Agriculture and Agri-Food Canada
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# CLUBROOT OF CRUCIFERS

## Control strategies

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Prepared in collaboration with the Association des Jardiniers Maraîchers du Québec (AJMQ) under the Agri-Food R&D Matching Investment Initiative administered by the Research Branch.


Photo 1 : Hernie des crucifères; racines de chou saines (A) et infectées (B)

Clubroot is a serious fungal disease of cruciferous crops that occurs worldwide. It was first identified in Europe in the 13th century. Clubroot is a major problem in Quebec and Ontario, where extensive crucifer acreages have been attacked by the disease.

Clubroot[1] occurs mainly on broccoli, Brussels sprouts, cabbage, cauliflower, Chinese cabbage, kale, kohlrabi, radish, rutabaga and turnip. The disease can also infect black mustard, canola and rape. Clubroot-resistant crucifers include winter cress and garden cress.

Major research efforts have been devoted to controlling the disease. This technical factsheet describes current knowledge of the disease and the options available to Canadian farmers who have to grapple with clubroot problems.

## THE DISEASE

The causal pathogen of clubroot is a myxomycete fungus called *Plasmodiophora brassicae* (Wor.), of which there are several soil-dwelling races. Yellowish, senescent leaves, and wilting and stunted growth are the main symptoms that can be seen on the above-ground parts of infected plants. These symptoms are most noticeable on hot days. On young plants, the foliage may wilt during the day but recover at night. **The disease can progress considerably in the roots before above-ground symptoms become visible**.

In the soil, the roots develop tiny, club-like swellings that enlarge rapidly (Photo 1). As the disease progresses, secondary organisms invade the whitish-coloured swollen roots, which begin to turn black. The resulting decay may lead to the plant's death. When this occurs, resting spores are released into the soil, creating an inoculum source. The spores may persist for more than 18 years in the absence of a host.

The life cycle of *P. brassicae* includes two generations of zoospores (Figure 1). The zoospores develop rapidly through their short cycle.

In the spring, resting spores of the fungus germinate, producing zoospores which swim in free water in the soil. These zoospores infect susceptible plants through tiny root hairs or through wounds. The fungus continues its development in the host organism, and a second generation of zoospores is eventually released. Plants infected by only the first generation of zoospores will not develop clubroot. The second generation of zoospores requires more soil moisture to be effective. Infection of plants by second-generation zoospores induces cell enlargement and cell division, causing the characteristic root swellings.

Daily temperatures between 19.5 and 23.5°C, high soil moisture and acidic soil are all factors that favour infection and disease development. Soils with a pH of over 7.2 tend to inhibit spore germination, although the disease can still develop.

There are several ways for the disease to disperse. A field without clubroot problems should be kept free of the disease by all means. Special care should be also taken to keep the field free of weeds of the crucifer family (mustards) which can act as reservoirs for the pathogen. Other non-cruciferous weeds can also be infected by the pathogen (bentgrass, orchardgrass, patience, poppy, ryegrass, sorrel and velvetgrass). The effect of these non-cruciferous weeds on the evolution of the infectious potential of the soil is not well known.

## PROBLEMS ASSOCIATED WITH CLUBROOT

### Wilting and yield losses

The severely deformed roots of affected crucifers are unable to absorb water and minerals. With an optimal supply of water, the plant will be able to obtain nutrients and grow; however, its vegetative growth will be diminished. If the water supply is insufficient, growth will cease. Yield losses occur in all of these situations.

### Longer rotations

In fields with a history of clubroot infection, it is strongly recommended that growers use the longest possible rotation. More specifically, fields should be free from cruciferous crops for about seven years, with this rotation applying also to weeds and all other crops that might be susceptible.

### Sanitation

Special care should be taken in cleaning agricultural equipments that may have come in contact with clubroot. Following use in infested fields, tools must be cleaned to prevent dissemination of the disease.

