JARQ 35(1), 39 – 45 (2001) http://www.jircas.affrc.go.jp

Methods of Control of Injury Associated with Continuous Vegetable Cropping in Japan
— Crop Rotation and Several Cultural Practices —

Mitate YAMADA[1]*

Department of Farmland Utilization, National Agriculture Research Center
(Tsukuba, Ibaraki, 305–8666 Japan)

Abstract

As vegetables are often grown under continuous cropping in Japan, injury associated with continuous cropping is frequently observed. Although the methods of control are based on the use of chemicals, the importance of promoting sustainable cultivation and environment-friendly technologies is being increasingly recognized. Plant diseases caused by fungi or bacteria, such as clubroot, yellows are major problems. To address these problems, crop rotation with sweet corn, introduction of resistant radish varieties as trap crops or inoculation with endophytes have been applied. Injury caused by nematodes is also a serious problem. Practical methods using antagonistic plants such as marigold have been developed, because only one season is required to introduce these plants with only minor changes in the cropping systems. Selection of crop combinations is essential. Taro (*Colocasia esculenta* Schott.) is severely damaged by a root lesion nematode (*Pratylenchus coffeae*). By examining the degree of suppression of this nematode by many kinds of crops, determination of crop sequence efficiency became possible for the control of nematodes and offers a wider range of selection of crop combinations. Taro is injured by *P. coffeae* and by the root knot nematode (*Meloidogyne incognita*), while radish (*Raphanus sativus* L.) is attacked by the root lesion nematode (*Pratylenchus penetrans*). The combination of these 2 vegetable crops with a third one, such as vegetable soybean (*Glycine max*), can minimize the injury caused by these 3 nematodes.

Discipline: Horticulture
Additional key words: trap crop, nematodes, antagonistic plant, radish, taro

Introduction

In Japan, vegetables are usually grown under continuous cropping, due to the small scale of land ownership and to promote effective use of fields, machines and markets. Several diseases of vegetables are caused by continuous cropping such as bacterial brown rot, fusarium wilt, clubroot and black rot, yellows in addition to nematode injury. Although the control measures of these diseases are based on the use of chemicals, the importance of promoting sustainable cultivation and environment-friendly technologies is being increasingly recognized. Therefore, crop rotation seems to be a key technology to address these problems. Though crop rotation technology is important, it must be flexible, clearly defined and attractive to the farmers. To control nematodes, practical methods using antagonistic plants such as marigold have been developed. Selection of crop combinations is generally the most efficient measure to control nematodes but it is difficult to achieve. Several researchers have succeeded in introducing antagonistic plants or crop rotations[4,14]. However, the kinds of antagonistic plant species are limited and the plants usually have no economic value. It is also difficult to identify the optimum rotation in terms of duration and to select the best sequence.

Regarding cropping systems and cultural practices, appropriate systems or practices must be utilized or adjusted to the prevailing natural and economic condi-

Present address:
[1] Production and Postharvest Technology Division, Japan International Research Center for Agricultural Sciences (JIRCAS) (Tsukuba, Ibaraki, 305–8686 Japan).
*Corresponding author: fax +81–298–38–6652, e-mail mitate@jircas.affrc.go.jp
Received 21 December 1999, accepted 3 February 2000.

tions. Therefore, a large number of methods must be developed and evaluated for the adoption of the best technology. In this paper, widely disseminated or promising practical methods are described. Methods to identify suitable cropping systems or to determine the applicability of technology are also introduced.

Control of plant diseases by the selection of cropping systems

1) Suppression of clubroot fungus (Plasmodiophora brassicae WORONIN) *by the introduction of sweet corn cultivation*

Summer in Japan is very hot and humid like in a tropical country and it is very difficult to grow temperate vegetables such as cabbage. In highland areas, farmers are able to produce good quality cabbage and obtain a high income only in the summer season. Therefore, they grow cabbage over wide areas in their farmlands, which results in continuous cropping of cabbage and leads to diseases associated with continuous cropping, for instance clubroot, black rot, etc. To avoid clubroot injury, they apply a large amount of PCNB (quintozene) or use clubroot-resistant varieties. In spite of their efforts, the situation is becoming more serious and they even apply chloropicrin. In one of the highland areas in Gifu prefecture, where farmers have encountered the same problems, cultivation of sweet corn has been increasing and fallow fields were also observed because of the lack of labor. Akaike[1] tried to combine these 2 crops and utilize fallow fields to control the disease. He set up 9 plots in the field for continuous cropping of cabbage as shown in Table 1. Sweet corn was introduced into 3 plots differing in the duration of cultivation. Fallow field was arranged in the same way as the sweet corn fields in another 3 plots. For the control, fields with continuous cropping of cabbage with or without application of chemicals (PCNB or chloropicrin) were set up.

