Biology and Management of Sugar Beet Diseases in the Big Horn and Wind River Basins of Wyoming

Cooperative Extension Service
UNIVERSITY OF WYOMING

B-1063
College of Agriculture
February, 1998

Issued in furtherance of cooperative extension work, acts of May 8 and June 30, 1914, in cooperation with the U.S. Department of Agriculture. Glen Whipple, director, Cooperative Extension Service, University of Wyoming, Laramie, Wyoming 82071.

Biology and Management of Sugar Beet Diseases in the Big Horn and Wind River Basins of Wyoming

Prepared by
Fred A. Gray, Ph.D.
Professor of Plant Pathology
Department of Plant, Soil, and Insect Sciences
College of Agriculture
University of Wyoming
Laramie, Wyoming

And

James S. Gerik, Ph.D.
Research Plant Pathologist
Plant Pathology Department
Holly Sugar Corporation
Tracy, California

February, 1998

Table of Contents

Introduction	1
Seedling diseases	2
Root and crown rots	4
Rhizoctonia root and crown rot	4
Phytophthora root rot	6
Fusarium yellows	8
Sugar beet nematode	10
Virus diseases	12
Beet curly top virus	12
Beet necrotic yellow vein virus (BNYVV) – Rhizomania	15
Leaf diseases	17
Phoma leaf spot	17
Other leaf diseases	18
A summary of control practices for developing an integrated disease management program	19
References	23

Introduction

Sugar beets have been grown in the Big Horn River Basin for more than 60 years. Many fields were planted to sugar beets every year for 20 years or more until disease pressure increased to the point that rotation with other crops became necessary. Even today many fields have relatively short rotations of one to two years between sugar beet crops. Under these farming practices, soil-borne pathogens and parasitic nematodes remain at relatively high levels. When weather conditions are optimum for disease development, stand and yield losses can occur. Under this intense sugar beet cropping system, effective management of diseases is essential if the current level of sugar beet production is to be maintained or increased.

A three-year disease survey was conducted in the Wind and Big Horn River basins from 1992 to 1994 (Gray 1995). Location of the 129 fields surveyed is shown in Figure 1. Of the more than 50 reported diseases of sugar beets (Whitney and Duffus, 1991), 16 were identified during the survey. Of these 16 diseases, five were considered major relative to their potential damage to the sugar beet crop (Table 1). These include beet curly top virus, Rhizoctonia root and crown rot, Fusarium yellows, sugar beet nematode, and Phytophthora root rot. All of these diseases, with the exception of beet curly top virus, are soil borne. If one or more of these diseases are present, they will occur every time sugar beets are planted. The number and frequency of these diseases within individual fields surveyed are shown in Table 2. Number and frequency of each disease were highest in Washakie and Big Horn counties, which are both within close proximity to the sugar beet factory in Worland (Table 2). Most fields in these two counties had two or more diseases and several had five major diseases present. This complexity of diseases within a given field in these two counties offers a unique challenge to growers relative to disease management. Disease distribution maps were developed for each major disease, providing information as to the disease or diseases that should be expected to occur in a given sugar beet growing district.

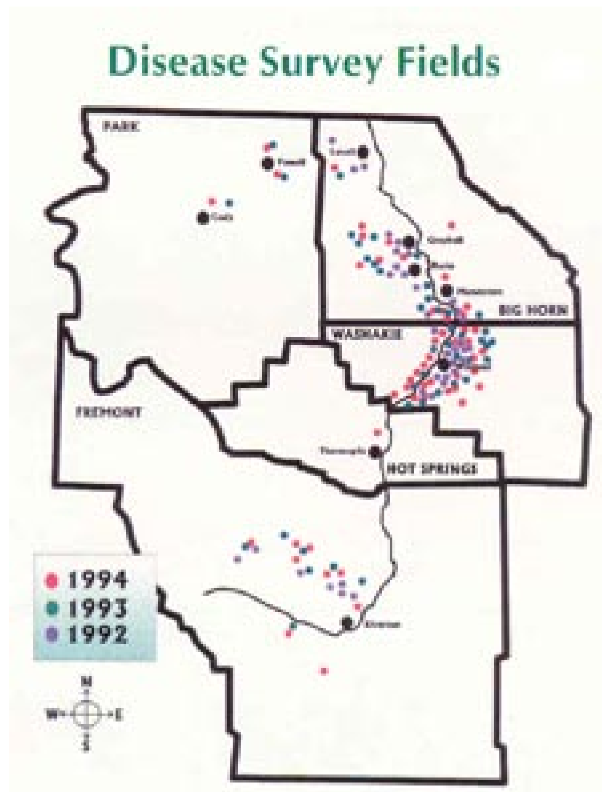

Figure 1. Location of the 129 sugar beet fields surveyed (36 in 1992, 42 in 1993, 51 in 1994).

This publication provides information on the identification and control of each sugar beet disease. Control practices are summarized at the end of the bulletin to assist you in developing an integrated disease management program. It is specifically developed for sugar beet growers in the Wind and Big Horn River basins and should not be applied to other sugar beet growing areas where diseases and their severity may differ.

Table 1. List of 16 sugar beet diseases identified from field surveys conducted in the Wind and Big Horn River Basins of northwestern Wyoming.

Diseases	1992	1993	1994
Fungal Diseases			
Fungi isolated from roots of diseased seedlings			
Fusarium sp./*F. oxysporium* f.sp. *betae*	X	X	X
Rhizoctonia solani	X	X	X
Pythium ultimum	X	X	X
Rhizopus sp.		X	
Aphanomyces cochlioides		X	
Phoma betae (Black Leg)	X		
Phytophthora drechsleri	X		
Root and Crown Rots			
Phytophthora Root Rot*	X	X	X
Rhizoctonia Root and Crown Rot*	X	X	X
Vascular Wilts			
Fusarium Yellows*	X	X	X
Leaf Diseases			
Phoma Leaf Spot	X		X
Alternaria Leaf Spot		X	
Powdery Mildew	X		X
Nematode Diseases			
Sugar beet Nematode*	X	X	X
Virus Diseases			
Beet Curly Top Virus*	X	X	X
Beet Western Yellows Virus		X	

**Considered a major importance relative to their potential damage to sugar beet.*

Table 2. Frequency of five major diseases within individual fields (Wind River and Big Horn River basins, northwestern Wyoming, 1992-1994).

Number of diseases/ fields	County and number of fields with disease				Total fields	Percent of total fields
	Fremont	Washakie	Big Horn	Park		
0	21	1	2	5	29	22.5%
1	2	9	8	5	24	18.6%
2	0	15	17	1	33	25.6%
3	0	21	10	0	31	24.0%
4	0	6	4	0	10	7.8%
5	0	2	0	0	2	1.6%
Total fields surveyed	23	54	41	11	(129)	

Major diseases included sugar beet nematode, beet curly top virus, Rhizoctonia root and crown rot, Phytophthora root rot, and Fusarium yellows.

