Control of Clubroot Disease of Crucifers, with Reference to the Soil Solarization Technique

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Clubroot is affecting 11,000 ha of the field in Japan which comes up to around 10% of total cultivation area of Chinese cabbages, turnips, and cabbages according to the result of a questionnaire in 1977.[4] Particularly, in recent years, clubroot has come to a serious problem in cropping those vegetables, though the disease was formerly regarded as a minor one. This may be attributed to the prevalence of large-scale and continuous cropping, which causes a rise of inoculum potential of the pathogen in soil. *Plasmodiophora brassicae*, the causal fungus, forms numerous propagules (ca. 10^9/g tissue of clubroot gall), so-called "resting spores," inside the host cells (Plate 1). Resting spores are released in soil when the gall tissue is decomposed, and there they survive at least several years being ready to be the infection source.

At present, some control measures against the disease are being practiced, but an effective system for sufficient control has not been established. Furthermore, no clubroot-resistant cultivar with practical commercial characters has been obtained as yet, though it is expected to develop in a few years by the great efforts of the breeders. Under the circumstances, the heavy

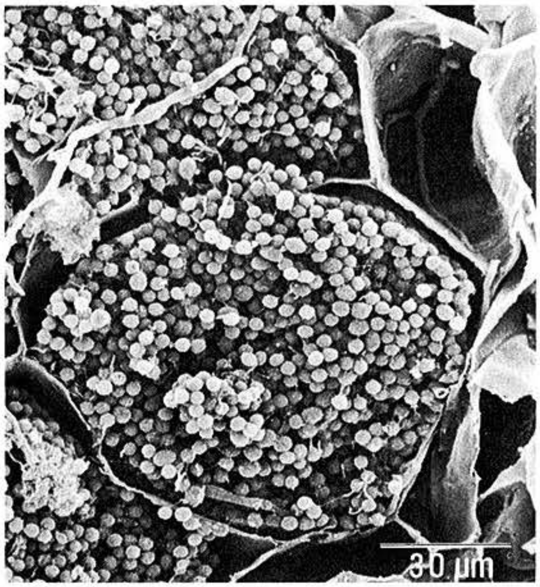

Plate 1. Scanning electron micrograph of resting spores of *P. brassicae* within host cells of clubbed tissue

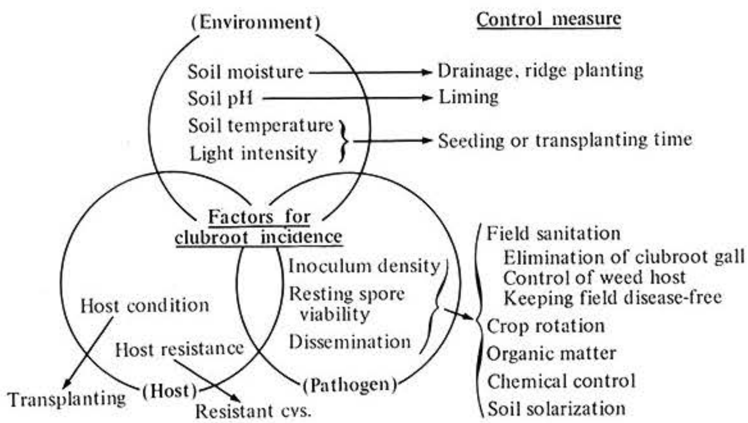

Fig. 1. Factors for clubroot incidence and corresponding control measures

infestation of the field may result in further difficulty in suppressing the disease.

In this paper, the authors wish to present the current status of controlling clubroot in Japan firstly. Secondly, the suggestible data for establishing soil solarization[7] technique will be presented. Soil solarization seems to be a new and promising method which is adoptable even for heavily infested fields. Since the method has many advantages such as energy-saving, non-hazardous, and preserving biological equilibrium in soil, the development of the method is being watched with keen interest.

