6.3 ± 0.2 | 11.6 ± 0.5 |

Mean values ± standard errors (*n* = 3).

### *3.2. Changes over Years in the Chemical Properties of the Soil under Cultivation of Ginseng*

The regression analysis of soil chemical properties with increasing years of ginseng cultivation revealed several interesting findings (Table 2). Among the soil chemical properties, the pH and the contents of Ca and Al were significantly correlated with the number of years of cultivation. Although the *p*-value for Cu (*p* = 0.068) was not significant at the 5% level, it indicates a significant correlation with the number of years of cultivation at the 10% level.

**Table 2.** Significance of the relationship between years of ginseng cultivation and soil chemical properties.

| | **pH** | **EC** | **P** | **K** | **Ca** | **Mg** | **Al** | **Fe** | **Mn** | **B** | **Zn** | **Cu** | **Ni** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *p* value | 0.010 | 0.505 | 0.545 | 0.810 | 0.034 | 0.089 | 0.015 | 0.432 | 0.751 | 0.662 | 0.189 | 0.068 | 0.650 |
| Significance | * | ns | ns | ns | * | + | * | ns | ns | ns | ns | + | ns |

+ Represents significance at the 0.10 probability level. * Represents significance at the 0.05 probability level.

Figure 4 depicts the changes in pH and EC with the years of cultivation. The pH of the 1st-year site soil was approx. 6.0 but tended to decrease with the increase in the number of years of cultivation, and a significant negative correlation was observed between the number of years of cultivation and the pH value. The EC values were low for the 1st and 2nd-year site soils and slightly higher from the 3rd year but tended to increase in variation from the 3rd year onwards. We speculate that this was due to the effect of fertilizer application, and no consistent trend with the number of cultivation years was observed.

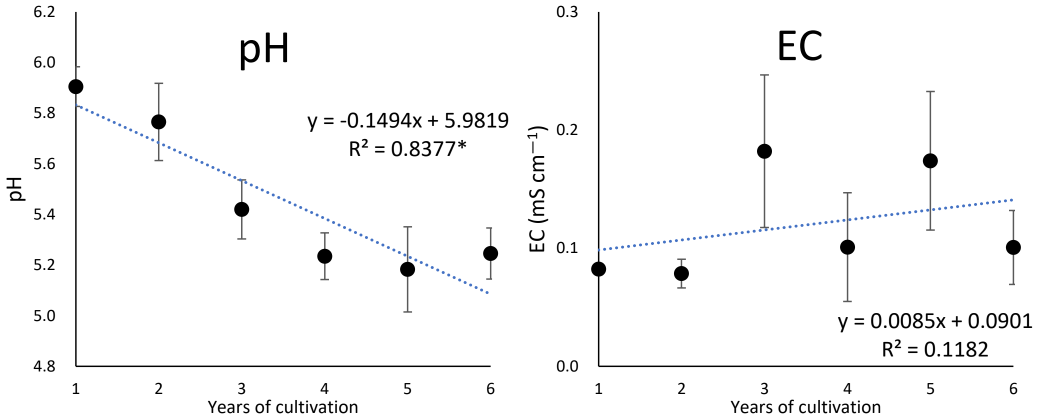

**Figure 4.** Relationships between years of ginseng cultivation and pH and EC in the soil. Mean values ± standard errors ($n = 3$). * Represents significance at the 0.05 probability level.

Figure 5 illustrates the annual variation of exchangeable cations and available phosphorus. There was no consistent trend in the variations of K and P with the years of cultivation. In contrast, Ca and Mg tended to decrease with the increase in the number of years of cultivation. There was a significant negative correlation between years of cultivation and the Ca and Mg contents, indicating that the content of Ca of the soils at the 6th year of cultivation decreased to <50% of that of the soils at the 1st year of cultivation. The content of Mg was also reduced by >30% in the soil of the 6th-year cultivation site compared to the soil of the 1st year.