Seedling Diseases

The most common disease of sugar beet seedlings in the Wind and Big Horn River basins are caused by the fungi *Pythium, Fusarium,* and *Rhizoctonia*. Seedling diseases are worse during years when rain occurs shortly after planting, resulting in wet-soil conditions. Use of high quality seed, fungicide seed treatment with Apron® and Thiram®, and a high plant population (47,000 plants per acre is suggested) have reduced losses from seedling diseases, however. Seedling diseases occurred in Big Horn, Fremont, Park and Washakie counties during the three-year survey. They were worse in 1992 than in 1993 and were not detected in 1994. Losses to seedling stand in individual fields were relatively low, ranging from 0.5 to 12.1 percent. Even a low level of seedling loss becomes critical with the "plant-to-stand" method of seeding, particularly if plant populations are at levels less than recommended. *Pythium* and *Rhizoctonia* may attack seedlings of most rotation crops, while all three may attack local weeds. Other fungal pathogens identified as causing seedling diseases included *Phoma*, *Phytophthora*, and *Aphanomyces.*

Symptoms

Symptoms consist of poor seedling emergence and/or death of emerged seedlings. Diseased seedlings that survive are usually stunted and unhealthy in appearance. Seedlings attacked by *Pythium* are usually killed prior to emergence. However, if environmental conditions are not favorable for these fungi until after seedlings have emerged, post-emergence damping-off may occur (Figure 2a). Seedlings infected with *Rhizoctonia* are pinched-off at or near the soil line with infected tissue turning black (Figure 2b and c). Many of these seedlings can be broken off with wind. Seedlings infected with *Fusarium* usually turn chlorotic (yellow), while leaf tips turn brown and curl downward (Figure 8c).

Pathogen biology

The genus and species of these fungi are *Rhizoctonia solani, Pythium ultimum, Fusarium oxysporium* f. sp. *betae, Phoma betae, Phytophthora drechsleri,* and *Aphanomyces cochlioides.* The organisms that cause seedling diseases are all fungi and survive in the soil for several years following the sugar beet crop. Each can be transmitted in soil peds (round balls of soil similar in size and weight to seed) which contaminate seed lots. *Phoma* and possibly *Fusarium* are transmitted by infected seed. *Fusarium* and *Rhizoctonia* both survive in the soil as dormant structures for several years, and they are able to grow saprophically on organic debris. While all three may grow and infect seedlings under conditions in which the sugar beet will grow, *Pythium, Aphanomyces,* and *Phytophthora* all favor very wet conditions. All of these fungi can attack seedlings at soil temperatures above 68 degrees Fahrenheit. *Phoma* prefers the coolest conditions (61 to 68 degrees Fahrenheit), while *Phytophthora* and *Aphanomyces* prefer the warmest (83 to 88 degrees Fahrenheit).

Figure 2a. Seedling diseases. Post-emergence damping-off caused by *Pythium* spp.

Figure 2b. Seedling diseases. Root girdling below soil line and death of seedling, caused by *Rhizoctonia solani*.

Figure 2c. Seedling diseases. Root girdling below soil line and death of seedling, caused by *Rhizoctonia solani*.

Control

1. **Use high-quality, fungicide-treated seed.** All seeds are currently treated with Apron® and Thiram®.
2. **Proper seeding depth.** Fields should be worked in such a manner as to reduce the amount of large clods so seed can be planted shallow, ¾- to 1-inch deep.
3. **High plant population.** When seedling disease is present, fields with high plant populations (47,000 or more) usually have a higher number of harvestable beets.
4. **Crop rotation.** *Rhizoctonia* is usually worse following alfalfa. Sugar beets should follow malting barley, corn, or another small grain in a three- to five-year rotation.
5. **Host resistance.** Due to the effectiveness of control with fungicides, varieties have not been developed with broad resistance to seedling diseases. HH-67 and ACH-184, which are resistant to Rhizoctonia root and crown rot, may express some resistance to "damping-off" caused by *Rhizoctonia*. Also, HMI-9155, HMI-WS-91, ACH-304, and ACH-323, which are resistant to Fusarium yellows, may express some resistance to the seedling phase of the disease. No varieties recommended for the Wind and Big Horn River basins have resistance to seedling disease caused by *Phytophthora*, *Phoma*, or *Aphanomyces.*

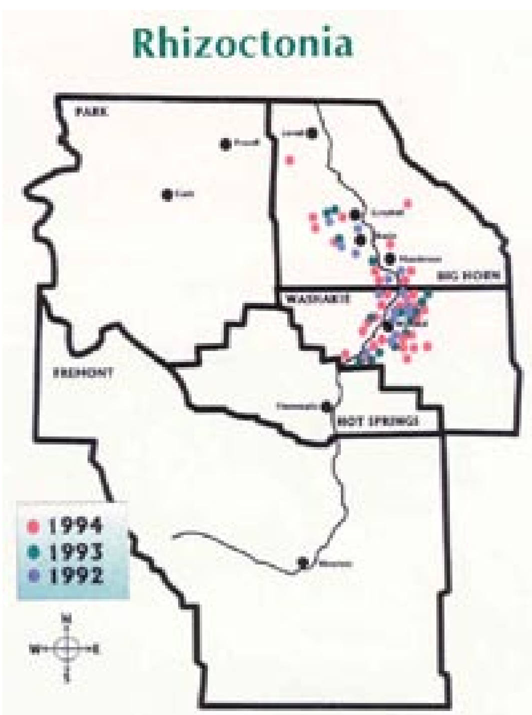

Figure 3. Location of 62 sugar beet fields with Rhizoctonia Root and Crown Root (15 in 1992, 15 in 1993, 32 in 1994)

Root and Crown Rots

The two most common fungal diseases of sugar beet roots and crowns in the Big Horn Basin are Rhizoctonia root and crown rot and Phytophthora root rot. While *Rhizoctonia* attacks the upper taproot, crown, and lower stems, *Phytophthora* primarily attacks the lower taproot. Both will attack seedlings. *Rhizoctonia* is by far the most widespread.

Rhizoctonia root and crown rot

Rhizoctonia root and crown rot was found in Washakie (68 percent of fields) and Big Horn (62 percent of fields) counties where it causes significant reductions in plant stands and yields (Figure 3).

Symptoms

Rhizoctonia causes the collapse and death of plants from shortly after seeding until harvest (Figure 4a). Younger plants tend to dry up and collapse. Diseased plants have a dry, dark brown to black rot of the root (Figure 4B) with brown tufts of fungus sometimes present. The crown rot phase becomes noticeable after cultivation shields are removed and worsens several weeks after the last ditching. At this time tractor speed increases and soil containing *Rhizoctonia* is thrown around the base of the plant and into the crowns. After irrigation, the fungus infects the base of leaf petioles and eventually the crown, killing the plant. Rotted basal petioles and crown tissue are black in color. When removed, crowns and upper roots of older beets have a black rot and many diseased plants have a large crack in the upper root containing large amounts of brown fungal growth. Other plants may have only the root-rot phase of the disease, and above-ground portions of the plant may appear healthy. However, plants with severely rotted roots will show symptoms of wilting. When removed, soil tends to adhere to the rotted portion of the root increasing tare soil at harvest. Diseased plants are scattered throughout a field but may be worse in low areas and at the lower end of fields. Extensive plant mortality may occur. After plants are killed, leaves turn a light brown in color and dry up.

Figure 4a. Rhizoctonia root and crown rot. Area in field with dead and diseased plants.

Figure 4b. Rhizoctonia root and crown rot. Healthy and rotted roots.

Pathogen biology

Rhizoctonia is widespread in agricultural soils throughout the world, attacking many crops and weeds. It produces dry, hard, compacted masses of fungal mycelium called “bulbils” which aid the fungus in survival and spread. *Rhizoctonia* can also survive as a saprophyte feeding on dead and decaying plant debris. *Rhizoctonia* is favored by warm temperatures (77 to 91 degrees Fahrenheit). It is worse in heavy, poorly drained soils.