Current status of controlling clubroot

The factors for clubroot incidence consist of three phases, i.e., environment, host, and pathogen, which influence each other as a matter of course. The control measures against the disease are closely related to those factors, namely to the ecology of the disease (Fig. 1). Inasmuch as those measures do not always show the sure effect when they are adopted solely on a field scale, it is necessary to combine them as many as possible. Actually, many instances of successful control were obtained up to the present, when those measures were "integrated."

Soil moisture is one of the most important factors. High soil moisture is favorable for the disease incidence because it may help the germination of resting spores, and primary and secondary infection through the zoospores of the pathogen.[2] Accordingly, drainage and ridge planting proved effective, and those measures have been practiced in lowland fields such as rotational paddy fields.

Soil pH is the factor greatly influencing the disease incidence. It is generally believed that lower soil pH results in a severer disease whereas less disease occurs in alkaline soils. Although very little is known about the mechanism of the effect of soil pH on the disease, it is suggested that soil pH affects the resting spore germination. The pH adjustment in the field by using hydrate lime or calcium cyanamide fertilizer is widely adopted for the control of the disease. Its effect, however, is occasionally diminished when the other factors such as population of resting spores in soil or soil moisture are favorable for the disease.

Soil temperature may affect the activity of the pathogen and the hosts. For the disease incidence, 20–25°C is assumed to be favorable. It has also been found that high levels of light intensity favor the disease occurrence. Since it is unlikely for the light to affect the pathogen in soil, it probably influences the growth of host plants. To make use of soil temperatures and light intensity for the control measures, the cropping season has to be changed. In the autumn cropping, the delay of seeding or transplanting time is effective as far as sufficient plant growth is secured.

It was found that the seedlings younger than 3-day age were most susceptible to the disease.[2] The disease can be diminished when the seedlings were grown on the clubroot-free soil and then transplanted in the disease-infested field, as compared with the direct-sown plants. Besides this, use of resistant cultivars is expected to be the most promising measure of control in the near future.

From the viewpoint of the pathogen, some factors such as viability of resting spores, their distribution in soil, and the manner of dissemination can eventually be regarded as a single factor, i.e., inoculum potential in soil. Some control measures have been developed aiming at the reduction of inoculum potential.

Field sanitation by elimination of clubroot galls is the most important and essential means for reducing resting spores in soil. This treatment, however, is not widely practiced because of its poor feasibility. Since the viability of the pathogen in soil is extremely high, it is likely that the efficacy of eliminating clubroot galls does not develop unless the treatment is repeated for some seasons. Elimination of weed hosts may be less important when susceptible crops are being cultured. In the fields free from clubroot, cares should be taken to prevent the invasion of the pathogen to the utmost. However, the attention to it seems to be scarcely paid.

Crop rotation is a fundamentally important control measure when the long-term conversion of crops can be carried out. When the short-term crop conversion is intended, no crop which shows clear efficacy to decrease the disease has been found yet. It was suggested that paddy rice culture in infested field caused no effect of diminishing the disease.

Under certain circumstances, field application of organic matter such as farmyard manure lessens the disease occurrence. However, clear relationship between organic matter and the disease has not been found out yet.

Chemical application is a basic measure in the present control system in Japan. Growers apt to depend upon the chemicals too much, and they easily regard the other measures as of little value. However, chemicals sometimes do not show sure effect in the field where the condition is favorable for the disease, especially where the inoculum potential is considerably high. On the contrary, chemicals jointly used with hydrate lime often show the improvement of the efficacy.

In Japan, PCNB (pentachloronitrobenzene) and TPN (tetrachloroisophthalonitrile) are permitted to use for the control of clubroot. PCNB has been used for over 20 years, and at present its dust (20% PCNB) is widely utilized for soil treatment at the dose of 200–250 kg/ha for cabbages and Chinese cabbages. TPN was registered for the use against the disease in 1978. Its dust (10% TPN) is permitted to use at the dose of 300 kg/ha only for Chinese cabbages.

