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인삼 연작지에서 윤작물 작부체계가 토양화학성 및 인삼뿌리썩음병 발생에 미치는 영향

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Effect of Crop Rotation System on Soil Chemical Properties and Ginseng Root Rot after Harvesting Ginseng

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ABSTRACT

Background: The application of crop rotation systems may reduce the occurrence of soil-borne diseases by releasing allelochemicals and by subsequent microbial decomposition.
Methods and Results: For reduction of ginseng root rot by the crop rotation system, after harvesting 6-year-old ginseng, fresh ginseng was grown along with continuous cultivation of sweet potato, peanut, and bellflower. Growth of 2-year-old ginseng was significantly inhibited in the continuous cultivation than in the first cultivation. Sweet potato, peanut and bellflower cultivations assisted in obtaining normal yields of ginseng in the first year after the harvest of 6-year-old ginseng. Salt concentration, potassium and sodium contents were gradually decreased, and, organic matter was gradually increased through cirp rotation. Phosphate, calcium and magnesium contents were not altered. The density of the root rot fungus was gradually decreased by the increase in crop rotation; however it was decreased distinctly in the first year compared to the second and third year. The severity of root rot disease tended to decrease gradually by the increase of crop rotation.
Conclusions: Short-term crop rotation for three years promoted the growth of ginseng, however root rot infection was not inhibited significantly, although it was somewhat effective in lowering the density of the root rot pathogen.

Key Words: *Panax ginseng* C. A. Meyer, Crop Rotation, Growth, Root Rot, Soil Chemical Property

INTRODUCTION

Ginseng (*Panax ginseng* C. A. Meyer) is a medicinal crop that has a long history of being used as medicinal herb for 5,000 years, and a special product representing Korea with high reputation in the world. In 2016, 134 million dollars of ginseng was exported to about 70 countries, and the export of ginseng is the largest among the agricultural products (MAFRA, 2017). Recently, the cultivation area of ginseng has decreased sharply. The cultivation area, which was 20,000 ha in 2000, decreased to 14,000 ha in 2016 (MAFRA, 2017). The reason for decrease is due to the stagnation of the ginseng price and the decrease of the farm income by the increase of the operating cost. The main reason for the increase in operating expenses seems to be the rise in material and labor costs, and the lack of virgin soil due to replant failure. As virgin soil is getting scarce, the number of farmers who move long distances increases, and therefore transportation costs and land rent increases.

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Replant failure of ginseng was caused soil-borne pathogens, such as *Cylindrocarpon destructans* and *Fusarium solani* (Kang *et al*., 2007; Rahman and Punja, 2005). The exudates of ginseng roots serve as a nutrient source for the growth of *C. destructans* and act as a signal to induce germination of pathogenic spores (Xu *et al*., 2016).

Soil disinfection with soil fumigant has been mainly used for reduce the replant failure of ginseng, and traditionally rice was grown in paddy soil for 4 to 5 years or cultivated in upland soil for 10 years or more (Kang *et al*., 2007). Growing rice or crop rotation systems for a long time could be reduce the density of root rot pathogens and decompose the substances inhibiting the growth of ginseng, also can reduce the replant failure to some extent (Lee *et al*., 2016).

The inhibition effect of ginseng root rot was investigated by cultivating *Sorghum sudanense*, *Ricinus communis* and *Helianthus tuberosus* for 1 year in ginseng field with replant failure (Lee *et al*., 2017). Medicinal plants belong to Compositae were effective to inhibit of ginseng root rot (Lee *et al*., 2015b). Cultivation of rape and Sudan grass as green manure crops were effective to decrease of potato wilt disease (Davis *et al*., 1996; Ochiai *et al*., 2007; Pinkerton *et al*., 2000). Streptomycetes collected from soil cultivated buckwheat inhibited the growth of potato wilt pathogen, VERTICILLIUM WILT (Wiggins and Kinkel, 2005).

In this study, sweet potato, peanut and bellflower were cultivated for 3 years in the field where 6-year-old ginseng were harvested, and then 2-year-old ginseng were replanted in order to investigate the growth and the incidence of ginseng root rot. The purpose of this work was to study the effect of crop rotation cultivation on the reduce of replant failure in ginseng.

