活性炭フロアブル剤を利用したアスパラガスのアレロパシー軽減技術

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Reduction of the Allelopathic Effect on Asparagus by the Flowable Agent of Activated Carbon

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Summary

In Nagano Prefecture, asparagus (*Asparagus officinalis* L.) was cultivated in the area of 1,930 ha in 1999, and is now being replanted in approximately 200 ha. However, when asparagus is planted in a field where it has been cultivated before, there are often lower yields and greater loss of young plants. One of the causes of these phenomena is allelopathy. In this study, we examined the effect of the flowable agent of activated carbon (hereinafter referred to as "activated carbon F") to mitigate allelopathy in asparagus. The results of the tests using lettuce (*Lactuca sativa* L.) and one-year-old asparagus as a bioassay plants showed that activated carbon F promoted the plant growth and acted to mitigate allelopathy. In all 3 areas where the effects of activated carbon F were examined, growth of plants, fresh weight of rhizomes and storage roots, the number of storage roots and GI' (growth index) increased in the plots treated with the agent (using a 25 to 100-fold dilution) compared to the non-treated plots. It can be concluded that the activated carbon F is effective to mitigate the allelopathy of asparagus in the field.

Key words: allelopathy, *Asparagus officinalis* L., bioassay, flowable activated carbon, local adaptability

Introduction

Asparagus (*Asparagus officinalis* L.) belongs to the perennial Liliaceous family. In Nagano Prefecture, asparagus plants in a field are considered economically viable for about 10 years, although they have been often cultivated for more than 30 years. It is known that the normal economic life of an asparagus field in New Zealand is 12 to 20 years (Scofield et al., 1997). When asparagus is planted in a field where it has been grown before, there are often lower yields and greater loss of young plants. One of the causes of these phenomena is allelopathy, which inhibits the plant growth in cultivation and has a harmful influence in subsequent generations (Miller et al., 1991; Shafer and Garrison, 1986; Yang, 1982; Young, 1984; Young and Chou, 1985; Young, 1986). In Japan, there is little arable-land area and successive cropping is widely prevailed. However, asparagus growth and yield decreased in the field replanted because of the injury by successive cropping. The research on the allelopathy of asparagus in Japan has just started, and also conventional method of replanting asparagus is generally taking off old roots and plant virgin area's without agrochemicals (Uesugi et al., 1997). In this study, we examined the effect of the flowable agent of activated carbon (hereinafter referred to as "activated carbon F") to mitigate allelopathy in asparagus.

Materials and Methods

Experiment.1. Bioassay with one-year-old asparagus plants

The asparagus variety 'UC157F_1' was used in all experiment. Asparagus seeds were sown on Mar. 17 and planted in Wagner's pots (1/5,000,000 ha) on Jun. 25 in 1998, 1999, and 2000. The pots were buried up to their shoulders in the ground in a greenhouse. Plants were irrigated three times a week and provided with 2 g/plant of manure (N-P-K=10%-10%-10%, Aspara-2-go, Nagano Prefectural Economic Federation of Agr. Coop. Jpn.) once a month. Other conditions for cultivation were based on the standard methods for asparagus production in Nagano prefecture (Motoki and Araki, 2001).

The storage and absorbing roots of 5-year-old asparagus plants were dried at 75 ℃ for 5 days and crushed in a crusher. Ten g of the crushed powder was mixed with 3 kg of the substrate soil (Mimaki baido, Otsuka Sangyo Co., Ltd. Jpn.) in each pot. Then the soil was treated with activated carbon F (Otsuka Chemical Co., Ltd. Jpn.) on Jun. 24 and the plants were planted on Jun. 25.

In 1998, two concentrations, 50-fold and 100-fold dilutions, of activated carbon F were used for the experiment. Three concentrations, 25-fold, 50-fold and 100-fold dilutions, in 1999 and one concentration, 25-fold dilution, in 2000 were used for the experiment, respectively. Other two treatments were examined for comparison: a non-treated plot where the root powder was added but activated carbon F was not, and a control plot where neither root powder nor activated carbon F was added. Each group consisted of one plot, in which 10 plants were planted in each pot.

The aboveground parts were examined on Nov. 24, 1998, on Oct. 26, 1999 and on Dec. 5, 2000, and the underground parts were examined on Dec. 9 in 1998, on Dec. 14, 1999 and on Dec. 5, 2000.