Table 1. Effect of introduction of sweet corn cultivation or fallow on the severity of outbreaks of cabbage club-root

No.	1988	1989	1990	1991
1	SC	88	SC	49
2	SC	SC	14	82
3	SC	SC	SC	2
4	FL	95	FL	66
5	FL	FL	30	79
6	FL	FL	FL	15
7	90	100	100	97
8	42+P	50+P	64+P	48+P
9	4+C	12+C	4+C	1+C

Figures show the index of severity of clubroot (0–100).
Figures also show cultivation of cabbage.
SC: Sweet corn, FL: Fallow, +P: PCNB, +C: Chloropicrin.

The results are shown in Table 1. Cultivation of sweet corn during a three-year period suppressed the outbreak of clubroot almost completely and the effect of fallow was rather limited but showed almost the same tendency. Introduction of sweet corn or fallow for 2 years did not enable to control the disease completely but was effective. Rotation of cabbage and sweet corn led to the decrease of the incidence of clubroot disease. Therefore, three - or four - year rotation for cabbage cultivation in fields with severe outbreaks can be recommended. Based on these results, the main effect of sweet corn on the suppression of clubroot was the lack of host plants in the summer season. In addition, sweet corn cultivation was more effective than fallow. It should be emphasized that the resting spores of *P. brassicae* survived over a long period of time in the soils.

2) Trap crops

Clubroot is widely observed in Japan, because important vegetables in the Cruciferae family which are host plants of clubroot, such as cabbage, Chinese cabbage, radish, cauliflower, broccoli and many kinds of leafy or root vegetables are used for traditional cooking. Resting spores are easily activated by root exudates from not only the root of a susceptible plant but also the root of a resistant plant[9], suggesting that the trap effect could be obtained in the field. Recently it has been reported that clubroot in Chinese cabbage cultivation had been controlled by using trap crops.

At first, Yamada et al.[15] cultivated resistant radish varieties and after harvest they transplanted Chinese cabbage. Clubroot disease spores were activated by radish cultivation but could not multiply in the roots of the resistant radish varieties and their number decreased. As the spore density is lowest around the radish root, it is preferable to plant Chinese cabbage seedlings into the hole made by radish root without disturbance of soil. To avoid soil incorporation with a high spore density soil, fertilizer for Chinese cabbage plant was applied at the same time as for radish cultivation. Mulching film was re-used to prevent the contamination with polluted soil. When the Chinese cabbage plant was transplanted, addition of 5–7 g calcium cyanamide into the holes was recommended to enhance the effects of nitrogen nutrient supply, sterilization and pH control.

In another report, resistant radish varieties[12] were grown for 2 months and incorporated into soil. In the current study, radish could not be harvested, but many

Table 2. Representative antagonistic plants for nematodes and availability in Japan

No.	Plant name	Scientific name	Availability					
			Root knot nematodes			Root lesion nematodes		
			Mi	Mh	Mj	Pp	Pc	Pv
1	Marigold	*Tagetes erecta*	○		○	○		
		T. patula	○	○	○	○	○	○
2	Guinea grass	*Panicum maximum* Steud.	○	○	○			
3	Crotalaria	*Crotalaria spectabilis*	○	○	○		○	○
		C. juncea	○	○			○	
4	Oat	*Avena sterigosa*		○		○		
5	Glaucous cassia	*Cassia glauca*		○		○		
6	Peanut	*Arachis hypogea* L.	○		○	○	○	

Mi : *Meloidogyne incognita,* Mh: *M. hapla,* Mj: *M. javanica,*
Pp : *Pratylenchus penetrans,* Pc: *P. coffeae,* Pv: *P. vulnus,*
○ : Effective.

methods of sowing radish including broadcasting were effective. Plowing of radish must be performed one month before transplanting of Chinese cabbage to obtain good results.

