ONIONS

ONIONS

CROP OVERVIEW, GROWTH & DEVELOPMENT

Onions have a biennial growth habit, but are commercially grown as an annual (except for seed production), and harvested for their bulbs. The plant has a very shallow root system reaching about 1 foot deep or less. Onions are a cool-season crop and tolerant of frost. They are highly sensitive to day length (photoperiods). Bulbing is initiated under long-day conditions, and varieties are classified as either short day, intermediate, long day, or very long day cultivars.[(1)]

Onions grow well on most well-drained, fertile soils, but are especially well-adapted to mucks. Onions on the Refuge are direct-seeded. Solid-set sprinklers are used for irrigation, as onions require even moisture throughout the growing season.

Both dehydrating and fresh market onions are grown on the Refuge, but the majority of production is destined for dehydration. Dehydrating onions are grown on contract with a company that provides the seed. Though each company has its own private varieties, selected for high solids and other desirable characteristics, they are all of 'Southport White Globe' origin, which is a medium- to long-day type (Ron Voss, Agronomist, U.C. Davis, personal communication, July 29, 1996).

Fresh market onions grown in the Basin are sweet Spanish-types or sweet Spanish X yellow globe cultivars. Specific varieties change rapidly as new ones are developed. None of the varieties available are resistant to common onion diseases of the Refuge (Ron Voss and Mike Davis, U.C. Davis, personal communications, July 29, 1997).

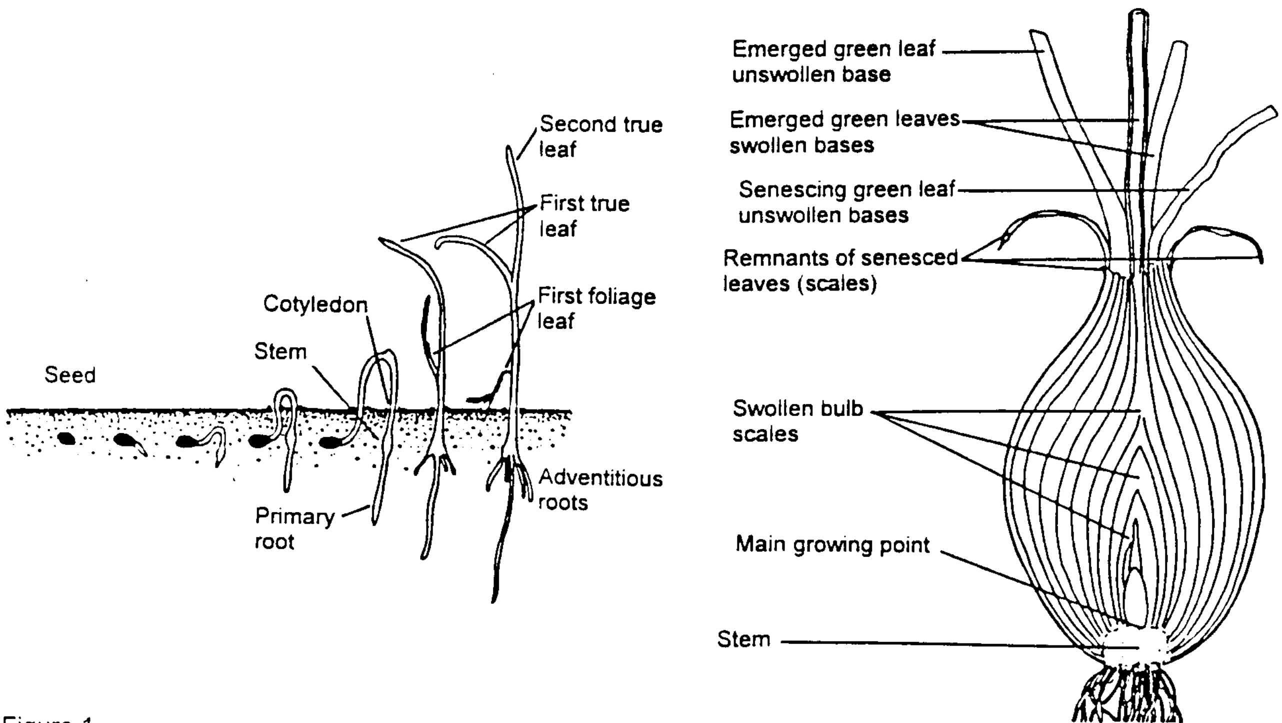

Figure 1.
Onion seedling stages and bulb structure
(after Schwartz, Mohran, 1995)

Onions are attacked by several insects and diseases, control of which currently relies on pesticide use. Horticultural, economic, and political pressures are being exerted to reduce pesticide use in onion production both on the Refuge and in most other regions of the U.S. Some of the factors contributing to changes in onion pest management include pesticide resistance by key onion pests, fewer new chemical registrations, loss of registration for existing products, public pressure, and competition from other regions.