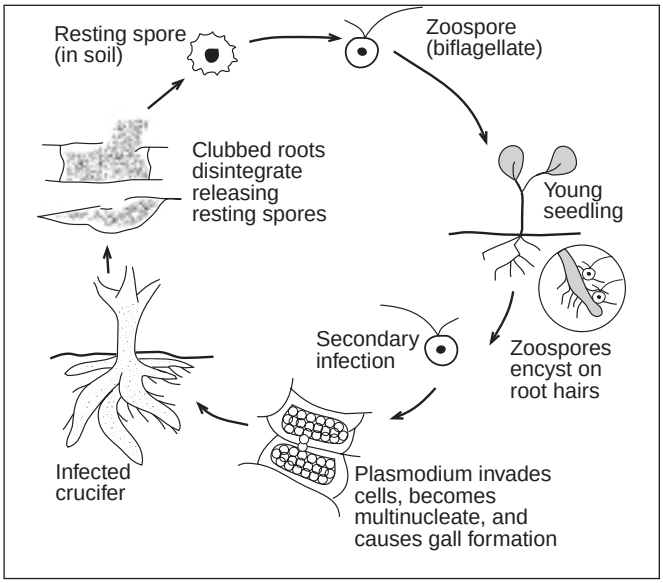


Figure 1: Life cycle of *Plasmodiophora brassicae*, the pathogenic fungus that causes clubroot (Source: Ohio State University).

[1] In this text, the term "clubroot" is used to denote "clubroot of crucifers."

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### Aesthetic considerations for the fresh market

Unsightly swellings are an impediment to the marketing of root crucifers such as kohlrabi, turnip, radish and rutabaga.

## FIELD MONITORING

The easiest way to detect clubroot in fields is to check the plants for symptoms during the season. Growers should be careful not to mistake herbicide damage or the hybridization nodules (swellings) that occur on canola, turnip and rutabaga for clubroot symptoms. Hybridization nodules are of genetic origin and completely unrelated to clubroot. Unlike what is observed in clubroot-affected plants, when hybridization nodules are cut, a uniformly unmarbled texture is noted. Furthermore, these nodules are not susceptible to decay, contrary to clubroot swellings.

Research is under way on an additional monitoring method, which involves estimating a field's infection potential based on soil sampled in fall before the crucifer harvest. A sensitive crop (Chinese cabbage usually) is subsequently grown in the greenhouse using the soil collected. After six weeks of growth, the severity of symptoms observed on the roots is converted to a pathological index.

## PREVENTION

Various precautions can be taken to prevent fields from becoming infested by clubroot. As the old saying goes, "*An ounce of prevention is worth a pound of cure.*"

**Well-drained soil**
The presence of excess water in fields for prolonged periods is highly conducive to disease development. Well-drained soil with a good structure is an essential part of prevention.

**Healthy transplants**
Growers should always use plants that have been grown in clubroot-free soil or growing medium.

**Movement of contaminated material**
It is crucial to avoid moving infested soil, equipment or plants to clean fields. When agricultural tools have been used in fields that may be infected or that have recently been used for crucifer production, they must be cleaned thoroughly prior to use in disease-free fields.

**Irrigation water**
Growers should avoid using irrigation water that is contaminated with the clubroot fungus. Irrigation ponds may be contaminated if they receive run-off from infested fields. In addition, wash water from contaminated vegetables should not be employed.

**Use of manure**
Manure from livestock fed clubroot-infested crop debris should not be used.

## SOLUTIONS

In contaminated fields, steps must be taken to avert large yield losses. At present there is no known method for eradicating clubroot. Nevertheless, the control measures described below will help to minimize the impact of the disease.

### A) Principal methods

**Containment**
In fields that have become infested, it is important to restrict the infection and prevent dissemination of the disease by applying the preventive measures mentioned above.

**Crop rotation**
Rotating crops is strongly recommended for clubroot-infested fields. No susceptible plants (cruciferous crops and weeds) should be grown in an infected field for five to seven years. Other crops may be cultivated instead.

**Liming**
Liming has been used as a control measure for clubroot since the early 19th century. There is a close relationship between soil pH and clubroot, with acidic soils generally favouring development of the disease.

While this approach does not eradicate the causal pathogen of clubroot, it creates conditions unfavourable for its development. To harness the appreciable benefits of liming, the soil pH (extracted with water) must be progressively increased and kept above 7.2.

The scientific jury is still out on whether liming aids in disease control by raising the pH or by increasing the calcium concentration. However, a study conducted at the HRDC, in collaboration with the Association des Jardiniers Maraîchers du Québec (AJMQ), showed that there is little association between the calcium level in the soil and the presence of clubroot. The research confirms nonetheless that a close relationship exists between the soil pH and the disease. Figure 2, which is taken from that study, illustrates the relationship between the spatial variation of pH values in a field and the pathological index for clubroot.