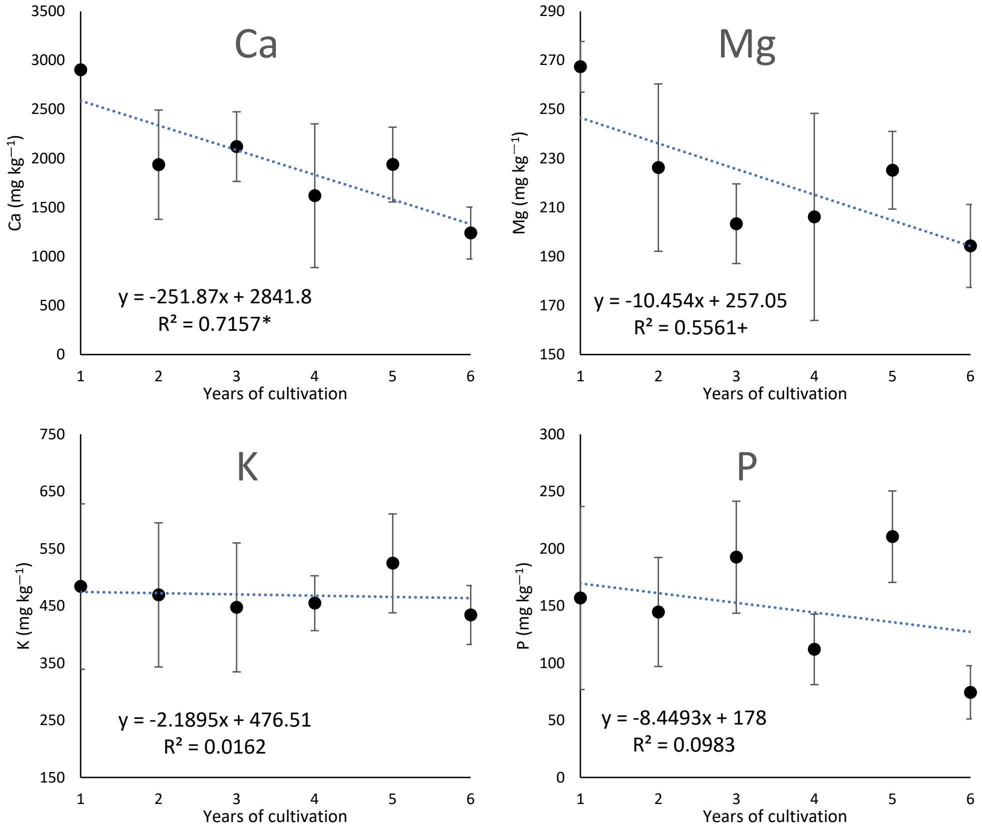

**Figure 5.** Relationships between years of ginseng cultivation and exchangeable cations and available phosphorus in the soil. Mean values ± standard errors ($n = 3$). + Represents significance at the 0.10 probability level. * Represents significance at the 0.05 probability level.

The relationship between the soil available trace elements and soluble Al and the number of years of ginseng cultivation at the sites is shown in Figure 6. No clear relationship with years of cultivation was observed for Mn, Fe, Ni, or B, whereas Zn (10% level) and Cu (5% level) showed significant decreases with the increase in the number of years of cultivation. The Al content increased significantly with the increase in cultivation years. It has been shown that a decrease in pH generally accelerates the dissolution of Al [26]. The relationship between the pH and Al values in the soil sampled in the present study is depicted in Figure 7. A significant negative correlation was observed between the soil pH and the Al content of the soil, with a tendency for the Al content to increase with decreasing pH.