Table 1.
Pest status

Major Pests (as noted by ♦)	**Minor Pests** (as noted by ◊)
Invertebrate onion maggots thrips cutworms	
Disease downy mildew damping-off white rot neck rot bacterial soft rot Botrytis leaf blight	**Disease** onion smut basal rot purple blotch pink root root-knot nematode stem and bulb namatode

MONITORING

Effective onion crop monitoring requires weekly scouting throughout the growing season, access to weather data, scouting sheets for recording data, a 10X hand lens or binocular visor, and baited cone traps for monitoring onion maggot flies.

Scout weekly beginning in early May and continue until harvest. Record crop growth stage and weed types and locations each week throughout the monitoring period. Set up baited cone traps for onion maggot adults in early May and collect trap counts throughout the growing season. During the early season, scout for cutworm larval damage and signs of damping-off disease. Thrips may begin to be a problem in late June or July then continue to increase in intensity through August, providing they have hot, dry weather. Cool wet weather slows them down. Assess fields mid-season (late May through June) for the percentage of onion maggot damage since this is when the young plants wilt and die from the first generation attack. Later on in the season, larger sized onion plants can support onion maggots underground without showing above-ground symptoms, and accurate determination of percent damage is more difficult. Use weather data to determine potential infection periods for Botrytis leaf blight and downy mildew.

Table 2.
Summary of monitoring methods and action thresholds for onion pests

Pests	When/how to scout	Interim action threshold*	Remarks
Onion maggot	Early May, predict timing of onion maggot adult flights using degree day accumulations. Set up baited cone traps to monitor onion maggot flights. Mid-season, rate fields for amount of onion maggot larval damage. Randomly select 10 sampling sites. At each, examine 20 consecutive plants in a row. Pull damaged plants to determine whether they have been infested with onion maggots. Undamaged onions should not be pulled (to reduce the impact on the field from scouting). A single scouting may provide a good general idea of the amount of damage, or samples can be taken weekly over a 3-to-4-week period when damage is most likely, to get a more accurate rating.	Make decision to use preventative Lorsban applications at planting based on the field location and history. If the field was not planted to onions the previous year, and if it is located more than a mile from any field where onions were grown the previous season, then Lorsban may be unnecessary. Foliar sprays against onion maggot flies should only be made on fields that sustained significant losses from the first generation larvae (i.e., more than 10 percent damage). Use baited cone trap counts to confirm presence of adult flies and to time pesticide applications to peak fly periods.	Onion crops that have reached the four-leaf stage (about 12 weeks of growth) rarely require additional treatments, depending on maggot population and weather conditions. To help avoid onion maggot resistance, use no more than one type of chemical in a single season.
Thrips	Begin field scouting when weeds in surrounding areas start drying (roughly around May), as thrips generally migrate into crop fields then. Sample at least five plants from four separate areas of each field. Pull leaves apart and examine them carefully using a hand lens to count all thrips present.	Consider treatments if 30 thrips per plant (roughly three thrips per leaf) are found at mid-season. Use a lower threshold for very young plants, and increase it for older plants.	High infestations occurring mid-season (during the bulbing stage) cause more yield loss than infestations occurring early or late season. Hot and dry conditions favor thrips damage, and cool rainy weather hinders it. To reduce the potential for pesticide resistance, hedge toward a more liberal threshold of five thrips per leaf, if possible.