3) Other environment-friendly technologies for the control of plant diseases

Yellows of Chinese cabbage is a major problem in the largest production area, namely, Ibaraki prefecture. Watanabe et al.[13] obtained good results by selecting resistant varieties and combining them with the inoculation of endophytes. This method can be applied in fields with mild or moderate outbreaks. The beneficial effect of the utilization of endophytes or microorganisms has been reported in the case of Welsh onion (*Allium fistulosum* L.) cropped with bottle gourd (*Lagenaria siceraria* STANDLEY var. *hispida* HARA) to suppress fusarium wilt of bottle gourd[2]. They showed that *Pseudomonas gladioli* multiplied in the below ground parts of Welsh onion and inhibited fusarium wilt of bottle gourd. Attempts to apply these technologies have been limited because of the unstable results. However as shown in the case of Chinese cabbage, stable results can be obtained by determining the conditions of application.

Control of nematodes by the selection of cropping systems

1) Antagonistic plants

Antagonistic plants for the control of nematodes are widely used by Japanese farmers because these plants can be introduced in the cropping systems without a major change in the systems. For example, for the production of radish in Miura peninsula, marigold (*Tagetes* sp.) is used to avoid injury caused by the root lesion nematode (*Pratylenchus penetrans*)[5]. The major crop, radish, is cultivated in the winter season. Watermelon or other vegetables are grown in the summer season, but the importance of these crops is negligible. Marigold can be introduced as an antagonistic plant in the summer season while radish continues to grow.

Several nematicidal substances have been isolated from antagonistic plants[3,10,11]. But the role of these substances in the control of nematodes in the fields has not been fully elucidated. Some of them are secreted into the surrounding soil, but the evaluation of the concentration and stability in soil is very difficult. To achieve a nematicidal effect, nematodes must be attracted to the roots where nematicidal substances are present. At the same time, other functions to suppress nematodes such as starvation operate[7]. Therefore, without practical tests, the evaluation of antagonistic plants is difficult.

The major antagonistic plants used in Japan[7] are listed in Table 2. Antagonistic plants No.1 to No.4 are widely used in Japan. Peanut is also a good antagonistic plant, but it is losing its economical value due to competition with imported peanuts except for the high quality of the peanuts produced in the area. Because it takes a long time to cultivate peanuts, it is rather difficult to introduce them between the cultivation of main vegetables.

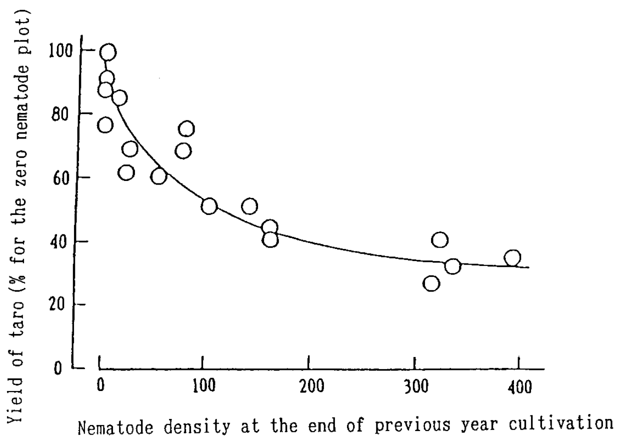

Fig. 1. Effect of nematode density on taro yield[14)]
Unit: Number of nematodes per 20 g soil.
Separated by Baermann method.

2) Evaluation of crop combinations in the control of the injury caused by root lesion nematodes

Taro is severely damaged by the root lesion nematode (*P. coffeae*) and is very sensitive even at a low nematode density. Yahiro[14)] formulated guidelines for selecting crop combinations, sequences and effective use of antagonistic plants in relation to taro cultivation. To avoid the damage caused by this nematode, the density before planting must be controlled almost at 0 level, which implies that the density at the end of the preceding plant cultivation (previous autumn) is less than 3–4 nematodes per 20 g surface soil as shown in Fig. 1. This nematode is widely distributed in Japan and is parasitic on many kinds of vegetables [6)]. Marigold (*Tagetes erecta* L., *T. patula* L.) and peanut (*Arachis hypogea* L.) are effective antagonistic plants for the nematode though their economical value is limited. Other plants are somewhat effective. The relationship between the nematode density at the end of cultivation of the preceding crops (X-axis) and that at the end of the cultivation year (Y-axis) is shown in Fig. 2, reflecting the effect of plant cultivation on the nematode density. For example, at the end of the cultivation of sweet potato (*Ipomoea batatas* Lam. cv. Shirosatsuma; semi-resistant) there were 100 nematodes while the start-