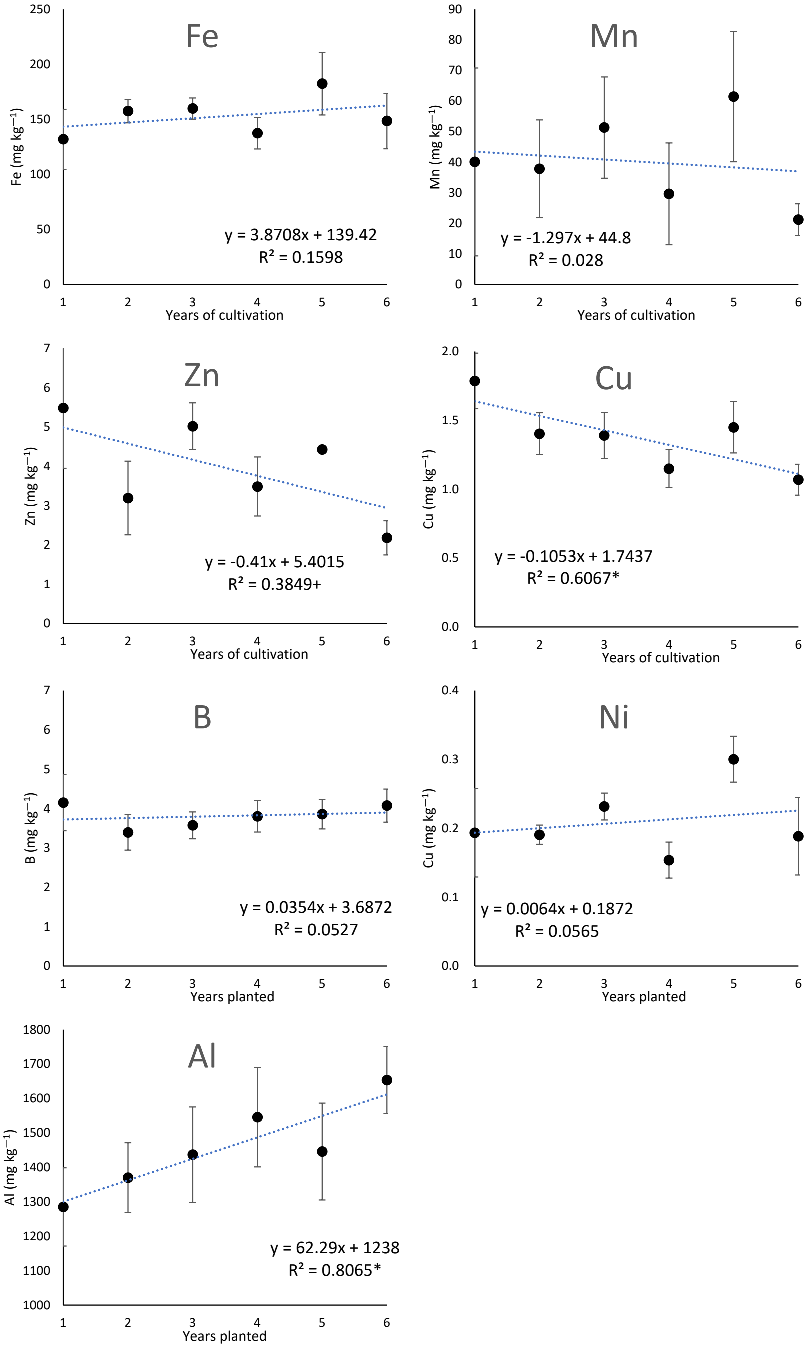

**Figure 6.** Relationships between years of ginseng cultivation and trace elements and soluble Al in the soil. Mean values ± standard errors ($n$ = 3). + Represents significance at the 0.10 probability level. * Represents significance at the 0.05 probability level.

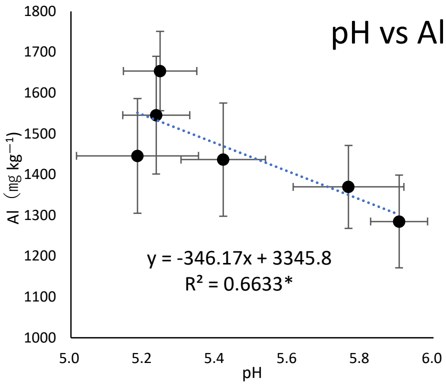

**Figure 7.** Relationships between years of ginseng cultivation and trace elements and soluble Al in the soil. Mean values ± standard errors ($n = 3$). * Represents significance at the 0.05 probability level.