Control

Control of *Rhizoctonia* is very difficult; however, it can be managed to reduce losses.

1. **Rotation.** Rotating out of sugar beets for five or more years will reduce damage from most soil-borne fungal disease, including Rhizoctonia root and crown rot. Sugar beets following a small grain, such as malting barley or corn, usually have less *Rhizoctonia* than when grown after alfalfa.

2. **Crop residue management.** Incorporation of small grain residue in combination with liquid fertilizers, which speed up the breakdown of the straw, increases soil populations of microorganisms that are antagonistic to root-rotting fungi such as *Rhizoctonia* (Davey and Papvizas, 1960).

3. **Weed control.** Control of pigweed (susceptible to *Rhizoctonia*), particularly during rotation crops, should reduce soil population of *Rhizoctonia*.

4. **Resistant variety.** If *Rhizoctonia* is the dominant disease in a field, a variety with resistance to *Rhizoctonia* should be selected for planting. HH-67 and ACH-184 are both resistant to this disease. Remember, in all districts except Fremont County, the variety must also have good resistance to beet curly top virus.

5. **Tillage practices.** In fields with a history of *Rhizoctonia*, plow sweeps should be adjusted and tractor speeds reduced during the lay by tillage and ditching operations. This will reduce hilling-up of soil infested with *Rhizoctonia* onto the crowns of sugar beet plants. Also, moldboard plowing prior to planting sugar beets will bury fungal inoculums and reduce incidence of the disease.

6. **Fungicide treatment.** Several experimental fungicides applied as a single spray application directly to the plant prior to ditching have shown promise in reduced Rhizoctonia crown rot in trials conducted at Torrington; however, none have received clearance for use on sugar beets. Benlate®, which is labeled for control of Cercospora leaf spots on sugar beets, has good activity against *Rhizoctonia*. Although it has not been tested, it should suppress Rhizoctonia crown rot. However, sprayer speed and spray volume should be adjusted so the fungicide runs down into the crown of the plant.

Figure 5. Location of 18 sugar beet fields with Phytophthora Root Rot (7 in 1992, 6 in 1993, 5 in 1994).

Phytophthora root rot

Phytophthora root rot was found in Washakie (21 percent of fields), Big Horn (7 percent of fields), Fremont (8 percent of fields), and Park (17 percent of fields) counties (Figure 5).

Symptoms

Phytophthora causes a collapse and death of plants from shortly after seeding until harvest. Although root rot may encompass the majority of the root tissue of younger plants, it usually is confined to the lower portion of the tap root of older plants (Figure 6b). When plants are removed, soil tends to adhere to the rotted portions of the root. In some cases, the bottom end of the rotted root appears frayed. If the root is cut open, rotted tissue is a brownish-orange in contrast to the white healthy tissue. Above-ground symptoms consist of midday wilting. Diseased plants are usually stunted with leaves turning either chlorotic or necrotic (brown) (Figure 6a), but many diseased plants remain alive until harvest.

The disease is usually confined to low areas of a field or at the lower end of fields where soils remain wet following irrigation or periods of extended rain. This disease is worse in fields having a high clay content of 25 percent or more, poor drainage, or a high water table.

Pathogen biology

Phytophthora drechsleri is a water mold, producing the infective, mobile zoospores only when free water is present in the soil. Zoospores swim to the root surface and initiate infection. The fungus survives for several years as thick-walled, round oospores. Optimum temperature for growth of this fungus is 82 to 88 degrees Fahrenheit.

Control

Once a field is infested, Phytophthora root rot is difficult to control. **Losses can be reduced through practices that prevent prolonged exposure of the sugar beet crop to high levels of soil moisture** such as providing adequate field drainage, preventing excessive seepage from irrigation pipes or ditches, subsoil plowing, sprinkler irrigation of problem fields, planting sugar beets in raised beds, and laser leveling of fields to remove low spots.

Several sugar beet varieties were found to have tolerance to Phytophthora root rot in a field test in California. However, none of these are recommended for the Wind and Big Horn River Basins.

Figure 6a. Phytophthora root rot. Diseased plants in field.

Figure 6b. Phytophthora root rot. Plants showing reddish-brown rot of lower root.

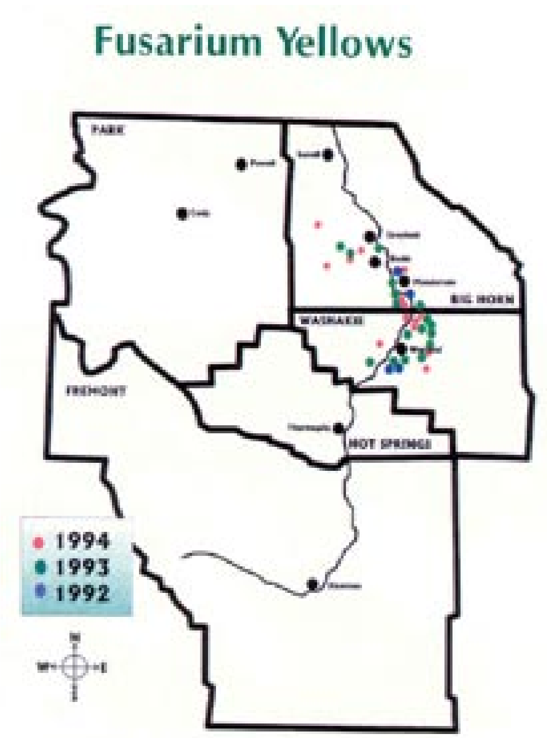

Figure 7. Location of 35 sugar beet fields with Fusarium yellows (4 in 1992, 18 in 1993, 14 in 1994).

Figure 8a. Fusarium yellows. Early seeding blight.

Fusarium yellows

Fusarium yellows has been found in Washakie (33.0 percent of fields) and Big Horn (38.5 percent of fields) counties (Figure 7). Fusarium yellows can cause significant reduction in plant stand and yield.

Symptoms

Plants can be affected from the seedling stage until harvest. The majority of plant death appears to occur when plants are in the seedling stage to the four-leaf stage of growth (Figure 8a). Infected plants turn chlorotic and die rapidly. Dead plants are a light brown in color, and many remain visible until harvest. Although diseased plants may be scattered throughout a field, most occur in localized areas. If fields are visited in mid-season, plants with Fusarium yellows vary in size and stage of disease development. Many plants that are infected when young are usually stunted and show severe symptoms of interveinal chlorosis and marginal leaf browning (Figure 8b). Plants infected later in the season will be larger in size and usually show very mild symptoms, consisting only of minor interveinal chlorosis. When plants are removed and roots are sliced in cross section, many show a yellow-brown to gray discoloration of the water-conducting, vascular tissues (Figure 8c). Some severely diseased plants have a dry rot of the very lower portion of the tap root.

Pathogen biology

The disease is caused by the fungus *Fusarium oxysporus* f. sp. *betae*. It is a soil inhabitant, surviving as microscopic chlamydospores which germinate and infect the sugar beet root under favorable conditions. It invades the water-conducting tissues of the root and grows upward into the leaf petioles. In seed production fields, this fungus may invade the seed stalks where it can become seed borne. Optimum conditions for infection are around 80 degrees Fahrenheit. Research conducted by the senior author has shown the younger the sugar beet plant when exposed to the fungus, the more susceptible it is to infection. Also, infection of seedlings results in greater disease severity and a higher level of plant mortality. The host range of *F. oxysporum* f. sp. *betae* is restricted to sugar beet and pigweed (*Amaranthus retroflectus*), which shows symptoms similar to those of the sugar beet.