Soil solarization technique

Soil solarization is a method of heating soil by covering it with transparent polyethylene or vinyl film during the hot season, thereby increasing soil temperatures and controlling soilborne pathogens. The effectiveness of the method was first reported by Katan et al.[5] for the open field in Israel. While in Japan, the method has been studied for the plastic greenhouse, which was closed up during the summer months.[6] Although the method has been tried against a number of diseases hitherto, little information is available as to clubroot.[1,8] Horiuchi et al.[3] conducted some experiments for obtaining fundamental data in a laboratory, and also for utilizing them in a field scale.

1) Laboratory experiment[3]

Soil which was artificially infested with *P. brassicae* as described by Horiuchi & Hori[2] was divided and packed in thin polyethylene bags, and immersed into water baths adjusted to different heat levels. After the treatment, soils were air-dried and examined for infectivity by sowing clubroot-susceptible turnip "Wase-Okabu" on them.

Clubroot incidence was remarkably suppressed when infested soils were heat-treated at 45°C for five days or longer, while at the heat levels below 40°C such an effect was not found. On the other hand, when calcium cyanamide fertilizer was incorporated into clubroot-infested soil, even the heat below 40°C caused the same effect. The effect of heating was thus greatly improved by addition of calcium cyanamide fertilizer, in accordance with the increase of its dose. Further experiment suggested that the effect was attributed to calcium cyanamide, neither to soil pH nor to soil reduction which was due to calcium component of the fertilizer. Since a remarkable

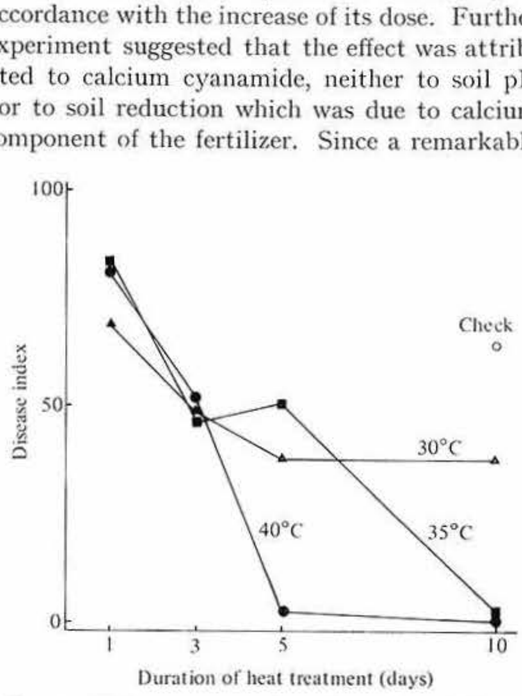

Fig. 2. Clubroot suppressing effect of periodical heating of infested soils for 7 hr a day, as shown by disease index* of turnips grown in those soils

800 kg/ha calcium cyanamide fertilizer was incorporated into each soil before heating. Check: stood at below 20°C for 10 days. *Disease index $=\sum i \cdot n_i/4N \times 100$, where i=disease degree divided into 0 (healthy) to 4(severely affected), n_i=no. of plants classified to each category, N= total no. of plants used.

Table 1. Effect of soil solarization on the disease incidence and the yield response of Wase-Okabu turnip in the field naturally infested with clubroot (in Yokaichi, 1980)

Treatment[a]	% of plants affected	Disease index[b]	Marketable plants[c]	
			% of plants	Yield[d] (kg)
Solarization, with 750 kg/ha CCF[e]	99	86	12	5.0
Solarization, with 1,500 kg/ha CCF	95	75	27	12.8
PCNB, 200 kg/ha	97	55	56	20.7
PCNB, 400 kg/ha	90	44	70	31.6
Check, with 750 kg/ha CCF	100	100	0	0
Check, with 1,500 kg/ha CCF	100	98	1	0.5
Check, untreated	100	100	0	0

a) Solarization was carried out from July 29 to September 4, 1980. Calcium cyanamide fertilizer was applied before solarization, and PCNB was applied at the time of sowing turnips.