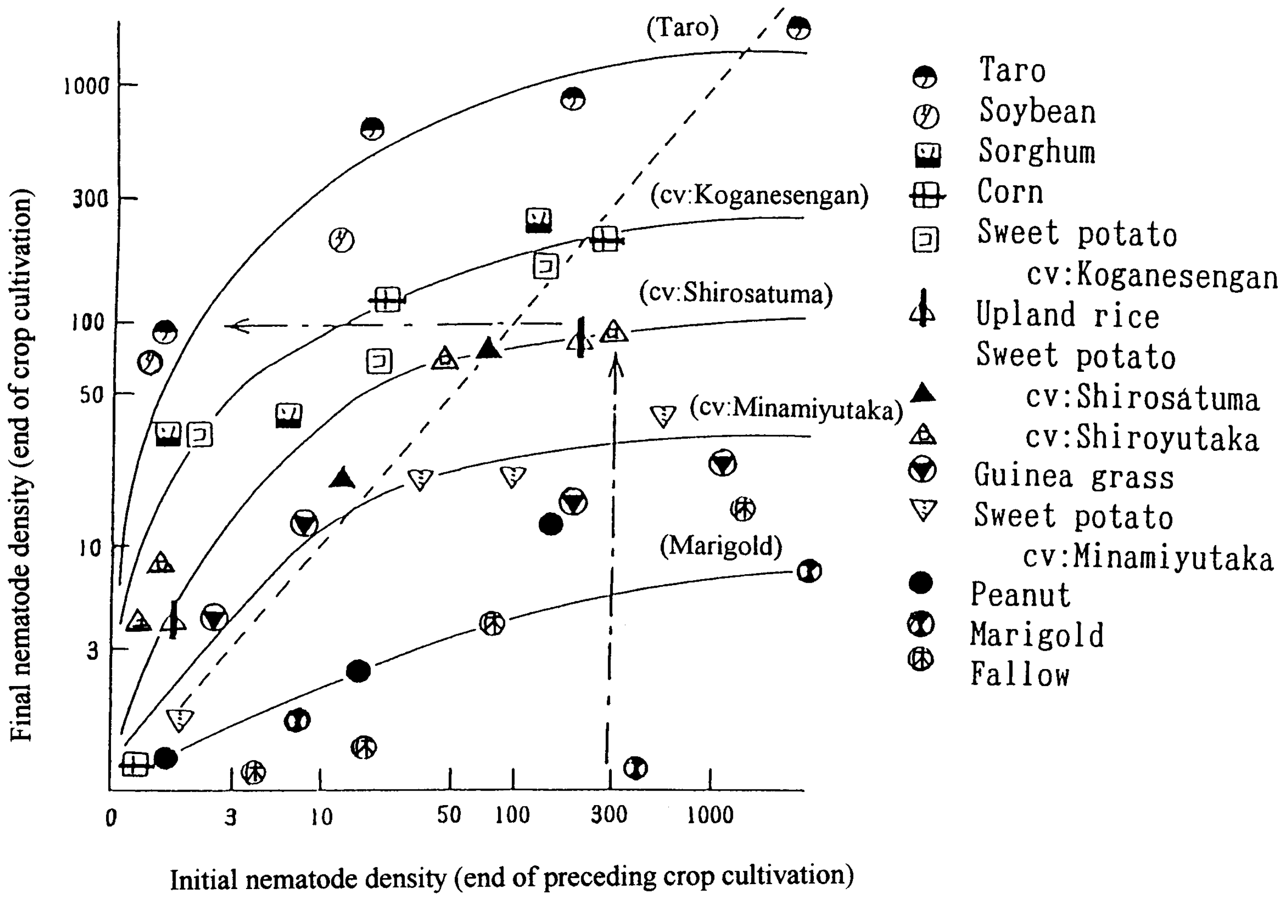

Fig. 2. Effect of cultivation of several plants at various initial nematode densities on the nematode density at the end of cultivation[14)]
Unit: Number of nematodes per 20 g soil. Separated by Baermann method.