Pests	When/how to scout	Interim action threshold*	Remarks
Cutworms	Early season (generally mid-May to mid-June), scout for larvae and their damage. Check along ditches, roads and in areas that are grassy, low, damp, or weedy. Also check small grain windbreak strips in the field. Estimate and record the size (feet of row) and location of any areas damaged by cutworms. Look for cut off or damaged seedlings. Larvae remain hidden in the soil during the day, so if cutworm damage is suspected, look for the larvae by sifting through the soil around the cut plants within a radius of about 2 inches to a depth of about 3 inches. Note and record if the larvae are small or large.	No established action thresholds exist. U.C. IPM guidelines suggest basing the need for treatment on the size of the worms observed, the amount of damage, and the crop stage. Older plants can tolerate more damage.	The abundance of cutworms fluctuates considerably from year to year and is affected primarily by rainfall. Populations will be higher in dry years.
Downy mildew	Mid-season to harvest, visually scout fields and record any signs of infection. Monitor weather conditions to determine potential infection periods. Pay special attention if these conditions exist since disease may develop rapidly if spores are present. Large circular clumps of yellowish plants (of a few to many feet in diameter) are often the first field symptoms.	Once diagnosis is confirmed, a fungicide treatment is typically required, especially if weather conditions are conducive to spread of the disease.	Times of high night-time relative humidity coupled with low to moderate daytime temperatures and night-time temperatures of 39-77 degrees are conducive to disease. Confirm diagnosis of downy mildew with a plant pathologist.
Botrytis leaf blight	Mid-season to harvest, visually scout for blighted leaves when sampling for thrips. Leaf blight lesions are characteristically white, with a necrotic center surrounded by a light green halo.	Once diagnosis is confirmed, a fungicide treatment typically is required, especially if weather conditions are conducive to spread of the disease.	During prolonged rainy periods when leaves remain wet for 24 hours or more, blighting is likely to follow. Disease is minimized during relatively dry conditions when the only leaf wetness periods are short nightly dews.

Pests	When/how to scout	Interim action threshold*	Remarks
Nematodes (Northern root-knot, Columbia root-knot, stem & bulb)	Preseason, sample soil from root zone just before harvest of previous crop; send to diagnostic laboratory. During the season, scout fields for nematode damage symptoms (e.g., patchy stands, galls on roots—typical of root-knot nematode damage, or swollen, misshapen, cracked or split bulbs—typical of stem & bulb nematode.	No action threshold established. Nematode populations on onions rarely warrant control actions.	Damage symptoms noticed during the season are useful for indicating a problem field, but are not sufficient for a positive diagnosis (this requires field sampling and laboratory analysis).

*Interim Action Thresholds will be used as guidelines on leased-lands until they are validated.

INVERTEBRATE PESTS

Onion growers on the Refuge report three key insect pests that attack their crops. These are onion maggots, thrips (both onion thrips and western flower thrips), and cutworms.

♦ ONION MAGGOT *S Delia antigua*

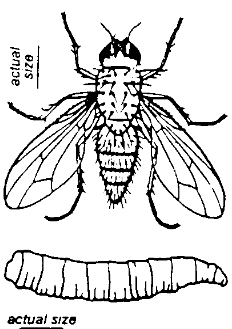

Figure 2.
Onion maggot
Top: adult. *Bottom:* larvae.
(after Ore. Ext. Serv. Bull. 747)

Life Cycle, Host Crops, Seasonal Development

The onion maggot was introduced into North America from Europe around 1875[(2)] and is now distributed across the northern United States and Canada. Members of the onion family are the only species attacked.[(3)]

Adult onion maggots are a brownish-grey fly that resemble the house fly, only they are smaller, with longer legs. The larvae are legless, cream-colored maggots. Pupae resemble grains of wheat and are 0.2 to 0.3 in. long and chestnut-brown.[(2)]

Onion maggots overwinter in the pupal stage in previous onion fields, usually in the top 6 inches of soil. There is no information known about wild hosts in the local area. Adult flies emerge from their pupal cases in the spring and feed on the pollen of flowering weeds.

Mature adult females begin looking for egg-laying sites and fly upwind in response to onion odors.[(4)] Though they can disperse over large areas (a mile or more), many remain within a few hundred yards of their emergence sites. Once they locate an onion field they typically remain in or near the field borders. Later generations emerging from onion fields disperse very little.[(2)]

Females tend to lay their eggs at night, spending most of the day in vegetation near the onion field. Consequently, damage is sometimes worse near field borders rather than in the field center.[3] Given the choice, the flies prefer high-density to low-density plantings as egg-laying sites.

After mating, females lay clumps of up to 30 eggs on top of or just under the soil surface at the base of onion plants. Eggs hatch in 2 to 5 days. Larvae usually feed for 2 to 3 weeks.