MATERIALS AND METHODS

1. Characteristics of soil harvested 6-year-old ginseng

This trial was conducted from March 2012 to November 2016 in the experiment field located in Eumsung-Gun, Chungcheongbuk-Do. This test soil was sandy loam and continuous cropping soil where cultivated ginseng for 6 years. In the end of March 2008, the seedlings were planted and then 6-year-old ginseng (*Panax ginseng* C. A. Meyer) was harvested in late October 2012 (Table 1). The incidence of ginseng root rot was 28.9% at that time. After 6-year-old ginseng was harvested, the chemical properties of soil were pH 5.97, electric conductivity 0.24 dS/m, organic matter 2.03 g/kg, P_2O_5 57.2 mg/g, K 0.10 cmol$^+$/kg, Ca 3.82 cmol$^+$ 0.84 cmol$^+$/kg. After the ginseng harvest, content of organic matter, potassium and magnesium were insufficient for cultivation of ginseng because no chemical fertilizer or compost was used at all.

2. Types and cultivation period of crops rotation

Sweet potato (*Ipomoea batatas* Lam.), peanut (*Arachis hypogaea* L.) and bellflower (*Platycodon grandiflorum* A. DC) were cultivated during three years from 2013 to analyze the changes of soil chemical properties by types of crops rotation and cultivation period after ginseng harvested. In order to avoid replant failure, rotation system was combined as follows: 1) control, 2) sweet potato (1st year), peanut (2nd year) and sweet potato (3rd year), 3) peanut (1st year), sweet potato (2nd year) and peanut (3rd year), 4) bellflower (1st year), bellflower (2nd year) and bellflower (3rd year). Sweet potato variety and Shinyulmi was transplanted in the late May at 26 × 30 cm spacing. Peanut variety, Ilmi and native bellflower were sown in late April at 15 × 18 cm spacing.

For the maintenance of soil moisture and control of weeds, black plastic film of thickness of 0.01 mm was covered on the soil surface and then sown. Peanut and sweet potato were harvested at the beginning and mid-October every year to measure fresh root and seed weight, respectively. Bellflower was harvested in late October and fresh root weight was measured each year.

Table 1. Root yield and root rot incidence of 6-year-old ginseng cultivated in virgin soil.

	Plant height (cm)	Leaf length (cm)	Leaf diameter (cm)	Ratio of survived root (%)	Root weight (g/plant)	Root yield (g/3.3 ㎡)	Ratio of root rot[1)] (%)
Virgin soil	65.9±4.72	14.3±0.30	5.8±0.23	71.1±13.37	40.9±8.95	1,560±141.9	28.9±13.37

[1)]Ratio of root rot; (withered plant + diseased plant)/planted number × 100.

3. Analysis of soil chemical properties

To investigate the changes of soil mineral content by crop cultivation, no fertilizer was sprayed in this field. The rotation crops were harvested yearly from 2013 to 2015, and soil samples were collected at the end of October to analyze their chemical composition.

Soil samples were dried, ground and passed through 2 ㎜ sieve, and finely ground in porcelain bowl for analysis. The pH, EC (electrical conductivity), organic matter, available phosphate and exchangeable cations such as K, Ca and Mg of soil were analyzed according to soil chemical analysis method (NIAST, 2000). 10 g of soil samples was placed in 100 ㎖ Erlenmeyer flask and 50 ㎖ of the extract (0.1 N HCl) was added. After shaking for 1 hour at 30℃ in the constant temperature water bath, the solution was filtered with Toyo No. 5B (Toyo Roshi Kaisha, Advantec, Tokyo, Japan). Exchangeable cations were analyzed with ICP-OES (Integra XMP, GBC Scienrific Equipment, Braeside, Australia).

4. Density analysis of ginseng root rot fungus, *C. destructans*

5 ㎖ of minimal mineral broth supplemented with 50 ㎎/ℓ of radicicol (Sigma-Aldrich Co., St. Louis, MO, USA) and 5 g of soil samples were placed in the 50 ㎖ falcon tube, and cultured with stationary culture under the condition of 20℃ for 48 hours. The falcon tube incubated with stationary culture for 48 h was centrifuged at 5,000 rpm for 1 min, and 1 ㎖ of the supernatant was diluted 100 times with sterile water. 400 ㎕ of the dilution was applied to a minimal mineral agar medium supplemented with 50 ㎎/ℓ of radicicol. After incubation at 20℃ for 7 days, the density of pathogen was analyzed by the shape and number of colony from the medium.