Experiment.2. Bioassay with Lettuce seeds

Seeds of lettuce (*Lactuca sativa* L., cv. 'Shinano Summer') were used for the bioassay. Four concentrations, 25-fold, 50-fold, 100-fold and 200-fold dilutions, of the activated carbon F were prepared by dissolving in (200 ml of) distilled water. One g of asparagus root powder was added to the carbon solution, then shaken in a Double Shaker R-30 (106 min^{-1}, TAITEC, Taiyo Sci. Industrial Co., Ltd. Jpn.) for one hour and left at room temperature for 40 hours. The solution was centrifuged at 3000 rpm for 15 minutes. Four ml of the supernatant was poured into sterilized Petri dishes (9 cm in diameter) with two sheets of filter paper (no. 2, ADVANTEC, Toyo Roshi Kaisha, Ltd. Jpn.). Other three treatments were examined for comparison: a non-treated plot where the root powder was added but the activated carbon F was not; a control plot where (200 ml of) distilled water alone was used; and an additional plot where the 25-fold solution of activated carbon F with no root powder was added. The 50 seeds were sown per Petri dishes under lights at 20 ℃ in incubator (10000 lx, NK System Biotron LPH200, Nippon Medical & Chem. Instruments Co., Ltd. Jpn.), then the germination rate and the length of radicles were checked after 5 days. The experiments were replicated three times and were conducted in 1998, 1999 and 2000.

Experiment.3. Application to a continuous cropping field of asparagus

Seven-year-old asparagus plants were plowed into the field with a riding plow on Jun. 14, 2000. The activated carbon F solution (500 ml per plant) was sprinkled on the field by using a watering can. The soil was tilled with a cultivator and then one-year-old asparagus plants were planted on Jun. 16, 2000. The experiment was conducted on 4 groups: 3 treated groups using 25-fold, 50-fold and 100-fold dilutions of activated carbon F and 1 non-treated control group (only 500 ml water per plant was sprinkled). For each group there were 2 replications, consisted of 10 plants (the area of each plot was 4.5 m^2). The aboveground parts were examined on Dec. 4, and the underground parts were examined by pulling out roots on Dec. 13.

Experiment.4.Local Adaptability

The local adaptability experiment was conducted in cooperation with Japan Agriculture (JA) Chikuma, JA Nakano City, JA Green Nagano, Nagano Prefectual Economics Federation of Agr. Coop., Nagano Agri. Ext. Ctr., and Hokushin Agri. Ext. Ctr. A 25-fold dilution of the activated carbon F was used on the local adaptability experiment. The solution was sprinkled on the field through a watering nozzle using a power sprayer on Jun. 1, 1999, on Jun. 4, 2000 and on Oct. 6, 1999.

(1) Yashiro, Koshoku City

In a field where asparagus had been harvested by greenhouse semi-forcing-culture for 13 years, the soil was tilled by a cultivator, and then one-year-old asparagus plants were planted on Jun. 8, 1999. Data was taken on the growth of the plants on Nov. 26, 1999 (one-year-old plants) and on Dec. 4, 2000 (2-year-old plants), and on the spring harvest from Apr. 21 to May 5 in 2000 (2-year-old plants). The experiment was conducted on 5 groups: 4 treated groups consisting of plots provided with 2,500, 5,000, 10,000 and 20,000 l/ha of 25-fold dilution of activated carbon F solution; and a non-treatment. Each group was replicated 2 times and the area of each plot was 60 m^2. Five plants were sampled per plot for growth data and 20 plants were harvested for yield data.

(2) Hiraoka, Nakano City

The experiment was conducted in an open asparagus field of successive cropping for 15 years. Plants were pulled out on Nov. 10, 1999. The soil was tilled by a cultivator and one-year-old asparagus plants were planted on Jun. 7, 2000. The growth of the one-year-old plants was examined on Nov. 20, 2000. The experiment was conducted on 3 groups: a treatment with 40,000 l/ha of the activated carbon F solution, a non-treatment and treatment with an additional 500 ml of the solution by sprinkling around the roots after planting. The area of each plot was 126 m^2. 5 plants were sampled for examining the aboveground parts in each plot and 3 plants for the underground parts.

(3) Entoku, Nakano City

The experiment was conducted in an open field where asparagus had been harvested by greenhouse semi-forcing culture for 10 years. The soil was tilled by a riding plow where one-year-old asparagus plants were planted on Oct. 7, 1999. The growth of the 2-year-old plants was examined on Nov. 20, 2000. The experiment was conducted on 3 groups: 2 groups treated with 20,000 and 40,000 l/ha of the activated carbon F solution and a non-treated group. The area of each plot was 300 m^2, and the examination was made on 5 plants per plot.