Onion maggots are adapted to cool weather but develop more quickly when temperatures are warmer. There are probably three onion maggot generations per year in the Intermountain Region, but the number and timing of the generations should be confirmed locally using degree day accumulations and trap counts.

The following key elements of the onion maggot life cycle should be considered when attempting to manage them:

- significant numbers of flies emerging from overwintering pupae will lay eggs on young onions planted up to 1 mile away from a field planted to onions from the previous year;
- mechanical damage and rotting onion tissue attract egg-laying females and subsequent larval invasion;
- healthy, undamaged bulbs become increasingly resistant to attack as they begin to mature; and
- huge numbers of overwintering onion maggots can develop on damaged bulbs left in the field after harvest.[4]

Damage and Symptoms

First-generation larva cause the greatest economic damage, since they attack emerging onion seedlings. Each larva can destroy 20 to 30 onion seedlings in the loop stage because it can move from plant to plant to feed. Females tend to lay eggs in batches, so damage often occurs in clumps within the bed.

Seedlings attacked in the loop stage may wilt and disappear. Older plants in the two- to three-leaf stage wilt; the foliage becomes flaccid and discolored before drying out or beginning to decompose.[3] The maggots often feed inside the rotting stem and are visible when wilting plants are pulled apart and examined. Larger bulb onions initially demonstrate few above-ground symptoms. Later, the outer leaves begin to yellow and wilt as the infested bulb begins to rot.[3]

Management of the fall generation is key to population reduction.

Host-plant attractiveness declines with age. Second generation larvae are less damaging than the spring generation since most onions at this point are hardened off and are much less susceptible to attack. ***Crops with over 12 weeks of growth are rarely attacked unless they have been injured.***[3]

Third generation adults emerge in late summer and lay eggs, usually after harvest, on cull onions and bulbs left in the field. This is a critical time for population increase, since they do well in cool, moist weather. The pupae from this third generation overwinter in the soil and emerge as adults the following spring.

Short- and Long-term Management Guidelines

▶ *Monitoring*

- Onion maggot fly activity can be predicted using a combination of degree-day accumulation and traps to confirm their presence and abundance. Sweep-net sampling is generally ineffective since many of the adults are out of the field most of the day. Extent of larval damage is determined by visual observations.

- **Prediction of adult emergence**. Initial increases in egg-laying adult flies precede significant larval damage by at least 7 days, since it takes several days for eggs to hatch. If growers are alerted at the time of the first surge of adult flies, they would have at least 1 week to prepare for preventive measures.[5]

  Developmental thresholds can be used to predict when adult flies will emerge. *Table 3* gives degree-day accumulations necessary for initial emergence of each onion maggot generation, based on a developmental threshold of 40 degrees F. (See Workbook Introduction for a discussion of predicting pest activity using degree days). The table also lists approximate flight dates for the Klamath Basin, but these must be verified locally to assure accuracy.

  Once initial build-up of flies occurred, scouts could take two counts a week from several traps baited with onion culls and located in a field with a history of high onion maggot damage to confirm the start of a population increase for the area. Growers could then be warned of a potential infestation. For example, traps could be checked starting in mid-May or at 400 accumulated degree-days and a “fly alert” given when trap counts verified a population surge.[5]

  Baited cone traps are set up in early May and are used to confirm adult flights throughout the season. Over time, use of these traps will enable growers and scouts to build a historical perspective of when flies normally emerge on Refuge lands, and they will be better able to time control practices against the adult flies if population levels warrant treatment. Trap counts also are useful for determining the effectiveness of foliar-applied pesticides, since they can be monitored both before and after an application. See *Appendix O-1* for diagram of a baited cone trap and details on construction and use.

Table 3.
Prediction and timing of onion maggot fly emergence and flight based on degree day accumulations
(adapted from *Integrated Pest Management for Onions*, Cornell Cooperative Extension Service)

Klamath Basin		
Approximate date of peak flight	1st flight	late May to early June
	2nd flight	mid- to late July
	3rd flight	late August through October
Threshold temperature		40°
Accumulated °Days (D)	spring (1st) generation	400°D (°F) to first adult emergence
	2nd generation	1500°D (°F) to first adult emergence
	3rd generation	2700°D (°F) to first adult emergence

- **Mid-season estimates of onion maggot damage**. During mid-June to early July, rate fields for amount of onion maggot larval damage. Randomly select 10 sampling sites. At each, examine 20 consecutive plants in a row. Pull damaged plants to determine whether they have been infested with onion maggots. Undamaged onions should not be pulled (to reduce the impact on the field from scouting). A single scouting may provide a general idea of the amount of damage, or, to get a more accurate rating, weekly samples can be taken over the 3-to-4-week period when damage is most likely.