5. Investigation of growth characteristics and root rot disease

From 2013 to 2015, the rotation crops were cultivated annually, and seedlings of ginseng were transplanted yearly to investigate growth and root rot incidence of 2-year-old ginseng. At the end of March yearly, ginseng seedlings of about 0.77 g were transplanted at a density of 70 plants per 3.3 ㎡. The plot area was 19.4 ㎡ and placed in 3 replicates by randomized block design. The shading facility was the four-folds polyethylene shading net (blue triple + black one) of type A. Other cultivation management was conducted according to the standard cultivation practices.

Growth characteristics of 2-year-old ginseng, such as plant height, stem length, leaf length and leaf width, was surveyed at the end of July. The incidence of root rot and underground growth of ginseng was examined at the end of October. The ratio of root rot was calculated as number of infected with root rot disease/planted number × 100. The ratio of disease-free plant was calculated as number of disease-free plant/planted number × 100. The severity of root rot disease was divided into 0, 1, 2, 3, 4 and then examined: 0 is on lesion, 1 is rotted-area below 10%, 2 is rotted-area below 50%, 3 is rotted-area below 70%, 4 is completely rotted root.

For example, the formula for determining the severity of root rot disease is $(X0 \times 0) + (X1 \times 1) + (X2 \times 2) + (X3 \times 3) + (X4 \times 4)/(X0 + X1 + X2 + X3 + X4)$. Statistical analysis was performed using the SAS program (Statistical Analysis System, Version 9.2, SAS Institute Inc., Cary, NC, USA), and significant differences among treatments were tested at the 5% significance level, Duncan's Multiple Range Test (DMRT).

RESULTS AND DISCUSSION

1. Growth difference of 2-year-old ginseng between virgin and replanted soil

Growth characteristics of 2-year-old ginseng (*Panax ginseng* C. A. Meyer) were compared between virgin and replanted soil after the harvest of 6-year-old ginseng in the previous year (Table 2). Plant height, leaf length, and leaf width were significantly decreased in the replanted soil than in the virgin soil. The root weight per plant was also significantly reduced from 4.7 g of virgin to 1.0 g of replanted soil. The incidence of root rot disease increased significantly from 9.5% of virgin to 92.3% of replanted soil. The main reason of decrease in the growth of the above-ground part was seems to be the poor absorption of nutrients because the fine roots of 2-year-old ginseng was infected with root rot fungus (Cho *et al*., 1995).

In addition, this also seems to be due to lack of inorganic nutrients by continuous cultivation (Fig. 2) and autotoxicity by alleochemicals such as phenolic acid (Lee *et al*., 2012; Suh and Lee, 1993; Sun *et al*., 2013). Lee *et al*. (2016) also reported that the growth of 2-year-old ginseng was significantly inhibited in replanted soil than in virgin soil.

Table 2. Growth and root rot ratio of 2-year-old ginseng between virgin and replanted soil.

Treat.	Plant height (㎝)	Leaf length (㎝)	Leaf diameter (㎝)	Ratio of survived root (%)	Root weight (g/plant)	Root yield (g/3.3 ㎡)	Ratio of root rot (%)
Virgin soil	18.3^{a}	7.2^{a}	3.7^{a}	90.5^{a}	4.70^{a}	312.7^{a}	9.5^{b}
Replanted soil	13.7^{b}	4.9^{b}	2.6^{b}	23.6^{b}	1.03^{b}	12.3^{b}	92.3^{a}

*Means with same letters are not significantly different in DMRT ($p < 0.05$).

2. Yield of crops by rotation system after harvesting ginseng

The sweet potatoes, peanuts and bellflower were cultivated in the soil harvested 6-year-old ginseng to evaluate the yield of the crops by the rotation system and cultivation period (Fig. 1).