Since we suspected that the decrease in soil pH is due to a decrease in bases, we investigated the relationships among Ca, Mg, and Al. Significant negative correlations were revealed between them (Figure 8). The changes in Al that were associated with the changes in pH with the increase in the number of years of cultivation were also shown to affect the dynamics of essential trace elements in the soil. A very strong and significant negative correlation was observed between the Al and Cu contents, and the Cu content decreased with increasing Al in the soil (Figure 9). The relationship between Zn and Al showed a trend that was similar to that of Cu (although not significant at the 5% level), and the Zn content decreased as the Al increased ($p = 0.076$, indicating that the relationship was significant at the 10% level).

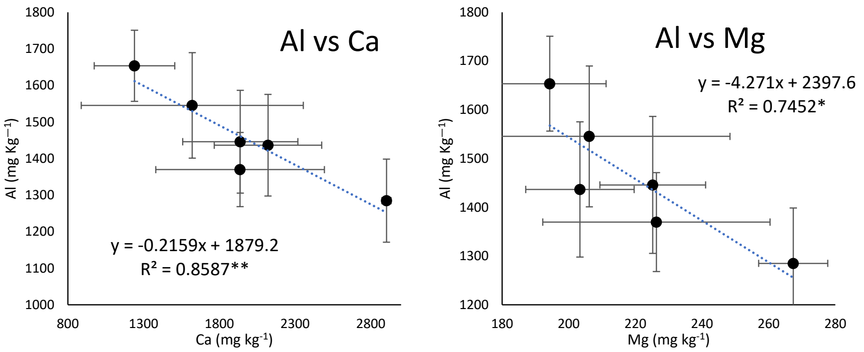

**Figure 8.** Relationships between soluble Al and exchangeable Ca and Mg in the ginseng cultivation soils. Mean values ± standard errors ($n = 3$). * Represents significance at the 0.05 probability level. ** Represents significance at the 0.01 probability level.

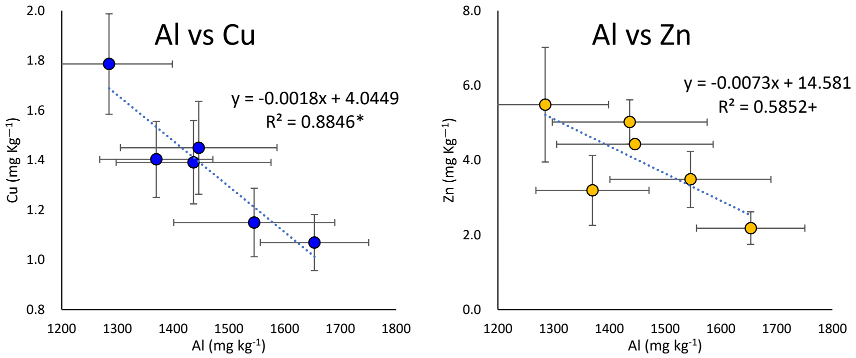

**Figure 9.** Relationships between soluble Al and exchangeable Ca and Mg in the ginseng cultivation soils. Mean values ± standard errors ($n = 3$). + Represents significance at the 0.10 probability level. * Represents significance at the 0.05 probability level.

## 4. Discussion

### *4.1. Ginseng Yield and Background*

The economic cultivation of ginseng as a raw material for Chinese herbal medicine in Japan started in the mid-17th century [10–12]. Although ginseng cultivation was originally conducted in many parts of Japan, cultivation techniques could not be successfully established in many areas and the practice fell into disuse, eventually leaving only three regions—Nagano, Fukushima, and Shimane—where ginseng continues to be cultivated. In addition, due to the aging of farmers, low sales prices, and difficulties in procuring materials, ginseng production in Japan has greatly decreased since its peak in the 1970s [10,12].