Figure 8b. Fusarium yellows. Early seeding blight.

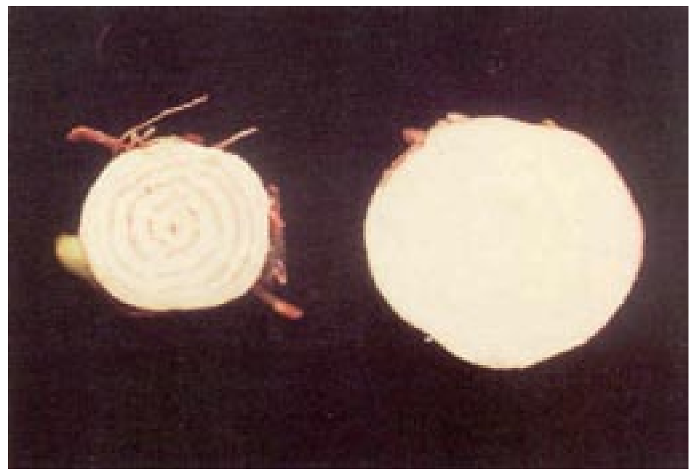

Figure 8c. Fusarium yellows. Discoloration of water-conducting tissues.

Control

Like most soil-borne diseases, Fusarium yellows is difficult to control. A combination of the management practices listed below should reduce loss from the disease.

1. **Rotation.** Although crop rotation will not eliminate this disease, rotation for three to five years with other crops grown in the basin should reduce sugar beet loss from Fusarium yellows. Observations in Washakie County indicated that even a one-year rotation with barley will reduce the incidence and severity of this disease.
2. **Early planting.** Planting when soil temperatures are cool should reduce the severity of the disease.
3. **Soil fumigation.** Soil fumigation with Telone®II in Texas has been effective in suppressing Fusarium yellows in sugar beets. However, from studies conducted in Big Horn and Washakie counties, it appears that soil fumigation only offers minimal control of this disease at best.
4. **Resistant varieties.** The use of host resistance may be the best means of managing Fusarium yellows. HMI-9155, HMI-WS-91, ACH-304, and ACH-323 are currently recommended in the basin and all have resistance to Fusarium yellows.
5. **Seed treatment.** Current seed treatments offer only limited protection to sugar beet seedlings. Studies are under way to evaluate other fungicides and biocontrol agents as seed treatments in hopes of obtaining more effective control.
6. **Plant population.** High plant population (47,000 or more per acre) will not control the disease but should ensure that an acceptable population of healthy plants will be left at harvest.
7. **Weed control.** Good weed control for alternate host plants of Fusarium yellows, such as pigweed, will aid in the overall control of the disease.
8. **Proper disposal of tare soil.** Since tare soil from fields with Fusarium yellows will be high in spores of Fusarium, it should not be returned to sugar beet ground.

Figure 9. Location of 37 sugar beet fields with the Sugar Beet Nematode (16 in 1992, 10 in 1993, 11 in 1994)

Sugar Beet Nematode

Although several parasitic nematodes attack the sugar beet plant, the sugar beet nematode *Heterodera schachtii* is the only one which causes yield loss in the Big Horn Basin (Gray and Koch, 1997). Roots of plants of all ages, including young seedlings, can be attacked. During the recent survey, the sugar beet nematode was found in 51 percent of fields in Washakie County and in 22 percent of fields in Big Horn County (Figure 9).

Symptoms

Soil populations of *H. schachtii* vary within a given field. When sugar beets are seeded, plants in areas with higher soil populations (usually circular or oval in shape) show more severe symptoms than the remainder of the field (Figure 10a). Plants within these areas will be severely stunted. Leaves eventually turn light green-yellow in color (Figure 10b). When removed, the main root is greatly reduced in size, and feeder roots may be increased, giving the root a bearded appearance. Parasitized plants may wilt during the hot part of the day.

Pathogen biology

Heterodera schachtii is an obligate parasite, only surviving on living root tissue. Mature females contain eggs, or unhatched first-stage juveniles which survive for several years within a dead female referred to as “cyst” (Figure 10c). Most other hosts are found in the Chenopodiaceae family (lambsquarter, pigweed, shepherdspurse, and purslane) and in the Cruciferae family (turnip, kale, rape, and mustard). Cysts containing viable eggs or juveniles are easily spread with soil as well as in surface water.

Control

1. **Sanitation.** Tare soil is primarily from the sugar beet roots and is high in populations of sugar beet nematodes and other soil-borne disease organisms including *Rhizoctonia, Fusarium, Phytophthora, Polymyxa betae* (vector of Rhizomania), and others. Tare soil should be used on a farm as fill dirt in washes and barrow pits or taken to a sanitary landfill. If tare

soil is returned to a sugar beet field, it should be applied evenly over the entire field and not dumped. Research in Europe has shown that composting tare soil prior to its return to the field will reduce populations of disease-causing organisms.

2. **Rotation.** Sugar beet fields should be rotated with other crops such as barley, corn, beans, or alfalfa for three to five years. During rotation, the nematode population is reduced approximately 50 percent each year. Weed hosts should be controlled during rotation crops.

3. **Chemicals.** Temik®15G is the most widely used nematicide due to its dual activity on both nematodes and insects. When applied as a band at planting and incorporated into the soil, it inhibits the hatching and disorients juveniles and adult males in the soil. When taken up by the plant root, Temik®15G becomes systemic and inhibits the development of *H. schachtii* after penetration into the root. Counter®15G and Counter®20CR, also labeled for insect control, will suppress moderate soil population of *H. schachtii* in sugar beet crops.

Figure 10a. Sugar beet nematode. Diseased areas in field showing severe yellowing and stunting.

Figure 10b. Sugar beet nematode. Close-up of healthy and parasitized plants showing foliage symptoms.

Telone®II is a soil fumigant which must be applied pre-plant. This material is injected into the soil as a liquid. When soil temperature is between 40 to 80 degrees Fahrenheit, the liquid volatilizes into a gas which moves upward, fumigating the soil. The soil should be sealed with press wheels to slow down the escape of the gas into the air, allowing for better fumigation of the soil. Prior to fumigation, the soil should be worked to remove large clods which can prevent a proper seal of the soil. When large clods are present, the fumigant will escape too rapidly, resulting in poor nematode control.

Since either chemical represents a significant capital investment into a farming operation, the presence, as well as the soil population level of the sugar beet nematode, should be determined to validate the need for treatment. Both chemicals can result in significant economical returns when soil populations of *H. schachtii* are high and when conditions are optimum for chemical activity. Additional information is available in the University of Wyoming Agricultural Experiment Station bulletin (AES) B-975R (Gray and Koch, 1997).

Figure 10c. Sugar beet nematode. Mature female nematodes attached to feeder root; white, mature female and brown, dead female "cyst" containing eggs, 8 magnifications.