The Duncan's multiple range test at $P \leq 0.05$ was used for mean separation.

Results and Discussion

Experiment.1.

In the plots treated with activated carbon F, stem fresh weight,

number of storage roots, fresh weight of underground parts and growth amount increased in comparison with those in non-treated plot (Table 1). All the plots treated with activated carbon F weren't inhibited by replanting, which is represented by the product of the fresh weight of the underground parts and by the storage root Brix when compared with the non-treated plot and even the control plot.

Experiment.2.

Treatment with activated carbon F had no effect upon the germination rate of lettuce (Table 2). The radicle length was 254%, 138% and 174% in the plot treated with the 200-fold and was 817%, 258% and 402% in the plot treated with the 25-fold dilution in comparison with the non-treated plot in 1998, 1999 and 2000, respectively. The radical length in the 25-fold dilution plot in which the asparagus root powder was added was almost the same as that in the control plot, while it was longer in the 25-fold dilution plot where no root powder was added than that in the control plot. These results of the bioassay with lettuce showed that activated carbon F had effects to mitigate allelopathy in the same way as Exp.1.

Experiment.3.

The growth of asparagus was the same or better in the treated groups than the non-treated plot (Table 3). In particular, the plots treated with the 25 to 50-fold dilution had better results in number of stems and storage roots, fresh weight of underground parts, growth amount and GI' (growth index) compared with those in the non-treated plot.

Experiment.4.

In all 3 areas, the growth of asparagus was better in the treated plot than that in the non-treated plot (Table 4,5,6). In particular the treated plots had better results in fresh weight of underground parts, number of storage roots, growth amount and GI' compared with those in the non-treated plot. Three local adaptability experiments showed the same result as *Expt.3.* Two-year-old plants in Koshoku City also revealed better growth in the treated

Table 1. Effect of activated carbon F on the growth of one-year-old asparagus.

Treatment	Longest Stem Length (cm)	No. of Stems	Thickest Stem Diam. (mm)	Fresh wt of Stem (g)	Longest Root Length (cm)	Thickest Root Diam. (mm)	No. of Storage Roots	Fresh wt of Under-ground Parts (g)	Storage Root Brix[v] (%)	Growth Amount[u]
(1998)[z]										
50-fold	102.6a[w]	12.8a	2.9a	59.8a	59.0a	3.9a	84.8a	180.0a	28.7a	51.6
100-fold	101.4a	12.6a	3.1a	62.4a	60.8a	3.2b	66.6b	161.4b	28.4a	45.8
Non-Treated[y]	105.0a	10.4a	3.1a	55.2a	60.2a	3.7ab	68.4b	145.6c	28.7a	41.8
Control[x]	100.0a	10.6a	3.4a	55.0a	55.8a	3.7ab	64.2b	172.2ab	26.1b	44.9
(1999)										
25-fold	79.6a	18.9a	2.6a	19.9a	60.1ab	3.5a	43.1a	123.0a	34.0a	41.8
50-fold	69.3b	17.3a	2.1bc	15.4ab	70.1a	3.4a	44.6a	109.6a	33.2bc	36.4
100-fold	73.5ab	15.4a	2.4ab	13.0bc	61.2ab	3.3a	47.3a	108.8a	33.4b	36.3
Non-Treated	69.9b	7.0a	1.6d	6.8d	50.3b	2.7b	27.3b	47.3c	32.7d	15.5
Control	72.5ab	12.1a	2.0c	9.6cd	59.9ab	2.9b	40.6a	88.9b	32.9cd	29.2
(2000)										
25-fold	72.6a	14.0a	2.0a	14.3a	66.7a	3.3a	57.4a	120.0a	32.0b	38.4
Non-Treated	64.3ab	13.9a	1.9a	9.5b	68.4a	3.1a	36.0b	72.4b	30.5c	22.1
Control	55.9b	17.8a	1.4b	12.6a	66.9a	3.0a	44.8b	81.3b	33.0a	26.8

[z] Year of culture.

[y] Non-treated = root powder was added but activated carbon F was not.

[x] Control = no root powder and no activated carbon F was added.

[w] Mean separation within columns by Duncan's multiple range test, $P \leq 0.05$ (n=10).

[v] The 5-10cm storage root brix from the crown and root was measured by ATAGO refraction sugar-concentration meter.