  Larval damage estimates are useful for determining if foliar sprays are warranted to control second generation maggot flies. Foliar sprays against flies should only be made on fields that sustained significant losses form the first generation larvae (i.e., more than 10 percent damage).

▶ *Cultural*

- ***Crop rotations with another crop at least every third year is key to reducing onion maggot build-up since the flies cannot survive without an onion crop each year***.[(6)] Research has shown that no field that grew onions the previous year should be within 1 mile of the current-year onion crop. Another alternative is to establish an onion-free year, because it has been demonstrated (in New York) that onion maggot flies can move about a mile from overwintering sites.

- If practical, implement an area-wide rotation out of onions for 1 out of 3 years. ***As little as 1-year, area-wide rotation out of onions with a 0.75-mile buffer has eliminated the need for chemical control of onion maggot in the subsequent cropping year.***[(7)] Effective buffer distances, it should be noted, are affected by physical barriers, prevailing winds, and pest population levels at the source. In areas where onion production is concentrated, crop rotation may provide only limited suppression due to the ready migration of adults between fields.

Fall plowing of onion fields postharvest to destroy potential overwintering sites would be allowed.

- ***Practice clean harvests.*** Removing cull onions from the field postharvest, and fall plowing will help reduce the number of overwintering flies.[8] Every dropped onion (especially damaged ones) are a potential host for overwintering onion maggots. Never disc an unharvested field and then leave the cut bulbs in the field. This practice can increase the number of overwintering onion maggots by 100 percent.[6]

- ***Avoid plant injury*** during pesticide applications, cultivation, fertilization and harvest since flies are most attracted to damaged bulbs.

- Delay planting (as late as practical) to reduce the time available for spring-emerging flies to lay eggs.

- There are no commercial varieties resistant to early- or mid-season attack by onion maggot. Some early-maturing varieties such as 'Norstar' and 'Ruby', however, demonstrate some tolerance to attack by the third generation of maggot larvae.[9]

Biological

- To promote biological control of onion maggots using naturally occurring beneficials, apply insecticides and fungicides only when necessary. Monitor for adult flies using heat-unit accumulation and trapping (as previously described), to determine pesticide needs. Scout carefully for disease signs, and use alternative methods of disease management to reduce fungicide applications and enhance natural biological control.

- Numerous beneficial organisms work to suppress the population of onion maggots in the field. These include rove beetles, of which there are both predatory and parasitic species; predaceous ground beetles and soldier beetles; robber flies and other predatory flies; predatory mites and spiders; and at least three species of wasp parasitoids, including a tiny braconid wasp, *Aphaereta pallipes*. Foliar insecticides can easily destroy these beneficials. Research in Michigan, for example, showed 90 percent of ground beetles in an onion field killed from a single foliar insecticide application.[9]

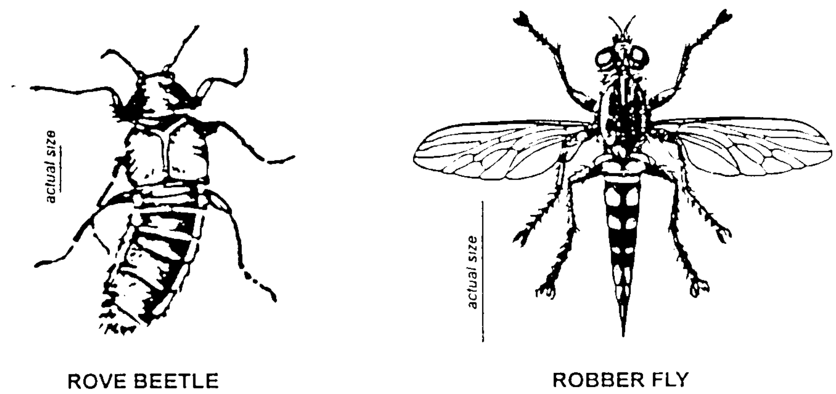

Figure 3.
Beneficial insects effective against onion maggots found in onions
(Rove beetle: *Handbook of the Insect World*, Hercules Powder Co. Robber fly: Metcalf, et al., *Destructive and Useful Insects*. 1993.)