As a control method for clubroot, liming must be done so as to raise soil pH to a suitable level quickly. Relatively massive applications may be envisaged—if necessary using faster acting types of lime than agricultural lime. Since soil has a natural tendency to become acidic, applications must be made every year, preferably in the fall, to maintain ideal pH conditions. For fall applications, calcitic lime [$CaCO_3$] is recommended. If the soil magnesium level is low, dolomitic lime [$CaCO_3$ + $MgCO_3$] provides better results. Lime efficiency can be increased by using a finer grind and by making sure that the product is perfectly homogenized in the top soil layer. (Dobson et al., 1983). Harrowing is therefore strongly recommended as a step prior to tillage.

If liming is necessary in the spring, hydrated lime [$Ca(OH)_2$] may be applied a month before the crop is planted. Quicklime may be incorporated as a last resort (at least a week before planting); however, extra precautions are necessary because this lime is very reactive (Please follow provincial recommendations). The Portland cement kiln dust can also be used to raise soil pH.

It is difficult to provide a general recommendation on the amount of lime to apply, given that responses differ with soil type and there are wide variations in soil pH within a single field (Figure 2). A given dose of lime may be sufficient or even harmful in an area with a high pH, whereas the same dose may be insufficient in a low pH zone. Ideally, a pH map should be produced using precision agriculture technology, and the lime dosage should be adjusted across the field based on that information. When a pH map is not available, a global positioning system (GPS) may be used to locate clubroot-affected zones and orient applications of lime.

Massive or repeated applications of lime reduce the availability of phosphorous and other micro-nutrients, such as magnesium, manganese, boron and zinc, and may also reduce yield. Indeed, in the aforementioned experiment, a 7% decrease in cabbage yields

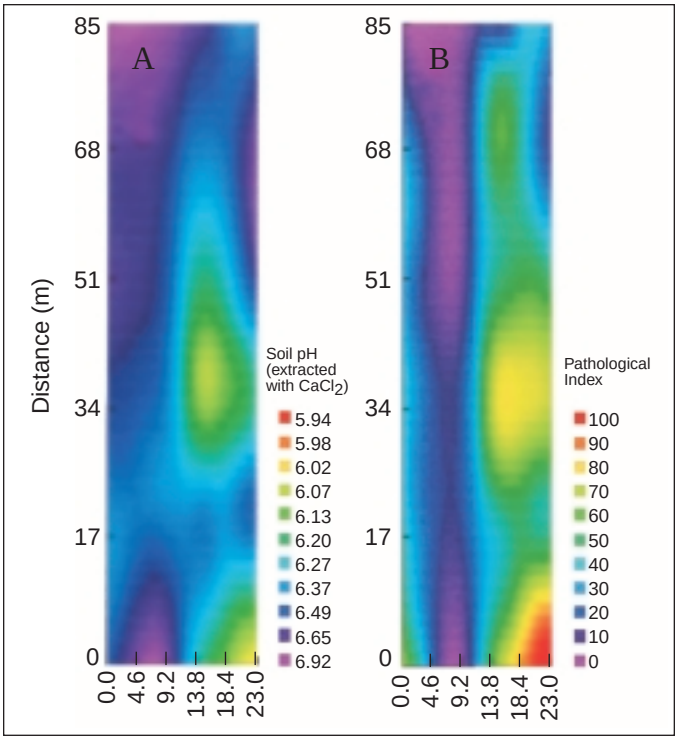


Figure 2: Map of pH zones (A) and pathological index of clubroot (B) in a given field. Zones with acidic pH values are infected by clubroot.

was measured after lime was applied on a clayey loam at a rate of 37 tonnes of lime ($CaCO_3$ equivalent) per hectare, over a three-year period. The pH level (measured in $CaCl_2$) rose from an average of 5.41 to 6.14 during this period. Hence it is important to ensure that the yield increases resulting from improved clubroot control outweigh the risk inherent in massive applications of lime.

Several studies suggest a certain effect of boron on clubroot development (Dixon, 1996). Boron application to soil to reach a level of 2 ppm may contribute to clubroot control. Since lime application can reduce boron availability and crucifers require relatively high boron levels, it is a good idea to complement fertilization of a cruciferous crop with this nutrient.