[u] Growth amount = Fresh wt of under-ground parts × Storage root brix / 100.

plots (Table 4). It is considered that the treatment of soil before planting affects the subsequent growth. No significant difference was observed in case of spring harvesting of 2-year-old plants in Koshoku City in the spear yield and number of harvested plants. It is probably due to a short harvesting time after sprouting. The examination on the growth of 2-year-old plants, however, showed a better result in the treated plots than in the non-treated plot. From the result, it can be estimated that the activated carbon F would have an effect on the spear yield of 3-year-old plants (data not shown).

In Nagano Prefecture, asparagus is grown in the area of 1,930 ha in 1999. Approximately 200 ha in Nagano Prefecture is now being replanted. In response to the result of our field, the activated carbon F was used for replanting of asparagus about 40 ha in Nagano Prefecture in 2001. However the allelopathic substances in the secretion of roots and stumps are not directly identified except for the parts of soil around roots (Miller et al., 1991; Young, 1986). From the results of our study, it can be concluded that activated carbon F appears to be effective in mitigating the allelopathy of asparagus in the field experiment. It is necessary to separate and identify the allelopathic substances in asparagus roots and residues to reveal their quantity, durability in a field, and to develop a replanting technology utilizing the activated carbon F.

Table 2. Effect of Activated Carbon F on Germination Rate and Radicle of Lettuce in 1998, 1999 and 2000.

		Activated Carbon F dilution						
	Year[z]	25-fold	50-fold	100-fold	200-fold	Non-[x] treated	Control[w]	25-fold added
Root powder (g)		1	1	1	1	1	0	0
Germination rate (%)	1998	98	97	98	100	91	100	-
	1999	100	100	100	99	99	100	100
	2000	100	100	100	97	99	100	100
Radicle length (cm)	1998	4.17a[y]	1.26c	0.91d	1.30c	0.51e	3.15b	-
	1999	4.98a	4.21ab	3.27bc	2.67cd	1.93d	5.00a	5.59a
	2000	3.90b	3.92b	2.48c	1.69cd	0.97d	4.10ab	5.24a

[z] The experiment was examined on Oct. 26, 1998, on Mar. 1, 1999, on Mar. 1, 2000.
[y] Mean separation within columns by Duncan's multiple range test, $P \leq 0.05$ (n=3).
[x] Non-treated = root powder was added but activated carbon F was not.
[w] Control = no root powder and no activated carbon F was added.

Table 3. Effect of activated carbon F on the growth of asparagus in 2000.

Treatment	Stem Length (cm)	No. of Stems	Stem Diam. (mm)	Fresh wt of Stem (g)	No. of Storage Roots	Fresh wt of Under-ground Parts (g)	Storage Root Brix[x] (%)	Growth[w] Amount	GI' (Growth Index)[v]
25-fold	114a[y]	49a	6.1b	252a	204a	1473a	22.0a	325a	1495
50-fold	106b	44b	6.8a	240a	156b	1148b	22.2a	255b	1406
100-fold	103b	46ab	5.2c	188b	161b	827c	24.0a	199c	1536
Non-Treated[z]	103b	35c	5.4c	190b	144b	808c	25.1a	204c	1254

[z] Non-treated = activated carbon F was not added.
[y] Mean separation within columns by Duncan's multiple range test, $P \leq 0.05$ (n=20).
[x] The 5-10cm storage root brix from the crown and root was measured by ATAGO refraction sugar-concentration meter.
[w] Growth amount = Fresh wt of under-ground parts × Storage root brix / 100.
[v] GI' (growth index) = Section area of 20 cm high from the ground per plant × Stem length.

Table 4. Effect of Activated Carbon F on the Growth of Asparagus
(Koshoku City, Nagano Prefecture, Japan)

Treatment[z]	Stem Length (cm)	No. of Stems	Stem Diam. (mm)	Stem Fresh wt (g)	No. of Storage Roots	Fresh wt of Under-ground Parts (g)	No. of Brood Bud Groups	Storage Root Brix[v] (%)	Growth[u] Amount
(1999)[y]									
2,500L Sprinkle	121c[w]	11.6b	5.0a	2295c	132ab	618ab	5.5b	21.6b	134
5,000L Sprinkle	134b	13.6ab	5.4a	2620b	127ab	503b	4.7bc	21.4b	108
10,000L Sprinkle	138ab	13.6ab	5.6a	3255a	148a	743a	6.8a	23.6a	175
20,000L Sprinkle	145a	16.3b	5.8a	2680b	128ab	507b	5.3bc	23.1ab	117
Non-Treated[x]	139ab	15.7b	5.6a	2930ab	113b	208c	4.0c	22.3ab	45
(2000)									
2,500L Sprinkle	-	-	-	-	375b	2300bc	-	12.1b	278
5,000L Sprinkle	-	-	-	-	372b	2800b	-	10.4bc	292
10,000L Sprinkle	-	-	-	-	361b	1700c	-	8.9cd	151
20,000L Sprinkle	-	-	-	-	468a	4150a	-	18.3a	757
Non-Treated	-	-	-	-	174c	720d	-	7.5d	54

