



PLANT DISEASE

CLUB ROOT OF CABBAGE AND OTHER CRUCIFERS

Club root probably affects most plants in the crucifer (mustard) family worldwide, including cabbage, cauliflower, Brussels sprouts, broccoli, kohlrabi, kale, collards, Chinese cabbage, mustard, and some varieties of turnips, radishes, and rutabagas. Alyssum and stock are also susceptible, as are many native and weed species in the mustard family. Horse-radish and winter cress are resistant. Several non-cruciferous species can be infected with club root, including members of the rose family (*Rumex* spp., e.g., sorrel and dock), poppy family (*Papaver* spp.), and grass family (*Agrostis* spp. = bentgrass, *Dactylis* spp. = orchard grass, *Holcus* spp. = velvetgrass, and *Lolium* spp. = ryegrass). However, these species rarely show typical symptoms of club root.

Causal agent

Club root is caused by the fungus *Plasmodiophora brassicae*, which produces a resting spore that can survive in the soil for 18 years or longer, as well as a motile spore (zoospore) that

can “swim” in wet soils. At least 9 pathogenic types (pathotypes) of the fungus have been identified.

Symptoms

The most distinctive symptom of club root is abnormally large, distorted roots. Clubs (swellings) may form on the fine roots, secondary roots, tap root, or even the underground stem, with larger clubs (up to 5" to 6" wide) usually forming on larger roots just below the soil surface. On crops in which the fleshy root is an enlarged hypocotyl (e.g., radish, turnip, and rutabaga), clubs form on the tap root or on secondary roots and are usually globular or spherical. For hosts with more fibrous root systems (e.g., cabbage, cauliflower, and broccoli), the

spindle-shaped clubs form on individual roots. Root swellings are usually not observed until about 3 weeks after infection.

If susceptible plants are infected as seedlings, they may die. However, often there are no symptoms on the top growth of seedlings, only small clubs on the roots. Club root rarely kills



Spindle-shaped clubs on the roots of a cabbage plant infected with *Plasmodiophora brassicae*.

plants infected at a later stage. Severe distortion of the roots reduces the ability of plants to absorb water and minerals, resulting in stunted top growth, yellowing of the lower leaves, and reduced yields. Infected plants may wilt during warm weather, but recover at night, and may bolt (produce a flower stem) prematurely in hot weather. Top growth may appear normal during cool, overcast conditions when the transpiration demand is low. As infection progresses, the clubs may be invaded by secondary organisms, resulting in decay of the roots and death of the plant.

Some plant species susceptible to club root (e.g., turnip, rutabaga, and rapeseed/canola) may form non-infectious hybridization nodules of an unknown cause that are easily confused with club root symptoms. Herbicide injury to the

roots can also be mistaken for club root (particularly dinitroaniline herbicides such as trifluralin).

Disease cycle

Plasmodiophora brassicae is most active in cool, wet, acidic soils such as those found west of the Cascade Mountains. In the presence of roots of a susceptible host, resting spores of the fungus germinate to produce motile spores (zoospores) that penetrate root hairs or at wound sites on thickened roots and underground stems. Underground stems may also be infected through leaf scars. Soil moisture levels of 50 to 70% of the maximum water-holding capacity (about -20 to -15 kPa) are required for infection to occur, and club root is more severe in soils with a pH <7.0. Germination of resting spores

occurs when soil temperatures reach $\geq 60^{\circ}\text{F}$.

Once a plant is infected, the fungus causes plant cells in the roots to enlarge and divide repeatedly, leading to gall (club) formation. The fungus produces masses of resting spores in these clubs. The resting spores are released into the soil when the clubs rot, and may remain viable in the soil for more than 18 years.

Plasmodiophora brassicae is spread by movement of infested soil clinging to farm equipment, tools, and shoes. The pathogen can spread on infected transplants and in contaminated manure, irrigation water, and drainage water. Repeated production of crucifers on the same land leads to rapid buildup of the pathogen in fields.

Management

Cultural control. Cultural practices play a very important role in effective long-term control of club root:

1. Purchase disease-free transplants from a reputable dealer and transplant seedlings into well-drained soils free from *P. brassicae*.
2. If producing transplants, sanitation is very important for effective control of club root. Use only non-infested seedbeds and clean transplant media, trays, and equipment. Do not lime seedbeds or transplant media heavily as this may mask symptoms of club root and symptoms could become severe after seedlings



Root system of a plant infected with club root, showing clump- or fist-like galls (clubs) which eventually rot and release resting spores of *Plasmodiophora brassicae* into the soil.

are transplanted into soil with a lower pH.