- Natural disease organisms also play a role in suppressing onion maggots. A fungal disease of insects, *Entomophthora muscae,* is known to attack maggot larvae.[10] These insect-attacking fungi can also be killed or suppressed by fungicides used to control onion diseases, such as downy mildew.[7]

- Refer to the Extension publication, *Beneficial Organisms Associated with Pacific Northwest Crops*, for life cycles and photographs of these important biological control organisms.

- **Small grain strip**. In New York, strips of small grains (such as barley, oats or rye) are commonly seeded along with the onions to protect the soil and young plants from damage due to wind erosion. The grain is broadcast or band seeded at the same time the onion crop is planted, using about 0.8 to 1 bushel of seed per acre. These small grain strips are killed with a grass-specific herbicide, such as Fusilade when the onions reach 4 to 6 inches tall (1- to-2-leaf stage).[9]

  Michigan researchers suggest leaving occasional strips of small grain in the field (instead of killing all of it) to promote biological control of onion maggots and other pests. The grains provide habitat for beneficials and resting sites for fungus-infected flies, thus spreading the disease to other flies.[9]

Chemical

- **Furrow applications at planting**. The most effective chemical protection is targeted at the larvae, and is applied at planting as an in-furrow application. Lorsban 15G positive displacement applications were PUP-approved in 1996.[11] Applied in this way, the pesticide creates a barrier between the seedling and the pest. Maggot larvae hatch from eggs laid on the soil surface, and must travel through the pesticide zone to reach the plant.

Well established plants that have reached the four-leaf stage seldom require additional treatments, depending on maggot population pressure and weather conditions.

In addition to its effectiveness, the prescribed method of Lorsban application minimizes environmental hazards of Lorsban. Furthermore, it has low water solubility, and is tied up by soil organic matter, limiting the possibility of leaching. As compared to foliage sprays, positive displacement band applications reduce the amount of pesticide applied by close to 60 percent, thus reducing the hazard still further, and limiting impact on beneficials. Testing has shown that within 2 months prior to harvest, Lorsban residues in the crop are essentially undetectable.[12] Lorsban has been shown to delay emergence of onion seedlings; seedlings were also reduced in size.[53]

Lorsban applications are used to ***protect*** a field against the possibility of maggot damage. ***The decision to use Lorsban should be based on the amount of damage sustained in the field the year before (if previously planted to onions), and if the new field is closer than 1 mile to a field planted to onions the year before.***

- **Foliar applications against adult flies**. The degree of effectiveness of pesticide applications against adult flies is questionable since flies spend much of the day out of the field, and are very pesticide-tolerant.

  Malathion is PUP-approved for foliar applications, and can be used to supplement in-furrow Lorsban treatments against the second and third generations. Foliar sprays should only be made on fields that sustained significant losses from the first generation larvae (more than 5 to 10 percent damage) (Charles Eckenrode, Entomologist, Cornell University, personal communication, October 23, 1996). Use baited cone traps to confirm presence of adult flies and to time pesticide applications to peak fly periods. Also, use cone trap counts taken after applications to determine if the Malathion sprays are reducing fly levels or not. Sprays should be applied early in the morning or late in the evening when flies are most likely to be in the field. Malathion is toxic to many species of beneficial plants.[53]

- **Onion maggot pesticide resistance**. Historically, onion maggots have become resistant to virtually all chemicals used against them.[13] Lorsban, used against onion maggots since the early 1980s, already has encountered low-intensity resistance among pest populations in New York, Michigan, and Wisconsin.[6]

  Onion maggot resistance develops quickly because the maggots feed exclusively on onions (and their relatives) and nearly all onions are treated with insecticides. Only maggots that are able to survive the pesticide treatment reproduce, thus passing on their resistant genes to the next generation.

Due to the onion maggot's exceptional ability to develop resistance to chemical pesticides, chemical controls should be rotated on a 2-to-3-year basis, if possible, and spraying of foliage should be minimized. Likewise, no more than one chemical should be applied in a single season to avoid selection for multiple resistance in this pest. Ideally, pesticide rotation should be coupled with crop and sump rotations, separating old and new fields as much as possible.