Nevertheless, ginseng has been re-evaluated as a healthy food in recent years, and the revival of ginseng production areas is desired [3]. Toward this goal, it is crucial to establish fertilizer management techniques based on soil nutrient dynamics as a basis for ginseng cultivation. The three remaining regions in Japan have one thing in common: they all have Andosols as their primary soil type. In Shimane in particular, ginseng is cultivated only on the rather small island of Daikonjima, and all of the ginseng grown there is produced on Andosols [21]. This is a major characteristic of ginseng cultivation in Japan compared to China, the Korean Peninsula, and North America (including Canada), where ginseng is cultivated on various types of soil including brown forest soil, reddish-yellow soil, and alluvial soil. It is therefore essential to understand the dynamics of soil nutrients associated with ginseng cultivation on Andosols.

The essential characteristic of ginseng cultivation is that it takes 4–6 years from sowing to harvest, and fertilizer is rarely applied after transplanting 1st- or 2nd-year seedlings [3]. Some fertilizers adding nitrogen, phosphate, and potassium may be applied, but other nutrients are not supplemented and are supplied by the soil. The fresh weight of ginseng roots harvested at 6 years of cultivation in the present study was approx. 90 g, which is not large for a six-year crop. It has been pointed out that the yields in this area (Daikonjima) are smaller than those in other production areas in Japan such as Nagano and Fukushima [10–12]. Genetic factors primarily influence the yield, but there are no so-called varieties of ginseng and no genetically fixed lines [12]. This is also the case in Nagano and Fukushima, where ginseng is genetically disjointed [11]. Therefore, the reason for the relatively small ginseng cultivated in Daikonjima remains unclear. The effects of environmental and genetic factors on ginseng size will have to be clarified in future studies.

### *4.2. Validity of the Mineral Concentrations in the Ginseng Roots in This Study*

There have been few reports on the concentrations of inorganic elements in the roots of ginseng cultivated on Andosol. Douglas et al. [8] reported the concentrations of major elements in the roots of ginseng cultivated in New Zealand, which were 5.8 g kg$^{-1}$ for P, 18–19 g kg$^{-1}$ for K, 2.5 g kg$^{-1}$ for Mg, and 3.0–4.0 g kg$^{-1}$ for Ca. Similarly, Zhou et al. [6] showed that Ca, Mg, and P were 6.0 g kg$^{-1}$, 1.2 g kg$^{-1}$, and 3.0 g kg$^{-1}$, respectively, as the major element concentrations in ginseng roots. By comparing our present findings with those values, it can be concluded that the concentrations of K, Mg, and Ca are almost equal, whereas the P level is slightly lower in this study. Andosol is known to generally have stronger phosphate adsorption and lower phosphate availability than other soils, which may be the reason for the lower P concentration [21].

Regarding trace elements, Douglas et al. [8] reported concentrations of 32–71 mg kg$^{-1}$ for Mn, 20–30 mg kg$^{-1}$ for Zn, 1.8–6 mg kg$^{-1}$ for Cu, 190–286 mg kg$^{-1}$ for Fe, and 15 mg kg$^{-1}$ for B, which are similar to the values we observed herein. Zhang et al. [27] and Proctor and Shelp [28] reported concentrations of trace elements that are similar to those in the present study. In other words, although the P concentrations of ginseng cultivated on Andosols tended to be slightly lower than those of ginseng cultivated on other soils, the concentrations of many elements (including trace elements) analyzed in this study did not deviate from those of previous reports, and these element concentrations were within the general concentration range for maintaining the growth of ginseng.