3. Do not allow water to drain from an infested field into an irrigation source, and avoid using irrigation water contaminated with *P. brassicae*.
4. If some crops are infected and others are free from club root, work in club root-free crops before moving people and machinery into infected crops to avoid spreading infested soil to non-infested areas. Clean soil thoroughly from machinery and equipment before moving from an infested field into a clean field. Use soap and water to wash tools used to handle infected plants.
5. Control wild mustards in crucifer crops.
6. Practice long-term (6+ years) crop rotation to help prevent buildup of inoculum of *P. brassicae*.
7. Dispose of infected plants in the garbage or a dump. Do NOT put infected culled plants in a compost pile.
8. Do not use manure from animals fed infected culled plants or from animals pastured in infected crops.
9. Good soil drainage and maintenance of a high soil pH by regular application of lime help control club root. The degree of control is influenced by soil pH, and different soil types vary in their response to altering pH with lime. High concentrations of calcium and magnesium may provide control of

club root when the soil pH is <7.2 . Conversely, low calcium and magnesium may permit club root to develop if the soil pH is >7.2 . If susceptible crops are to be planted into suspect or infested fields, incorporate limestone at least 6 weeks prior to planting to raise the soil pH >7.0 . Late summer or fall applications of lime, when the soil is dry, are more effective than spring applications. Use lime that will increase both soil pH and soil calcium, i.e., calcitic lime is usually more effective than dolomitic lime unless soils are low in magnesium. Mix the hydrated lime thoroughly into the soil (1,500 lbs/acre) for maximum disease control. Finely-ground lime alters the pH more rapidly than coarse granules. Lime will not prevent development of club root if the concentration of spores of *P. brassicae* in the soil is high. Periodically monitor changes in soil pH in subsequent years to determine the stability of the pH change. Be aware that increasing the soil pH of coarse-textured soils may lead to boron deficiency, which can be alleviated with foliar applications of boron or inclusion of boron in the transplant water. In addition, some non-crucifer crops have problems with high lime content in the soil, which should be taken into consideration if a non-crucifer crop will follow the

crucifer crop. For example, scab of potatoes is made worse by liming.

10. Nitrogen fertilization can affect development of club root. Fertilization with calcium nitrate may result in less disease compared with applications of ammonium sulfate or urea. Research done in Canada (by Elmhirst and Zimmerman, as reported in the 2001 Pest Management Research Report for Agriculture and Agri-Food Canada) showed that side-dressing brassica crops with calcium nitrate 3 weeks after transplanting significantly reduced root clubbing.
11. If club root develops in a crop, hilling the plants promotes production of adventitious roots which may help the infected crop yield better.
12. Cabbage cultivars with resistance to multiple lines of the club root fungus are available, e.g., "Badger Shipper" and "Richelain." Some cultivars are resistant to select races of the fungus.

Chemical control. For home gardeners, no fungicides are registered for control of club root. For commercial growers, several fungicides have shown efficacy for control of club root and can be incorporated into an effective integrated disease management program with the cultural practices described above.

1. Seedbeds can be fumigated if pathogen-free soils are not

- available. Preplant soil treatment with PCNB (Terraclor 75WP or Terraclor F) does not prevent development of club root, but reduces the number of clubs formed as well as secondary root rots. PCNB can be broadcast or banded into the soil at planting, or applied in the transplant water.
2. Soil fumigation with metam sodium (e.g., Vapam or Sectagon) applied by rotovate-and-roll or spray-blade fumigation effectively controlled club root when evaluated in a cauliflower crop in western Washington.
 3. Researchers in British Columbia, Canada, demonstrated that cyazofamid (Ranman) provided excellent control of club root when applied in-furrow with a surfactant. There was no evidence of phytotoxicity from cyazofamid (Elmhirst and Zimmerman, 2001 Pest Management Research Report for Agriculture and Agri-Food Canada). This product is currently not registered for this use in Washington State.
 4. In Canada, application of fluazinam (Omega) in-furrow in the transplant water provided good control of club root on cauliflower in organic soils (Elmhirst and Zimmerman, 2001 Pest Management Research Report for Agriculture and Agri-Food Canada). However, fluazinam was phytotoxic to cauliflower on mineral soils. This product is currently not registered for this use in Washington State.
- Follow label directions and precautions when applying any pesticide. Only use pesticides legally registered in your state for the particular crop on which you wish to make the application.

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▲Warning. Use pesticides with care. Apply them only to plants, animals, or sites listed on the label. When mixing and applying pesticides, follow all label precautions to protect yourself and others around you. It is a violation of the law to disregard label directions. If pesticides are spilled on skin or clothing, remove clothing and wash skin thoroughly. Store pesticides in their original containers and keep them out of the reach of children, pets, and livestock.

The law requires that pesticides be used as label directs. Uses against pests not named on the label and low application rates are permissible exceptions. If there is any apparent conflict between label directions and the pesticide uses suggested in this publication, consult your county Extension agent.

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