The root yield of sweet potatoes showed the highest in the first year, but decreased significantly in the second and slightly increased in the third year. Seed weight of peanut, like sweet potato, was the highest in the first year, but decreased significantly in the second and recovered somewhat in the third year. The root yield of bellflower increased gradually with the increase of the year, showing the highest in the third year. There are many farmers who worry that if the crop is grown after harvesting ginseng, the yield of the crop will be decreased. However, the yield of sweet potato, peanut and bellflower did not decrease in the first year.

According to Lee *et al*. (2015a), the tuber weight of 30 g or more in sweet potato variety, Shinkunmi is 4,694 ㎏ per 10 a. If this yield is converted into total yield, it will be similar to 5,552 ㎏ produced in the first year of this test. The seed weight of peanut per 10 a in this test was 558 ㎏ in the frist year, which was slightly higher than the average yield of 447 ㎏ for three years in six regions (Pae *et al*., 2013). Seong *et al*. (2004) reported that the weight of bellflower per 10 a was 457 ㎏ in first year and 898 ㎏ in second year, which was similar to that of this test. The reason why the yield of sweet potato and peanut decreased in the second and third years seems to be mainly due to lack of nutrients in the soil and increase of leaf spot disease, respectively.

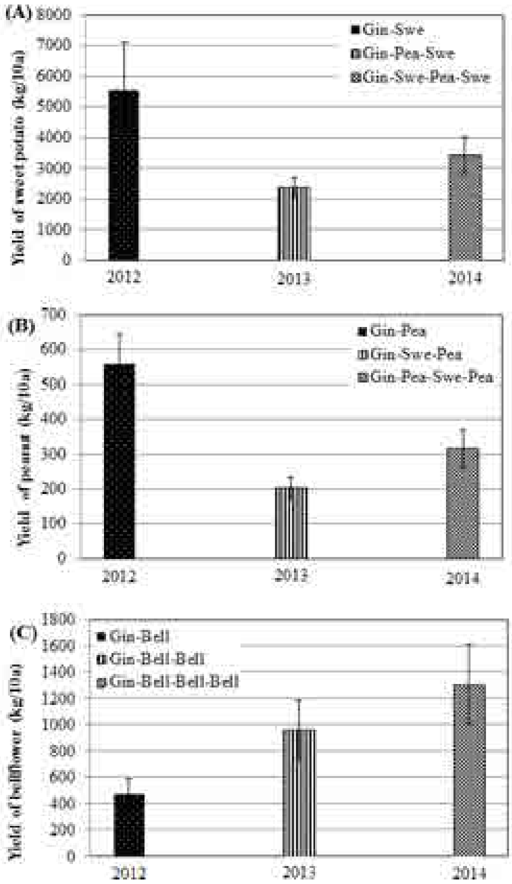

Fig. 1. Yield of rotation crops by the rotation system and cultivation period after harvesting 6-year-old ginseng. (A); tuber weight of sweet potato, (B); seed weight of peanut, (C); root weight of bellflower. Legend of graphs represent the order of rotation crops cultivated every year after ginseng cultivation (Gin; Ginseng, Swe; Sweet potato, Pea; Peanut, Bell; Bellflower). Vertical bars represent the standard errors of means.

3. Changes of soil chemical properties by the rotation of crops

After 6-year-old ginseng was harvested, sweet potato, peanut, and bellflower were cultivated and then chemical composition of the soil was analyzed by the rotation system and cultivation period (Table 2).

Soil pH was increased steadily and showed the peak in the second year, then decreased in the third year. Electrical conductivity (EC) was significantly decreased in sweet potato and peanut until the second year, however there was no significant change in the third year. EC of