### *4.3. Factors Contributing to Acidification with Increasing Years of Ginseng Cultivation and Their Effect on the Dynamics of Inorganic Elements*

We investigated the changes in soil chemical properties over 6 years of ginseng cultivation. No significant correlation was found between EC, K, and P and the number of years of cultivation. These variations during the growing period could be attributed to fertilizer application. Since the fertilizer types used and the doses and timing of fertilizer application varied between farmers, no clear relationship was assumed between these values and the number of years of cultivation. Significant correlations with the increase in the number of years of cultivation were revealed for the pH and the Ca and Al contents. There have been several prior investigations of changes in soil chemical properties with ginseng cropping on various types of soils, and it was reported that a decrease in pH causes an increase in the acidification of soils at ginseng cropping sites [29]. A significant negative linear relationship between the number of years of cultivation and the soil pH was also revealed in the present study. One of the reasons for this decrease in pH could be the decreases in Ca and Mg in the soil with increasing years of cultivation. Our analysis results demonstrated a significant negative correlation between the number of years of cultivation and the exchangeable Ca content in the soil. Although the change in Mg content was not significant at 5%, it was significant at the 10% level, indicating that exchangeable Mg in the soil tended to decrease with increasing years of cultivation. The decreases in Ca and Mg, which significantly affect the pH, may thus be factors contributing to soil acidification. You et al. [4] showed that the Luvisol soil pH decreased after ginseng cultivation due to a significant decrease in exchangeable Ca.

A reduction in soil pH has been reported to significantly affect ginseng growth. Konsler and Shelton [18] showed that when American ginseng was produced at a soil pH of 5.5, the yield doubled compared to pH 4.4. They also noted that raising the soil pH to 6.5 resulted in slightly smaller roots and that the optimum pH was around 5.5 [16]. Root enlargement has been shown to be highly correlated with Ca uptake [4,18,29,30], but in many cases, the Ca is not replenished during the growing season and depends solely on the supply from the soil. An application of lime prior to planting was reported to promote the enlargement of ginseng root [9,30]. Thus, although Ca is an essential element for promoting root enlargement, the effects of an application of Ca include controlling the leaching of Al from the soil and maintaining the pH at unity.

### *4.4. Increase in Aluminum Leaching with the Increase in the Number of Years of Ginseng Cultivation*

We observed that Al content in the Andosol soil increased with the increase in the number of cultivation years, and a significant positive linear relationship was present. This may be due to a decrease in soil pH due to Ca absorption by ginseng, which promotes Al leaching and a further decrease in pH. Similar findings were reported by You et al. [4], Nadeau et al. [9], Douglas et al. [8], and Kochian [31], which are consistent with our present results. The accelerated leaching of Al with increasing years of ginseng cultivation is thus confirmed in all regions of the world where ginseng is grown.

Aluminum is known to be generally toxic to plants [32–35], and Al in the soil has been reported to act in an inhibitory manner on root growth in the cultivation of ginseng [2,9]. Aluminum has also been reported to be a causal factor of red-skin root, which is a problem of poor-quality ginseng, and high concentrations of Al oxides were detected in red-skinned tissue [6,36]. The application of Ca is considered effective for mitigating this Al toxicity [6]. The soil at the present study sites was Andosol, which has a high Al leaching rate; in addition, Al is more than ten times more abundant in Andosols than other soil types [23,37]. We thus speculate that Al is present in Andosols at a level that would be disturbing in other soil types. Although the ginseng yields from Daikonjima are not high, the quality of ginseng is known to be among the highest in Japan [12]. Although Al is highly toxic to many plants, it is also known to be toxic to bacteria, filamentous fungi, and nematodes [38]. Aluminum may thus have advantages in pest control. Further research on this point may help clarify why the cultivation of ginseng has remained in areas of Andosols in Japan.