**Fungicides**
Quintozene (Terraclor) in 75% wettable powder form is the only product currently registered in Canada for control of clubroot of crucifers. When applied during transplanting in accordance with the manufacturer's directions, this fungicide may reduce disease incidence and severity. For detailed recommendations, please consult your provincial government agronomists.

## B) Other methods

Several other approaches may be used to control clubroot. However, contradictory results have been reported in some cases and research is still under way. Most of the alternative approaches are described below:

**Promote overall crop health**
Except in the case of root vegetables, good production practices underpinned by suitable irrigation and fertilizer use can mitigate the impact of the disease on marketable yields.

**Fumigation**
Soil fumigation can be incorporated into a control program for clubroot. This treatment is recommended especially when there is some doubt regarding the hygiene of the soil used for transplant production in the greenhouse. To minimize the cost in commercial fields, localized fumigant applications can be made. The currently available fumigants which are least damaging for the ozone layer are metham sodium, metham potassium and methyl isothiocyanate. Please consult your provincial government agronomists for more details and be sure to read the manufacturer's directions prior to use.

**Resistant cultivars**
One of the ways to control clubroot is to use resistant cultivars. Unfortunately, few resistant cultivars exist. In addition to being resistant to only certain strains of the pathogen, the resistant cultivars do not meet market standards in every regard. For a list of such cultivars, contact your provincial agriculture department and your seed supplier.

**Green manure**
According to certain sources, ploughing under green manure, especially rye, inhibits the development of clubroot. Unfortunately, trials conducted by the Quebec Department of Agriculture, Fisheries and Food (MAPAQ) and others conducted by the HRDC, in collaboration with the AJMQ, failed to substantiate this claim. Nevertheless, green manure application is recommended from an agronomic standpoint.

**Surfactants**
Trials involving the use of a specific surfactant were carried out by the Atlantic Food and Horticultural Research Centre and the HRDC in collaboration with the AJMQ. When applied during transplanting and followed by a second application two weeks later, the surfactant was found to be somewhat effective. The product in question **is not registered for that use in Canada**.

**Nitrogen source**
Calcium nitrate [$Ca(NO_3)_2$] is a good choice as a nitrogen source because of its alkalinizing properties (Dobson et al., 1983). This type of fertilizer is relatively expensive, however, and leaches easily from the soil. Another N source, calcium cyanamide (20% N), characterized by both herbicidal and fungicidal properties, has shown good potential for clubroot control (Klasse, 1996) provided that the application be made 1 week before planting, the product be well homogenized in the top soil layer, and irrigation be provided (if no sufficient rainfall occurs) to activate the product. Application rates are based on N requirements of the crop. Producers should consult their provincial government agronomists for detailed recommendations in this regard.

**Bait crops**
Growing plants that are sensitive to clubroot (e.g., canola and mustard) for four to five weeks at the start of the season will induce the resting spores of the fungus to produce zoospores. The zoospores will swim in free water in the soil and eventually penetrate the tiny roots of those plants. If the bait crop is harvested or ploughed under at that point, the first-generation zoospores will not have time to complete their cycle, so the disease will not develop on the primary crop that is planted afterwards. According to Harling and Kennedy (1991), the bait crop method produces good results if the infection is not too severe and if liming is also carried out. However, this approach is restricted to late plantings.

## IN SUMMARY

To lessen the effect of clubroot on crucifer yields, growers should:
- Rotate crops;
- Apply lime and incorporate it well to raise the soil pH and maintain it at or above 7.2;
- Prevent the disease from being spread by water, soil and equipment;
- Ensure good soil drainage and prevent the formation of water-saturated zones in fields;
- Use healthy transplants; fumigate the growing medium (or soil) in the event of any doubts regarding its disease-free status;
- Incorporate a solution of quintozene in the transplanting water for fields at risk;
- Promote overall crop health through suitable irrigation and fertilizing;
- Use resistant cultivars if available;
- Eliminate weeds that are likely to act as a disease reservoir.

**Web site suggestions:**
http://www.ag.ohio-state.edu/~ohioline/hyg-fact/3000/3118.html
http://ppathw3.cals.cornell.edu/DiagLab/CLUBROOT.HTM
http://pmo.umext.maine.edu./factsht/clubroot.htm
http://www.ipm.ucdavis.edu/PMG/r108100111.html

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