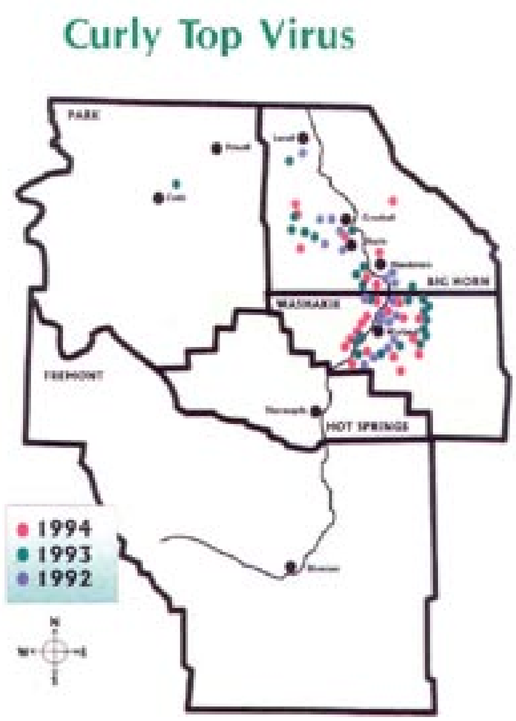

Figure 11. Location of 68 sugar beet fields with Curly Top Virus (19 in 1992, 25 in 1993, 24 in 1994).

4. **Sugar Beet Nematode Trap Crop**. Varieties of sugar beet nematode-resistant radish or mustard, bred in Germany to reduce soil populations of *H. schachtii*, have been field tested with several growers in the Big Horn Basin. When theses crops are planted following barley harvest and where volunteer barley is controlled, sugar beet yields have been increased the following year from two to five tons per acre (Koch et al., 1995). Trap crops also provide excellent fall grazing for livestock.

Additional information on the control of sugar beet nematode is provided in the AES bulletin B-975R (Gray and Koch, 1997).

Virus Diseases

Beet Curly Top Virus

Beet curly top virus (BCTV) is widespread throughout the Western United States. It was found extensively throughout the Big Horn Basin during the recent survey, occurring in 72 percent of sugar beet fields in Washakie County, 60.8 percent in Big Horn County, and 16.7 percent in Park County (Figure 11).

Symptoms

Depending on sugar beet leafhopper migration, sugar beet plants can be infected with the virus at all growth stages. Younger plants and seedlings are more susceptible than older plants. Early stages of the disease consist of plant exudates appearing on leaves and leaf petioles which eventually turn brown to black in color. Mild symptoms include stunted leaves which are smaller than normal, crinkled, and rolled upward and inward (Figure 12a). Leaf veins are roughened on the underside of the leaf and often have small, spine-like protrudings. Roots may be stunted and malformed. Proliferation of feeder roots, referred to as hairy root, may occur. When roots are cross sectioned, the vascular tissue is discolored showing yellow to brown concentric rings (Figure 12b). More severe symptoms consist of chlorosis and necrosis of the plant crown and eventual death of the sugar beet plant (Figure 12c). Many plants have only a portion of the crown remaining alive. Symptoms of plants within a given variety vary from mild curling of leaves to severe curling, chlorosis, necrosis, and death. Variations of symptoms may relate either to differences in virus strains or variability in reaction of the variety to a given virus strain. Incidence of BCTV in fields is relatively low since all varieties grown are resistant. Planting a susceptible variety in the Big Horn Basin however, may result in complete loss of the sugar beet crop (Figure 12d).

Pathogen biology

BCTV is a member of the Geminivirus group. Its virons (single virus particles) are only visible under the electron microscope. BCTV has an extensive host range of more than 300 plants species in 44 families. The virus can only be spread by the beet leafhopper, *Circulifer tenellus.* Beet leafhoppers are very active in the early season prior to canopy formation when overlapping leaves between rows occurs. Once the plant canopy has formed, hopper activity is reduced due to shading and increased humidity. In addition to the sugar beet plant, flax, tomato, and beans are also hosts. Several weeds serve as hosts for the virus as well. After crop harvest, leafhoppers fly to adjacent non-farmland and feed on weed hosts such as Russian thistle. After the first hard freeze, leafhoppers move onto winter annuals of the mustard family where adult females lay their eggs and overwinter. In the spring, eggs hatch, and infected leafhoppers move to other weed hosts, including other mustards, kochia, and Russian thistle. After these spring weeds dry up, infected leafhoppers migrate to sugar beet fields.

Control

Control of the BCTV consists of the combination of host resistance, controlling weed hosts, insect vector control, and cultural practices. Both early planting and protection of seedlings with soil-applied insecticides provide early season control when the sugar beet plant is the most susceptible.

Figure 12a. Beet curly top virus. Mild strain of BCTV or mild reaction of plant.

Figure 12b. Beet curly top virus. Vascular discoloration caused by BCTV in xylem vessels.

Figure 12c. Beet curly top virus. Severe strain of BCTV or severe reaction of plant, which can cause death of the growing plants.

1. **Host resistance.** Sugar beet production in the Western United States was almost eliminated by BCTV in the early 1900s. The first resistant variety, US 1, was released in 1934. Today, most varieties used in the Western United State have some resistance to BCTV. All varieties approved by the Rocky Mountain Joint Grower – Holly Research Committee for the Big Horn Basin must have a BCTV rating of 5.59 or less. Varieties are rated in the BSDF disease nursery in Kimberly, Idaho, on a scale of 1 to 9 (1=healthy, 9=dead). HMI-9155 (rating of 4.3), HMI-WS-91 (rating of 4.1), and ACH-323 (rating of 3.8) are currently recommended for use in the basin areas where severity of BCTV is usually the highest. However, even when BCTV-resistant varieties are grown, if very young seedlings are infected with the virus, considerable injury may still occur.

Figure 12d. Beet curly top virus. Comparison of BCTV susceptible and resistant sugar beet varieties grown in the Big Horn Basin in 1996.

2. **Reduce leafhopper breeding areas.** The chief sources of beet leafhoppers that move into cultivated fields are weedy areas resulting from abandoned farmland, overgrazing, burning, or other practices which are destructive of natural vegetation. Annual and perennial weed hosts in these areas, as well as around sugar beet fields and irrigation ditches, should be destroyed and seeded with perennial grasses to discourage establishment of broadleaf weed hosts.

3. **Chemicals.** Early season insect control of sugar beet seedlings is essential to maximize the benefit of the resistant variety. Several chemicals are labeled for use in controlling this disease in sugar beets (Roth and Spackman, 1983). Field tests with systemic insecticides (Thimet®, Meta-Systox®) and insecticides/nematicides (Temik®, and Counter®) have shown excellent potential for control of the beet leafhopper and suppression of BCTV. Thimet® and Temik®15G, applied as soil treatments at planting, are labeled for early season control of the beet leafhopper. The insecticide Meta-Systox®, applied as a foliar spray, is labeled for season-long leafhopper control. Counter®, applied at planting, is labeled for control of leafhoppers.

4. **Chemical control in non-crop areas**. Spraying non-crop areas with insecticides may reduce the number of leafhoppers which carry the virus and result in lower infection rates of sugar beet plants.

5. **Date of planting**. Sugar beet seedlings in resistant varieties are susceptible to BCTV, but resistance increases with age. Therefore, establishment soon after the last possible freeze date to maximize seedling age at leafhopper migration will help increase the benefit of resistant varieties. Unfortunately, this management practice may provide only minimal protection due to the short growing season in the basin.