### 4.5. The Effects of Acidification with Increasing Years of Cultivation on Trace Elements' Availability

No trace elements showed a significant correlation at the 5% level with the number of years of ginseng cultivation in this study. The Fe and B contents remained relatively stable with slight variations throughout the cultivation years, while Mn and Ni showed larger variations during the cultivation years. The factors that do not show a clear relationship between the variation of these trace elements and the year of cultivation are currently unknown. It may be possible to clarify the factors by investigating the amount absorbed by ginseng and the chemical forms of these elements in the soil. However, Cu and Zn were significant at the 10% level and tended to decrease with the increasing years of cultivation: Cu and Zn had decreased by 41% and 60%, respectively, in the 6th-year cultivation sites compared to the 1st-year sites. The leaching of these trace elements from the soil generally increases under acidic conditions. As mentioned above, the soil pH clearly decreased and became more acidic with the increasing years of ginseng cultivation on Daikonjima. Nevertheless, the Cu content in the soil tended to decrease with the increase in cultivation years. Decreases in Cu and Zn contents in the soil with increasing years of cultivation were also reported by Zhang et al. [27].

The forms of Cu and Zn in soil have been shown to exist as exchangeable forms, inorganic bindings, organic bindings, and free oxide absorption forms, with exchangeable forms and inorganic bindings being the primary forms of Zn in soil, while a higher proportion of organic bindings was reported for Cu compared to Zn [39–42]. Among these, the available forms are considered to be part of the exchangeable forms and inorganic binders, and the Mehlich-3 method employed in the present investigation has shown that these forms can be extracted [22–24]. The cultivation of ginseng apparently increases the leaching of trace elements such as Cu and Zn due to acidification caused by a decrease in Ca and an increase in Al, but the available Cu and Zn may decrease at higher rates due to absorption by the ginseng.

Douglas et al. [8] reported that among the trace elements, the rate of absorption and the requirement of Cu had a significant effect on the growth of ginseng. Indeed, Cu- and Zn-deficiency symptoms were often observed in ginseng cultivation on soils with relatively high pH in Northeast China [27]. These symptoms have been shown to be ameliorated by foliar spraying [27]. Historically, the application of trace elements such as Cu and Zn in the cultivation of ginseng has been infrequent, and most of the Cu and Zn absorbed by ginseng is thus considered to be dependent on the availability of Cu and Zn from the soil.

As mentioned above, the available forms of trace elements absorbed by a crop are the exchangeable and partly inorganic bindings [39–41]. The source of those forms is the organic-bound form, and in particular, the proportion of Cu that is present in the soil is higher in the organic-bound form than in the exchangeable or inorganic-bound form [39–41]. Andosol is rich in organic matter, and high proportions of Cu and Zn are firmly adsorbed on organic matter, which is not quickly mineralized and activated [39,40]. We thus speculate that in the root zone soil, Cu and Zn leached by acidification are absorbed by the ginseng throughout the long 6-year cultivation period and that available Cu and Zn are reduced because they are not replenished in corresponding amounts. A consideration of the changes in soil pH and trace element availability during cultivation is thus an essential aspect of fertilizer management for the continued cultivation of ginseng on Andosol.

## 5. Conclusions

Andosol is one of the primary soils for ginseng cultivation in Japan. This study investigated the relationship between ginseng cultivation and soil chemical properties in Andosol. In the root-zone soil of ginseng, which takes six years from sowing to harvesting, there was a significant decrease in pH with increasing years of cultivation. This decrease in pH was mainly attributed to the absorption of calcium and magnesium by ginseng in the root-zone soil. Since Andosol is rich in active aluminum, the decrease in pH was thought to accelerate aluminum leaching and further acidification. Al is also known to be a limiting factor for root growth, which may be why ginseng yields in this region are not so high compared to other regions. Soil acidification promoted the leaching of Cu and Zn among the trace elements, which were absorbed by ginseng. The available Cu and Zn content of the root-zone soil tended to decrease with increasing years of cultivation. These results suggest that acidity correction and applying trace element fertilizers may be essential fertilizer management techniques in ginseng cultivation on Andosol.

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