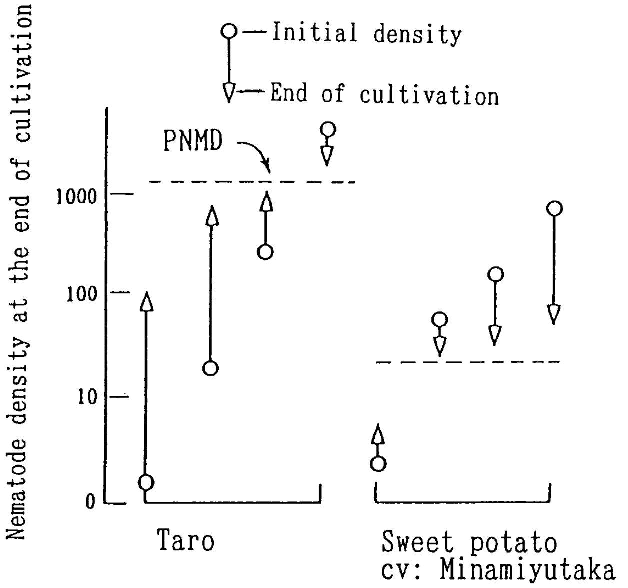

Fig. 3. Effect of initial nematode density on the density at the end of cultivation[14)]

ing density was 300 nematodes per 20 g soil (arrow in Fig. 2.). This figure also indicates that peanut cultivation leads to a level of about 10 nematodes which may damage taro. Peanut cultivation for a consecutive period of 2 years results in a safe level (first year, from 300 to 10 nematodes; second year, from 10 to about 2 nematodes). Peanut cultivation in the first year can be substituted by the cultivation of Guinea grass (*Panicum maximum* Steud.) (300 to 30 nematodes in the first year, Guinea grass; 30 to 2 nematodes in the second year, peanut). However, the cultivation of Guinea grass for 2 consecutive years may not decrease sufficiently the number of nematodes (300 to 30 nematodes in the first year and 30 to 20 nematodes in the second year). Opposite results can also be obtained by changing the sequence of the 2 plants. Namely, peanut - Guinea grass sequence may lead to a high nematode density (300 to 10 nematodes in the first year, peanut; 10 to 11 nematodes in the second year, Guinea grass). In the meantime, as the maximum nematode density in a given field is around 1,000, the Guinea grass - peanut sequence always leads to a safe nematode density (1,000 to 40 nematodes in the first year, Guinea grass; 40 to 3 nematodes in the second year, peanut). Almost all the curves in Fig. 2 are crossing with a 45°line (dotted line) and are located in the upper part of the line in the low X-axis range from 0 to the crossing point. We defined the density at the crossing point as the "Specific residual nematode density" (hereafter referred to as PNMD). The cultivation of plants at this density will not alter the nematode density. If the plant is introduced at an initial density below the PNMD, the cultivation will lead to an increase of the number of nematodes. These relationships can be expressed in another way as shown in Fig. 3. The tendency of nematode density affected by the cultivation of some plants at various initial densities is denoted by arrows in Fig. 3. The density of nematodes reached by the cultivation of certain plants seems to move toward a certain level that is specific to the plant, hence the adoption of PNMD. If the initial nematode density is higher than the PNMD, even a plant which is usually a good host of the nematode, will decrease the density. Consequently, plants cultivated at a higher initial nematode density than the PNMD will decrease the nematode density. In contrast, plants will increase the nematode density when they are introduced at a level below the PNMD. Though the sweet potato cultivars can not suppress completely the nematodes, resistant sweet potato cultivars, such as Shiroyutaka and Minamiyutaka can be used and a wider range of selection of crop species for the crop combinations can be applied.