6. **Increasing rate of early plant growth**. Young seedlings are the most susceptible to infection and injury caused by BCTV. Every effort should be made to provide optimum moisture and fertility to ensure early emergence and to avoid herbicide injury that may stunt or retard seedlings' growth.

Beet Necrotic Yellow Vein Virus (BNYVV) – Rhizomania

Surveys conducted in 1994 by Holly Sugar Corporation found Rhizomania to be widespread throughout the Big Horn and Wind River basins (Gerik 1994, Duncan 1995). Both the soil-borne fungal vector and symptomatic beets were detected; however, the short growing season and cool soil temperatures during the spring months in these growing areas are unfavorable for disease development, and significant crop losses are not expected to occur. Most likely, the disease has been present in these sugar beet growing areas for quite some time, but was previously undetected.

Symptoms

Typical symptoms of infected plants are a slight yellowing of the leaves which have an upright appearance. There is a proliferation of leaves with an increase in crown tissue. Leaves may also become flabby and wilt. On rare occasions, leaves may turn yellow and have necrotic lesions on veins. Storage roots are stunted with a proliferation of lateral roots giving the beet a bearded appearance (Figure 13a). The root is often rotted at the lower end, is constricted below the soil level, (Figure13b) and has dark vascular rings when cross sectioned. However, diseased plants do not die. Diseased plants usually occur in low, poorly drained areas in a field. Much milder symptoms have been seen on diseased beets in northwestern Wyoming and usually include stunting, constriction of storage root, and minor vascular discoloration.

Pathogen biology

Beet necrotic yellow vein virus (BNYVV) is the causal agent of Rhizomania. It is a member of the flurovirus group of fungal transmitted viruses.

Figure 13a. Rhizomania. Sugar beet showing excessive fiberous roots.

Figure 13b. Rhizomania. Sugar beet plant from the Big Horn Basin showing slight symptoms of Rhizomania. Note acute tapering of the taproot.

BNYVV can only infect a few plant species within three plant families including Chenopodiaceae, which includes the sugar beet plant. Common purslane (*Portulaca oleracea*) in the Portulacaceae family is one of several weeds which serve as host to BNYVV. The virus is transmitted by the soil-borne fungus *Polymyxa betae*. This fungus attacks the fine root hairs of the sugar beet and other host plants and eventually produces both motile zoospores, which may infect other roots, and resting spores called cystosori. These dormant spores can survive for several years. Only a small portion of these soil-borne spores contain the virus. Warm soils (around 68 degrees Fahrenheit) that are excessively wet are favorable for spore germination. Root infection is optimum around 77 degrees Fahrenheit. When these conditions occur during the early stages of sugar beet growth, severe disease loss may occur in susceptible varieties. In California and Texas, where favorable environmental conditions occur shortly after planting, severe disease and loss in sugar beet yield has occurred. Since soils are usually much colder in the basin during this plant growth stage, root infections and yield loss appear to be limited during most years.

Control

Like most soil-borne fungal pathogens, control is difficult; however, several things can be done to help manage this disease. Growers can have soil and symptomatic plants tested to confirm the presence of this disease pathogen by the Holly Sugar Corporation Plant Pathology Laboratory in Tracy, California.

1. **Early planting**. Early planting of sugar beets allows seedlings to be well developed by the time soil temperatures reach the level for optimum infection, thus reducing damage from this disease.

2. **High plant population**. High population (47,000 or more plants per acre) will ensure sufficient numbers of healthy plants at harvest.

3. **Irrigation management**. Delay post emergence irrigation for as long as possible. Avoid overirrigation, particularly of fields which remain wet due to poor drainage of high clay soil content.

4. **Improvement of soil drainage**. Fields that have poor or slow horizontal, in-row, or vertical drainage, may have worse Rhizomania than well-drained fields. Such fields should be laser leveled to increase the in-row flow rate and should be subsoiled (chiseled) or have drain tiles installed to improve vertical drainage.

5. **Soil fumigation**. Soil fumigation with Telone®II has been effective in fields in California and Texas in reducing sugar beet yield loss from Rhizomania. Under optimum soil conditions, use of Telone®II for the control of the sugar beet nematode in the Big Horn River Basin most likely has provided some control of Rhizomania in years when the disease has occurred.

6. **Host resistance**. Holly Sugar Corporation has released several varieties with resistance to Rhizomania. However, **none have resistance to beet curly top virus** and are currently not recommended in the Big Horn Basin.

7. **Weed control**. Several weeds, including common purslane, are known hosts of BNYVV. Control of these weeds should be considered in an overall disease management program.

8. **Narrow row spacing**. Narrow row spacing, used in the Wind and Big Horn River basins, results in early closure of the plant canopy which shades the soil surface. This lowers the soil temperature, making conditions unfavorable for germination of resting spores and root infections by *Polymyxa betae*. Germination of the resting spores occurs very slowly when soil temperature is below 68 degrees Fahrenheit.

Additional information on Rhizomania can be found in the Cooperative Extension Service bulletin B-979 (Franc et al., 1993).

Leaf Diseases

Diseases of sugar beet leaves are not a major problem in northwestern Wyoming, and control measures are not usually necessary. Only three leaf diseases were identified during the three-year survey. These included Phoma leaf spot, Alternaria leaf spot, and powdery mildew. Cercospora leaf spot, which occurs annually in southeastern Wyoming, was not detected during the survey.

Phoma Leaf Spot

Phoma leaf spot was only detected in one of the three survey years (1992) but was found in 41.7 percent of the fields (Figure 14). The disease occurred throughout Fremont (29 percent of the fields), Washakie (42 percent of the fields), and Big Horn (46 percent of the fields) counties. Yield loss may have occurred in fields where the disease was most severe. Since *Phoma betae* is seed-borne, it is expected to occur sporatically during years when weather conditions in seed production areas are optimum for pod and seed infection.

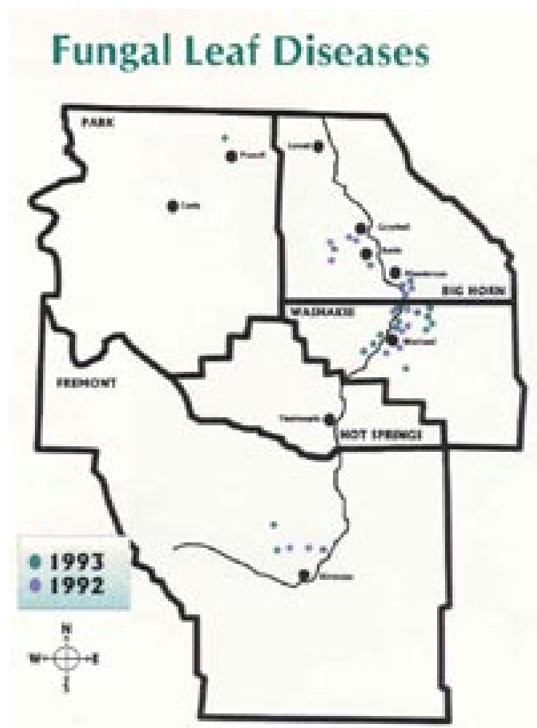

Figure 14. Location of 15 sugar beet fields having Phoma Leaf Spot in 1992 and 19 fields having Alternaria Leaf Spot in 1993.