b) Disease index $= \sum i \cdot n_i / 3N \times 100$, where i = disease degree divided into [0 (healthy) to 3 (severely affected), n_i = no. of plants classified to each category, N = total no. of plants used.

c) Marketable plants : plants graded as 0 and 1.

d) Weight of subterranean part of turnip per test plot (3.2×6.0 m).

e) CCF = calcium cyanamide fertilizer.

effect was not revealed by treating at low temperatures such as below 30°C, it is believable that the heat may induce the effect of calcium cyanamide in the process of its decomposition. Nevertheless, the effect of calcium cyanamide fertilizer in soil solarization is controvertible with the disease other than clubroot.[1,6]

Some workers[5,7] emphasized the importance of maintaining high soil moisture during the solarization, for improving its efficacy. When clubroot-infested soils with water content between 50 (thoroughly water-logged) and 10% (ca. 18% maximum water holding capacity) were heated at 45°C, the disease incidence was greatly suppressed by 5-day treating, while the same treatment on dry soils (5 and 2%) did not cause a marked effect. The result indicates that solarization may be more effective in the field with higher soil moistures, but it simultaneously suggests no necessity of water supply exceeding the usual irrigation.

Heavy reduction in the field soil often occurs during the solarization. It was found that the organic matter added to the infested soil gave rise to the soil reduction and the rapid decline of the disease when the soils were heat-treated.

Periodical heating of infested soil was also tested because the soil temperatures during solarization should not be constant under the field condition. When the infested soils with 800 kg/ha calcium cyanamide fertilizer were heat-treated at 35° and 40°C for 7 hr a day, the disease-suppressing effect was developed by treating for 10 and 5 days, respectively (Fig. 2). Subsequently, supposing that the time of exposure to heat can be accumulated as suggested by Fukui et al.,[1] 35 and 70 hr will be required for the heat level 40° and 35°, respectively.

2) *Field trial*[3]

Naturally clubroot-infested field in Yokaichi, Shiga Prefecture, was employed for the experiment. On July 29, 1980 the field site was rotary-tilled after applying 10 t/ha farmyard manure with sawdust, and small ridges were made on it. After 700 or 1,500 kg/ha calcium cyanamide fertilizer was applied on the surface layer in the ridged soil, the site was covered with clear 0.1 mm vinyl film, and then furrow-irrigated. Solarization was conducted until September 4.

Probably because the summer of 1980 was exceptionally cool, raising soil temperatures was not fully successful. The accumulated hours of temperatures exceeding 35° and 40°C in soil at the depth of 10 cm below surface were 178 and 22 hr respectively, within the duration of 37 days. The heat dose for 40°C did not reach to the assumptive value, i.e., 35 hr, obtained by the laboratory experiment.

In the soil samples collected from the solarization plot before, during, and after the treatment, clubroot was not suppressed at all when examined in a greenhouse using turnips as the test plants.

The field plots after solarization were sown with turnips to examine the effect of the treatment. So heavily were the check plots infested that almost all plants were severely affected either to stunt or to die, and subsequently very few marketable plants were obtained. While in the solarization plots, the growth of turnip top was clearly more vigorous than that in the check plots. At the harvesting time, however, only a little effect for disease suppression was exhibited even by the supplement of 1,500 kg/ha calcium cyanamide fertilizer. Although some marketable plants were obtained in the solarized plots, disease-controlling effect of the solarization was lower than that of PCNB (Table 1).

The field trial was thus unsuccessful probably because of the insufficiency of heat dose. The improvement of the method, therefore, should be studied hereafter. It is also worthy of consideration to combine solarization with the other control measures, such as chemical application at reduced dosage. The method, in addition, must be more promising in the tropical zones where one can utilize full solar radiation.

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