3) Control of multiple species of nematodes by crop rotation

Taro is injured by root lesion nematodes as shown in Fig. 4 and the root knot nematode (*M. incognita*) while radish is attacked by the root lesion nematode (*P. penetrans*). Although the growth of radish is not retarded considerably by *P. penetrans*, the injury on the root surface decreases its marketable value, as shown in Fig. 5. Radish is very sensitive to this nematode. Soybean is also attacked by a cyst nematode (*Heterodera glycines*) and root lesion nematode (*P. penetrans*). As a result, there were many nematodes in every plot with continuous cropping corresponding to the host-parasite relation as shown in Fig. 6. Introduction of marigold or a kind of oat (*Avena sterigosa*) is common in the control of *P. penetrans* in radish cultivation fields. Chikaoka[4)] reported that taro was not a good host of *P. penetrans* and recently Shimizu[8)] has observed that taro suppressed this nematode as strongly as fallow. In the crop rotation plot, there was no *P. penetrans* at the end of taro cultivation[16)]. These results indicate that both soybean and radish increase the incidence of *P. penetrans*, while taro can suppress this nematode almost to a 0 level in crop rotation. For *P. coffeae*, radish is not a good host nor is soybean in the Kanto area, in the central part of Japan. As a result, a low density of both nematode species was observed in the rotation plots while a high nematode density was observed in the plot with continuous cropping. If we focus on the injury of radish and taro, a radish - taro rotation may also be effective. On the other hand, the root knot nematode of taro (*M. incognita*) does not injure severely taro, but has a very wide host range and injures

Fig. 4. Injury of taro attacked by nematodes *(P. coffeae)*

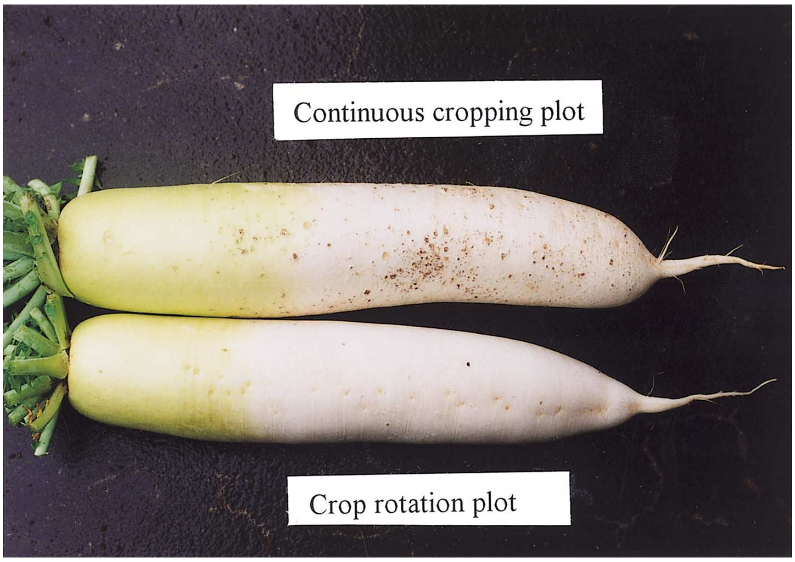

Fig. 5. Injury of radish attacked by nematodes *(P. penetrans)*

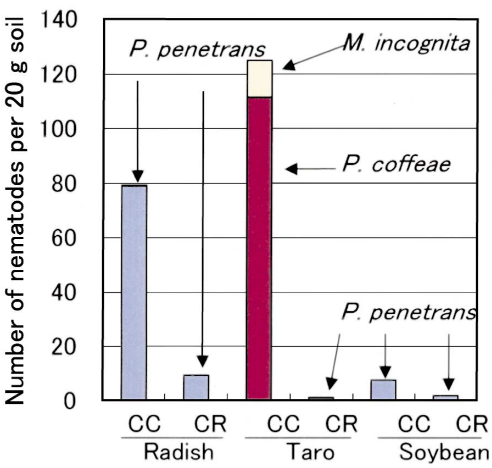

Fig. 6. Species and density of nematodes affected by crop rotation
CC: Continuous cropping plot, CR: Crop rotation plot.

tomato, melon, carrot, etc. Since it is preferable to keep the nematode density at a low level, a 3-year crop rotation is more effective. Regarding the sequence of crop rotation, the taro - radish - soybean rotation is more suitable than the radish - taro - soybean rotation because radish is more sensitive to *P. penetrans* than soybean and the density directly after taro cultivation is the lowest. Soybean is also attacked by a cyst nematode (*Heterodera glycines*) and the longevity of the cyst exceeds 3 years. To solve this problem, new methods have to be developed.