Symptoms

Phoma leaf spot causes large (up to one inch in diameter) circular spots on leaves (Figure 15a and 15b). Each spot has a concentric ring of dark brown to black spore-baring pycnidia. The outside of this ring is dark brown while the center is a lighter brown with a small central raised area. Up to 25 spots may occur on a given leaf and can severely reduce photosynthesis.

Figure 15a. Phoma leaf spot. Diseased leaf.

Figure 15b. Phoma leaf spot. Close-up of diseased spots.

Pathogen biology

Phoma leaf spot is caused by the fungus *Phoma betae*. The fungus is seed-borne. Infected seed may die prior to emergence or may emerge but remain stunted and unproductive. Spores, produced in round black pycnidia on these diseased seedlings, later infect leaves. A sexual spore stage (*Pleospora bjoerlingii*) is formed in the autumn under spots on leaves. Spore-producing structures, called perithecia, contain ascospores which appear similar to the pycnidia on the upper leaf surface. Prior to harvest, spores from diseased leaves may infect the crown and upper root of the sugar beet plant and result in an upper root rot and storage rot of sugar beets after harvest. In field soil, the fungus can survive in infected plant debris for up to two years. The fungus also has been isolated from roots of lambsquarters. The disease is most severe during periods of high humidity and temperature (range of 58 degrees Fahrenheit to 90 degrees Fahrenheit, optimum of 68 degrees Fahrenheit).

Control

The disease has primarily been controlled by improved seed-cleaning methods and fungicide seed treatments. Crop rotation for two or more years is necessary to allow sufficient time for infected leaf debris to decompose. During years when the disease is severe, one application to the foliage with a systemic fungicide such as Benlate®, applied with a ground-operated sprayer, may be economical.

Other Leaf Diseases

Two other sugar beet fungal leaf diseases were identified during the survey. These were Alternaria leaf spot, caused by *Alternaria brassicae*, and powdery mildew, caused by *Erysiphe polygoni*.

Alternaria leaf spot occurred in 45.2 percent of the survey fields in 1993 (Figure 14). The disease was found in Washakie (45 percent of fields), Big Horn (21 percent of fields), Fremont (43 percent of fields), and Park (17 percent of fields) counties. Leaf spots were predominately on green leaves and were much smaller (¼ inch in diameter) than those of Phoma leaf spot. Damage from this disease appeared to be slight. Powdery mildew (Figure 16) was detected in 2.8 percent of fields in 1992 and in 3.9 percent of fields in 1994. Incidence may have been greater since this disease occurs late in the season after the last survey of each year was conducted. However, loss from powdery mildew appears to be very slight.

Figure 16. Powdery mildew. Healthy and diseased leaves.
Table 1. List of 16 sugar beet diseases identified from field surveys conducted in the Wind and Big Horn River Basins of northwestern Wyoming.

A Summary of Control Practices for Developing an Integrated Disease Management Program

Crop Residue Management. Since an increase in organic matter in the soil increases microorganisms that suppress growth of *R. solani*, incorporation of barley, corn, or oat residue may reduce the incidence of Rhizoctonia disease. Application of liquid nitrogen fertilizer speeds up the breakdown of the straw and hastens microbial activity. The greater the amount of residue plowed down, the greater the control. Suppression of other soil-borne pathogens from increased organic matter may occur as well.

Crop Rotation. Rotation with any other crop grown in Wyoming, except canola which is susceptible to the sugar beet nematode, will reduce soil-borne fungal spores of all major sugar beet diseases, as well as eggs and first-stage juveniles of the sugar beet nematode. Fusarium yellows and Phytophthora root rot are the most difficult to control with rotation. Crops such as corn and barley will usually provide the best rotation crops for disease management of sugar beets. RRCR may be increased following beans or alfalfa. The sugar beet nematode may increase following the planting of forage turnip, kale, rape, or oil seed canola. **Remember, the longer other crops are rotated between beet crops, the fewer disease problems will be encountered.**

Soil testing for the Sugar Beet Nematode. Prior to the sugar beet crop planting, soil should be sampled and analyzed for the sugar beet nematode to determine if a potentially damaging level is present. If using chemical control, soil should be tested in late summer or early fall, preceding spring sugar beet planting. If late summer or early fall seeded trap crops are to be used, barley crop samples should be taken mid-season or sooner, prior to the year of sugar beet planting. Results from a soil analysis and the previous history of the sugar beet nematode in the field should be considered in management decisions for nematode control. Damage threshold for *H. schachtii* in Wyoming is estimated at two to three eggs and/or first stage juveniles per cubic centimeter (cc, which is approximately one gram) of dry soil. For laboratories that give number of cysts per quantity of soil, an average of 16.5 eggs per cyst are found in fields coming out of rotation in the Big Horn Basin. In order to interpret the results, convert to eggs per cc of soil and determine if they are below or above the damage threshold.

Table 3. Reaction to three major diseases of sugar beet varieties recommended for the Big Horn Basin.[a]

Variety	Curly Top[b]	Rhizoctonia[c]	Fusarium
1. Beta 3bg360	5.4	No	No
2. Beta 9125	4.7	No	No
3. Beta 2bg6303	5.3	No	No
4. Beta 8422	4.7	No	Yes
5. Beta 8256	5.2	No	No
6. Beta 8754	5.2	No	No
7. HMI-WS-91	4.1	No	Yes
8. HMI 1311	5.1	No	No
9. Bighorn	5.1	No	No
10. 94hx213	5.3	No	No
11. HMI 9155	4.3	No	No
12. Beta 3bh6328	4.9	No	No
13. ACH 203	4.7	No	No
14. Ranger	4.7	No	No
15. HH86	5.1	No	No
16. Chinook	4.7	No	No
17. HH 83	4.8	No	No
18. ACH 304	5.0	No	Yes
19. Stampede	5.5	No	No
20. HMI R2	5.0	No	No
21. 94hx231	4.6	No	No
22. Wrangler	5.4	No	No
23. ACH 184[d]	Unknown	Yes	No
24. ACH 323[d]	3.8	No	No
25. HH67[d]	5.0	Yes	no

a. BCTV=beet curly top virus, RR&CR=Rhizoctonia root and crown rot, and FY-Fusarium yellows.
b. Varieties are rated for reaction to BCTV at the BSDF Nursery in Kimberly, Idaho, on a scale of 1 to 9 (1=healthy, 9=dead)
c. Varieties are evaluated for reaction to RR&CR at Fort Collins, Colorado.
d. Specialty varieties only.

Varietal resistance. Due to the potential destructiveness of beet curly top virus in Washakie, Big Horn, and Park counties, emphasis should be placed on selecting a variety of good resistance to BCTV. Recommended varieties and their reported resistance to BCTV and other disease are listed in Table 3. HMI-9155, HMI-WS-91, and ACH-323 have the highest level of resistance. Certain districts, as well as certain areas within these districts, have traditionally higher incidences of BCTV than others, and varieties with the highest level of resistance are recommended for these areas. Ask a sugar company agriculturist for assistance in selecting the right variety.

HH-67 and ACH-184 both have resistance to Rhizoctonia root and crown rot, while ACH-304, HMI-WS-91, and Beta-8422 have resistance to Fusarium yellows. HMI-WS-91 has a higher level of resistance to BCTV and is resistant to Fusarium yellows. If any of these diseases have resulted in yield losses, try one of these varieties. No varieties are currently available with resistance to the sugar beet nematode.

Note: Varieties given are for growers contracting with Holy Sugar Company for 1997. Check with a Holly Sugar agriculturist for the current list of recommended varieties.