[z] 25-fold dilution of activated carbon F.

[y] Year of culture. 1999:1-year-old plants, 2000:2-year-old plants.

[x] Non-treated = activated carbon F was not added.

[w] Mean separation within columns by Duncan's multiple range test, $P \leq 0.05$ (1999: n=20, 2000: n=12).

[v] The 5-10cm storage root brix from the crown and root was measured by ATAGO refraction sugar-concentration meter.

[u] Growth amount = Fresh wt of under-ground parts × Storage root brix / 100.

Table 5. Activated Carbon F and Growth of Asparagus
(1-year-old plants; Hiraoka, Nakano City, Nagano Prefecture, Japan, 2000).

Treatment[z]	Stem Length (cm)	No. of Stems	No. of Storage Roots	Fresh wt of Under-ground Parts (g)	No. of Brood Bud Groups	Storage Root Brix[w] (%)	Growth[v] Amount	GI' (growth index)[u]
40,000L Sprinkled	100	18b[x]	268a	900a	7.0a	18.2a	164a	1274
40,000L Around Plants	110	29a	242b	860a	6.7a	19.4a	166a	1649
Non-Treated[y]	95	15b	179c	620b	6.0a	19.4a	121b	927

[z] 25-fold dilution of activated carbon F.

[y] Non-treated = activated carbon F was not added.

[x] Mean separation within columns by Duncan's multiple range test, $P \leq 0.05$ (n=6).

[w] The 5-10cm storage root brix from the crown and root was measured by ATAGO refraction sugar-concentration meter.

[v] Growth amount = Fresh wt of under-ground parts × Storage root brix / 100.

[u] GI' (Growth index) = Section area of 20 cm high from the ground per plant × Stem length.

Table 6. Activated Carbon F and Growth of Asparagus
(2-year-old plants; Entoku, Nakano City, Nagano Prefecture, Japan, 2000)

Treatment[z]	Stem Length (cm)	No. of Stems	Storage Root Brix (%)[w]	GI' (growth index)[v]
40,000 L sprinkle	125	28a[x]	19.7a	2902
20,000 L sprinkle	130	21b	21.8a	2588
Non-treated[y]	105	18b	18.6a	1546

[z] 25-fold dilution of activated carbon F.
[y] Non-treated = activated carbon F was not added.
[x] Mean separation within columns by Duncan's multiple range test, $P \leq 0.05$ (n=6).
[w] The 5-10cm storage root brix from the crown and root was measured by ATAGO refraction sugar-concentration meter.
[v] GI' (growth index) = Section area of 20 cm high from the ground per plant × Stem length.

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活性炭フロアブル剤を利用したアスパラガスのアレロパシー軽減技術

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摘　要

長野県のアスパラガス（*Asparagus officinalis* L.）の栽培面積は 1,930ha(1999 年)で，毎年 200ha 程度が改植されている．アスパラガスでは改植した後に新植圃場に比べて減収したり，若年株から欠株が発生するなどの障害が多く見られ，その一因としてアレロパシーの関与が知られている．本研究では，活性炭フロアブル剤(以下，活性炭Ｆ)のアレロパシー軽減効果について検討した．指標植物としてレタス（*Lactuca sativa* L.）およびアスパラガスの１年株を用いて検定を行った結果，活性炭Ｆのアスパラガスに対するアレロパシー軽減効果および生育促進効果が認められた．さらに，活性炭Ｆの適応性試験を行った３カ所の現地のいずれでも，活性炭Ｆの 25～100 倍希釈液を処理すると，アスパラガス株の生育がおう盛になり，特に地下部重，貯蔵根数，株養成量，ＧＩ'（生育指数）について処理区が無処理区に優った．これらから，活性炭Ｆは圃場レベルでもアスパラガスのアレロパシー軽減効果が高いと推察された．