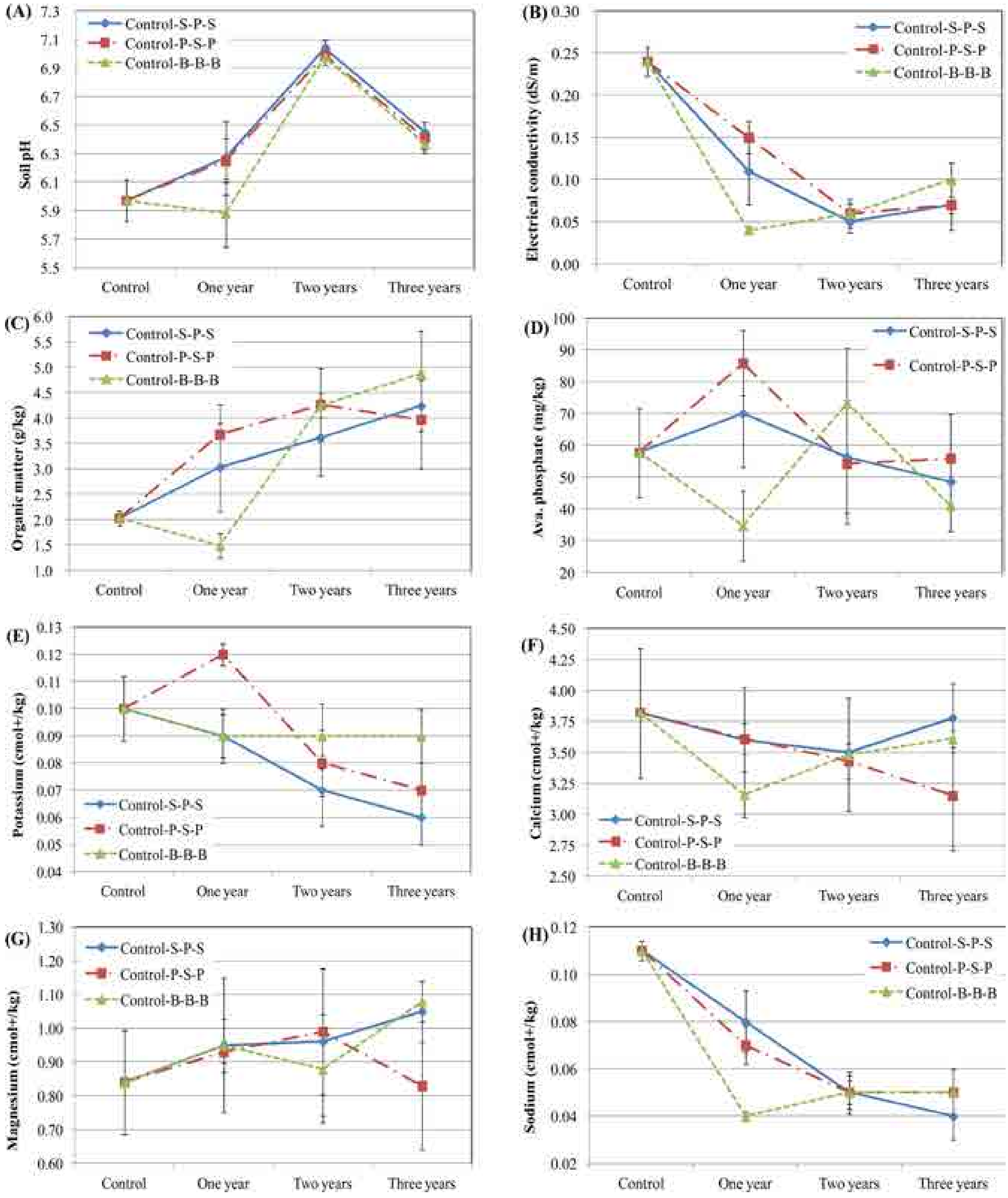

Fig. 2. Changes of soil chemical properties by the rotation system and cultivation period of crops after harvesting 6-year-old ginseng. (A); soil acidity, (B); electrical conductivity (dS/m), (C); organic matter (g/kg), (D); available phosphate (mg/kg), (E); potassium ($cmol^{+}/kg$), (F); calcium ($cmol^{+}/kg$), (G); magnesium ($cmol^{+}/kg$), (H); sodium($cmol^{+}/kg$). Legend of graphs represent the order of rotation crops cultivated every year after ginseng cultivation (Control; non-cultivation, S; Sweet potato, P; Peanut, B; Bellflower). Vertical bars represent the standard errors of means.

bellflower was decreased lower in the first year, but gradually increased in the second year.