Soil fumigation. Use of soil fumigation with Telone®II has been effective in increasing sugar beet yield where the sugar beet cyst nematode is present, especially in fields with short rotations (one to two years out of sugar beets).

More recently, it has been used to control Rhizomania, as well. Tests conducted by the senior author during 1995 and 1996 near Worland showed that soil fumigation provided no control of Fusarium yellows.

Although soil fumigation usually results in yield increase, it may or may not be economical due to cost. If soil fumigation is used, read the label thoroughly. Make sure the soil is thoroughly worked to reduce large clods, that the soil is not too wet, and that the soil temperature at 6 inches is 50 degrees Fahrenheit or higher. If any one of these conditions is not met, effective fumigation and disease control may not occur. Fumigate soils in early fall when soil temperatures are well above the minimum 50 degrees Fahrenheit at 6 inches or in the spring after the soil has dried out sufficiently and soil temperature has increased above 50 degrees Fahrenheit. The recommended applied broadcast label rate of Telone®II to control the sugar beet nematode in mineral soils is 18 gallons per acre. Since this constitutes a considerable investment, growers should make sure that sugar beet cyst nematode populations are high enough to justify treatment. Commonly used rates in the basin are 12 to 15 gallons per acre. Cost of Telone®II must be weighed against the potential yield increase to determine if the treatment is economically justifiable. Use of "site-specific farming," based on intensive soil sampling, may make future use of Telone®II more profitable.

Seed treatment. All seeds are currently treated with Apron® and Thiram® fungicides. This offers a wide range of protection against fungal seedling pathogens present in northwestern Wyoming. Studies are currently underway to evaluate other fungicides and biological agents for better control of Fusarium. A priming advancement technique (PAT), a seed priming process, has been field tested by Holly Sugar Corporation in several counties in northwestern Wyoming. This treatment increased the rate of emergence and should reduce seedling disease.

Planting time and planting method. Early planting in the Wind and Big Horn River basins is recommended for several reasons, including reduction in seedling disease, especially that caused by Fusarium, reduction in injury from the beet curly top virus, reduction in infection by *Polymyxa betae* and possible transmission of the BNYVV, and a general increase in yield due to an increase in number of days for sugar beet growth.

Insecticide and insecticide-Nematicide Applications. Temik®15G, applied at planting, should provide control of sugar beet nematodes. Counter®15G, applied at planting, will provide suppression of moderate populations of the sugar beet nematode. Both are labeled to provide early season control of beet curly top virus. Thimet®20G, applied under the seed, and Meta-Systox®, applied to the foliage, should provide season-long control of the beet leafhopper and suppression of beet curly top virus. Temik® and Thimet® applied as a side dressing about one month after planting may increase the severity of Rhizoctonia root rot (Ruppel and Hecker, 1982).

Plant population. Seeding for a high plant population (47,000 per acre or higher) will not control disease. However, high plant population will increase the potential number of plants that escape infection, ensuring a higher number of healthy sugar beets at harvest. Most beets in the basin are planted in rows on 22-inch centers. Holly Sugar Corporation recommends six-inch spacing between plants, resulting in a plant population of 47,000 per acre.

Irrigation management. High soil moisture favors several diseases, including most seedling diseases, Rhizoctonia root and crown rot, Phytophthora root rot, Rhizomania, and to a lesser extent the sugar beet nematode. Therefore, proper management of irrigation water to avoid high soil moisture conditions for prolonged periods of time should reduce these diseases and increase yield potential.

Diagnosing and mapping diseased areas in sugar beet fields. When disease symptoms develop in a sugar beet crop, field maps should be drawn to show exact areas of disease occurrence. Positive identification of each disease is important. These maps can be used for rotation and possible soil fumigation decisions to reduce inputs and ensure minimum loss of yield when sugar beets are again planted.

Other cultural practices

Weed control. Many weeds, especially those in the sugar beet plant family (Chenopodiaceace), serve as alternate hosts for many sugar beet diseases. Therefore, good weed control, not only in the sugar beet field but along ditch banks and on surrounding non-farmland, will aid in reducing loss from these diseases.

Plant nutrients/soil fertility. Rhizoctonia root rot may be increased in certain varieties when nitrogen is deficient (Hecker and Ruppel, 1980). Therefore, optimum soil fertility for plant growth should be provided to maximize plant health.

Tillage practices. When cultivation shields are removed, soil is frequently thrown around the base of plants and onto plant crowns. In fields where *Rhizoctonia* is present, this can increase the crown rot phase of the disease. In fields known to have *Rhizoctonia,* cultivation speed should be reduced to aid in control of this disease.

Sanitation. Many soil-borne disease organisms are readily spread with infested soil. Machinery and livestock are major carriers of soil within and between fields. Much of this, however, may be unavoidable. When fields are known to have severe disease problems, machinery should be cleaned to avoid spreading these disease organisms. Tare soil from sugar beet fields is a concentration of soil shaken loose from sugar beet roots and is a major source of disease-causing organisms. Tare soil is extremely high in soil-borne root pathogens and should never be dumped back onto a sugar beet field.

Improvement of soil drainage. Fields with hardpans, low spots, high clay content (25 percent or greater), high water table, or poor drainage are prone to have severe disease problems. Any effort to better manage the amount of water applied, or to increase drainage, will reduce root and crown diseases. If this cannot be accomplished, avoid planting beets in these fields.

References

Duncan, C. “Rhizomania in the Big Horn Basin.” *Sugar Beet Update*. Vol. 5, No. 1 (1995): 4-5.

Franc, G. D., E. D. Kerr, W. M. Brown, Jr., and J. H. Riesselman. “Rhizomania of sugar beets.” University of Wyoming, Cooperative Extension Service Bulletin, B-979, 1993.

Gerik, J. S. “Rhizomania: An Update.” *Sugar Beet Update*. Vol. 4, No. 4 (1994): 10-11.

Gray, F. A. “Distribution and incidence of sugar beet diseases in the Wind River and Big Horn River Basins of Northwest Wyoming.” Agricultural Experiment Station Bulletin, B-1031. 1995.

Hecker, R. J., and E. G. Ruppel. “Rhizoctonia root rot of sugar beet as affected by rate and nitrogen fertilizer carrier.” *Journal of the A.S.S.B.T.* 20 (1980): 571-577.

Whitney, E. D., and J. E. Duffus. “Compendium of beet diseases and insects.” 1991.

Gray, F. A., and D. W. Koch. “Biology and management of the sugar beet nematode.” Agriculture Experiment Station Bulletin, B-975R. 1997.

Koch, D. W., F. A. Gray, and J. M. Krall. “Nematode-resistant trap crops: A new method of pest control for Wyoming sugar beet growers.” University of Wyoming, Cooperative Extension Service Bulletin, B-1029. 1995.

Davey, C. B., and G. C. Papavizas. “Effect of dry mature plant materials and nitrogen on *Rhizoctonia solani* in soil.” *Phytopathology* 50 (1960): 522-525.

Roth, Don and Everett Spackman. “Curly top and beet leafhopper.” University of Wyoming, Cooperative Extension Service, Pest Report, B-883. 1983.

Ruppel, E. G., and R. J. Hecker. “Increased severity of Rhizoctonia root rot in sugar beet treated with systemic insecticides.” *Crop Protection* 1 (1982): 75-81.