Future perspective

As mentioned above, although many environment-friendly technologies have been developed, their application in farmers' fields is not common. Cropping systems are usually specific or adapted to the environment tested. Development of new technologies that are compatible with the economic and natural conditions of a certain environment is very important. In this regard, a participatory approach involving a close collaboration between researchers and farmers should be promoted to identify the most suitable technologies for specific systems.

References

1) Akaike, Y. (1992): Effects of sweet corn cultivation in the field of severe outbreak of cabbage clubroot in highland area. *New technol. Kanto Tokai Agric. (H.3)*, 237–240 [In Japanese].
2) Arie, T. et al. (1987): Biological control of fusarium wilt of bottle gourd by mix-cropping with Welsh onion or Chinese chive inoculated with *Pseudomonas gladioli*. *Ann. Phytopath. Soc. Jpn.*, **53**, 531–539 [In Japanese with English summary].
3) Bakker, J.et al. (1979): Photoactivation of the nematicidal compound α-Terthienyl from roots of Marigolds (*Tagetes* Species). *J. Biol. Chem.*, **254**, 1841–1844.
4) Chikaoka, I. (1979): Host plants of *Pratylenchus penetrans*. *Jpn. J. Nematol.*, **9**, 49–53 [In Japanese with English summary].
5) Chikaoka, I. (1983): Studies on the damage of crops by the root lesion nematode, *Pratylenchus penetrans* Cobb, and control measures especially by the utilization of marigold (*Tagetes* spp.). *Bull. Agric. Res. Inst. Kanagawa*, **125**, 1–39 [In Japanese with English summary].
6) Gotoh, A.(1974): Geographic distribution of *Pratylenchus* spp. (Nematoda: Tylenchida) in Japan. *Bull. Kyusyu Agric. Exp. Stn*. **17**, 139–224 [In Japanese with English summary].
7) Sano, Z. (1992): Effects of antagonistic plants and resistant varieties on suppression of nematode density. Progress in nematology. A commemoration of the twentieth anniversary of the Japanese nematological society. Japanese Nematological Society, Ibaraki, Japan, 253–257 [In Japanese].
8) Shimizu, K. (1997): Effects of non-host cropping on soil density of *Pratylenchus penetrans*. *Res. Prompt Rep. (Integrated Agric. 1996),* 111–112 [In Japanese with English summary].
9) Suzuki, K. et al. (1992): Some properties of germination-stimulating factor from plant for resting spores of *Plasmodiophora brassicae*. *Bull. Hokkaido Ann. Phytopath. Soc. Jpn.,* **58**, 699–705 [In English with Japanese summary].
10) Takasugi, M. et al. (1977): The relation between the structure of asparagusic acid-related compounds and their nematicidal activity. *Bull. Hokkaido Agric. Exp. Stn.,* **118**, 105–111 [In Japanese with English summary].
11) Uhlenbroek, J. H. & Bijloo, J. D. (1958): Investigation on nematicides I. Isolation and structure of a nematicidal principe occurring in *Tagetes* roots. *Recueil,* **77**, 1004–1009.
12) Watanabe, K. & Iwase, I. (1997): Suppression of clubroot of Chinese cabbage by cultivation and plowing-in radish resistant variety 'Kozena'. *Res. Prompt Rep. (Kanto Tokai Agric. H.8)*, 13–14 [In Japanese].
13) Watanabe, K., Tanaka, K. & Narisawa, T, I. (1999): Selection of clubroot resistant Chinese cabbage varieties 'T741' and utilizaition. *Res. Prompt Rep. (Kanto Tokai Agric. H.10)*, 332–333 [In Japanese].
14) Yahiro, K. (1982): Effects of plant introduction on the density of root lesion nematode. *Res.Prompt Rep. (Integrated Agric. 1981),* 197–198 [In Japanese].
15) Yamada, K. et al.(1997): Cultivation method to suppress clubroot of Chinese cabbage using trap crop. *Res.Prompt Rep. (Kanto Tokai Agric. H.8)*, 65–66 [In Japanese].
16) Yamada, M. & Nakagawa, I. (1998): The crop rotation to suppress all kinds of nematodes to attack radish and taro plant in Kanto district. *New Technol. Kanto Tokai Agric. (H.9)*, 163–169 [In Japanese].