Lee *et al*. (2016) and Yang *et al*. (2011) also reported that the rotation of green manure crops was increased soil pH and decreased EC. Organic matter content of sweet potato and peanut was gradually increased by the increase of cultivation year. That of bellflower was decreased in the first year, but increased in the second year. Available phosphate content of sweet potato and peanut were increased slightly in the first year, then gradually decreased in the second year. The content of that in the bellflower was decreased in the first year, increased in the second year, and decreased in the third year. The potassium content of the peanut showed the highest in the first year, then decreased gradually. That of sweet potato was gradually decreased by the increase of cultivation year. That of bellflower showed not significant change by the increase of cultivation year.

Lee *et al*. (2016) also reported that potassium content was reduced by 46% in potato cultivation for one year, and potato cultivation was effective for potassium absorption. Calcium and magnesium contents did not change with the increase of cultivation year. Sodium content of sweet potato and peanut decreased significantly until the second year, however it was not changed significantly in the third year. That of bellflower was decreased significantly in the first year and there was no significant change in the second and third year.

Summarizing the above results, EC, potassium and sodium contents were gradually decreased by the increase of cultivation year, and the organic matter content was gradually increased adversely. The contents of phosphate, calcium, and magnesium did not showed any significant change by the increase cultivation year.

4. Pathogen density of ginseng roots rot by rotation system of crops

From the soil where sweet potato, peanut and bellflower were cultivated after 6-year-old ginseng was harvested, the density of ginseng root rot fungus (*C. destructans*) was analyzed by the rotation system and cultivation period (Fig. 3).

The average spore number of *C. destructans* per soil gram was 10.5 in the first year, 5.9 in the second year,

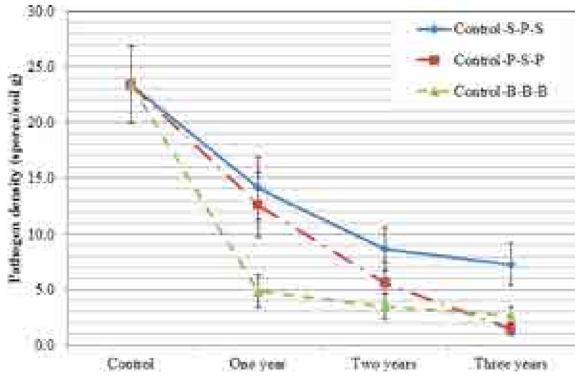

Fig. 3. Changes of pathogen density of ginseng root rot by rotation system and cultivation year of crops after harvesting 6-year-old ginseng. Legend of graphs represent the order of rotation crops cultivated every year after ginseng cultivation (Control; non-cultivation, S; Sweet potato, P; Peanut, B; Bellflower). Vertical bars represent the standard errors of means.

and 3.8 in the third year. The pathogen density was gradually decreased as cultivation year was increased. Cumulative reduction rate of pathogen was 55.1% in the first year, 74.8% in the second year, and 83.8% in the third year, which was significantly reduced in the first year but decreased relatively little from the second year.

Bellflower cultivation significantly decreased pathogen density in the first year, but did not decreased significantly in the second year. The cultivation of sweet potato and peanut gradually reduced the pathogen density by the increase of cultivation year. The reason why the density of ginseng root rot fungus was reduced by the crop rotation seems to be the increase of soil inorganic nutrients and the improvement of soil microorganisms due to the absence of host plants infected with root rot. As shown in Fig. 2, the soil pH was increased and the sodium content was decreased by the increase of cultivation year. Mycelium growth of ginseng root rot fungus was inhibited at pH 7 than pH 5 (Lee *et al*., 2014). The sodium content in the soil causing root rot of ginseng was higher than that of the control soil (Chung *et al*., 1984). The soil to inhibit ginseng root rot has higher antagonistic, bacterial and fungal density than the soil causing root disease (Chung *et al*., 1984, 1983). Nguyen *et al.* (2016) reported that bacterial diversity decreased as cultivation period of ginseng increased and that was highly correlated with soil pH, available phosphate and calcium.

Table 3. Growth and root rot disease of 2-year-old ginseng by to the rotation system and cultivation year of crop after harvesting 6-year-old ginseng.

CY[1)] (year)	Cropping system	Plant height (㎝)	Leaf length (㎝)	Leaf diameter (㎝)	Ratio of survived root (%)	Root weight (g/plant)	Ratio of root rot (%)	Root rot index[5)] (0 - 4)
0	Control	13.74^{b}	4.91^{d}	2.61^{c}	23.6^{c}	1.03^{c}	92.3^{ab}	3.75^{a}
1	SP[2)]	13.60^{b}	4.89^{d}	2.58^{c}	52.9^{ab}	1.19^{bc}	67.3^{d}	3.18^{bc}
	P[3)]	13.80^{b}	5.16^{cd}	2.83^{abc}	51.8^{ab}	1.15^{c}	70.8^{cd}	3.59^{ab}
2	SP → P	17.80^{a}	6.46^{a}	3.11^{a}	37.6^{bc}	1.66^{a}	98.8^{a}	3.43^{abc}
	P → SP	16.13^{ab}	5.90^{ab}	2.72^{bc}	43.6^{abc}	1.49^{ab}	93.8^{ab}	3.26^{abc}
	B[4)] → B	16.89^{a}	6.06^{ab}	3.05^{a}	63.7^{a}	1.79^{a}	82.5^{bc}	2.34^{d}
3	SP → P → SP	16.76^{a}	5.90^{ab}	2.87^{abc}	41.6^{abc}	1.59^{a}	86.4^{ab}	2.90^{c}
	P → SP → P	16.20^{a}	5.64^{bc}	2.98^{ab}	36.6^{bc}	1.06^{c}	92.1^{ab}	2.92^{c}
	B → B → B	17.26^{a}	6.09^{ab}	2.99^{ab}	45.7^{abc}	1.76^{a}	92.4^{ab}	2.86^{c}

*Means with same letters are not significantly different in DMRT ($p < 0.05$). [1)]CY; Cultivation year, [2)]SP; Sweet potato, [3)]P; Peanut, [4)]B; Bellflower, [5)] Root rot index; (X0 × 0) + (X1 × 1) + (X2 × 2) + (X3 × 3) + (X4 × 4)/ (X0 + X1 + X2 + X3 + X4), X0; on lesion, X1; rotted-area below 10%, X2; rotted-area below 50%, X3; rotted-area below 70%, X4; completely rotted root.

5. Changes of ginseng root rot by crop rotation system

The growth and root rot of 2-year-old ginseng by the rotation system and cultivation year of crops after harvesting 6-year-old ginseng were shown in Table 3. In plant height and leaf length, there was no difference between control and rotation for one year, but it was better than control in the second year of rotation. The reason why the growth of above-ground parts was better in the second year than the first year of rotation seems to be the decrease of a substances inhibiting the growth of ginseng (Lee *et al*., 2012; Suh and Lee, 1993). Root weight per plant showed not significant difference between control and rotation for one year, while it showed better growth than control from the second year of rotation.

Though survival root rate was increased in the cultivation of crop rotation than in the control, but it was not significantly increased even when the number of rotation year was increased. Therefore, the cultivation of crop rotation for 1 - 3 years had no effect on increasing the survival root rate. The ratio of diseased plant was decreased significantly in the first year of rotation, but increased again in the second year of rotation and showed no significant difference with the control. Crop rotation for 2 to 3 years did not have any effect on the decrease of diseased-plant rate.

Larkin and Honeycutt (2006) reported that cultivation of rapeseed, barley and corn for 3 years inhibited the infection of *Rhizoctonia solani* in potato. According to Kang *et al*. (2007), the growth of 2-year-old ginseng was promoted by growing *Sorghum sudanense* for 1 year after harvesting ginseng, but the incidence of root rot was not significantly inhibited. Though the incidence of root rot disease gradually was decreased with the increase of crop rotation, however did not show significant difference among three kinds of crop. Lee *et al*. (2017) reported that *Sorghum sudanense*, *Ricinus communis* and *Helianthus tuberosus* significantly inhibited the incidence of root rot when 22 kinds of green manure crop were grown for one year after harvesting ginseng.

In summary, short-term cultivation of crop rotation such as one to three years promoted the growth of ginseng but did not significantly inhibit the infection of root rot, but it was somewhat effective in lowering the severity of root rot disease.

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