Lorsban is currently the only PUP-approved pesticide for use against onion maggot larvae, thus pesticide rotation is not possible. If Trigard (an insect growth regulator) becomes legal in California as a seed treatment, it could be considered for use (see Field Trial Recommendations for further discussion of Trigard). Diazinon has shown only limited effectiveness against onion maggot larvae in other regions, suggesting it should not be considered as a practical alternative to Lorsban on the Refuge.

An integrated approach to controlling onion maggots will prolong the effectiveness of Lorsban and other pesticides. Crop rotations, injury prevention, sanitation, and farm management to promote and conserve beneficials should be considered.

♦ ONION THRIPS S *Thrips tabaci*
♦ WESTERN FLOWER THRIPS S *Frankliniella occidentalis*

Life Cycle, Host Crops, Seasonal Development

Thrips adults and nymphs overwinter on plants or rubbish in fields, or along weedy borders. The eggs are laid into the leaves or stems and hatch in 5 to 10 days. Nymphs grow to adults in 2 to 4 weeks and pass through four instars (growth stages). Two of the stages are passed in the soil. There are generally 5 to 8 generations per year. Both species of thrips attacking onions have a wide host range, including cereals and broadleaved crops.[14]

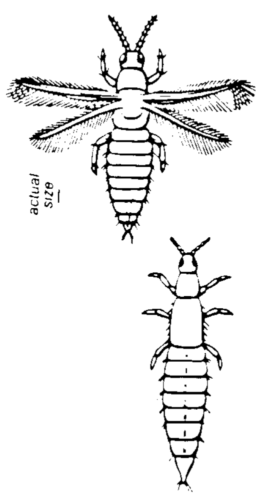

Figure 4.
Onion thrips
Top: nymph. *Bottom:* adult.
(after Sommerman)

Damage and Symptoms

Thrips feed on onion foliage and their effect on bulb production is indirect. Their feeding can reduce the food production capability of the plant, and interfere with transportation of nutrients from the leaves to the bulb. Their feeding also enables various plant pathogens to gain entry, thus increasing disease problems. Entire fields of onions can be destroyed, especially in dry seasons.

Onion plant architecture influences thrips population levels. Cultivars with flat-sided leaves and a compact growth point (where the leaves are closely compressed) protect thrips from natural enemies, weather, and insecticides. Round, openly-spaced leaves reduce thrips protection.[15]

The stage of growth when an infestation occurs seems to determine the extent of yield loss. It appears that early- and late-season infestations cause less yield reduction than those occurring in mid-season during the bulbing stage.[15]

Short- and Long-term Management Recommendations

▶ *Monitoring*

- Begin field scouting when weeds in surrounding areas start drying (roughly around May), as thrips generally migrate into crop fields then.

- Sample at least five plants from four separate areas of each field. Pull leaves apart and examine them carefully using a hand lens to count all thrips present.[14]

- Reliable treatment levels are currently speculative. In California, a threshold of 30 thrips per plant at mid-season (roughly three thrips per leaf) has been used successfully for dry bulb, fresh market, and drying onions. In New York State, a conservative action threshold of three thrips per green leaf is recommended.[9] Use a lower threshold for very young plants, and increase it for older plants.

- No single number will always be reliable as a guide, but to reduce the potential for pesticide resistance, hedge toward a more liberal threshold of five thrips per leaf, if possible. Climate is a factor; hot and dry conditions favor thrips damage, and cool rainy weather hinders it. Control thrips before onions reach the early bulbing stage so that populations do not exceed levels that can be managed.[14]

▶ *Cultural*

- Destroy weeds in the field and surrounding margins (if not destructive to wildlife habitat), as these sites harbor overwintering thrips.

- Avoid water stress because it increases onion susceptibility to thrips damage and thus lowers yields.[15]

- Plant cultivars with open canopy growth (if available) as they are somewhat resistant to thrips damage and increase the potential for chemical and biological control. Some variety resistance among sweet Spanish types is noted in the literature. It is suggested that these may be older cultivars with more open canopy growth.[9]

▶ *Biological*

- Numerous beneficial organisms attack thrips. These include lady beetles (ladybugs), minute pirate bugs, big-eyed bugs, lacewings, hover flies, predatory mites, and spiders. Naturally-occurring fungal diseases can also devastate thrips populations.[9] Unfortunately, control by these beneficials may be hampered by the fact that thrips feed hidden under close-fitting leaves and down in the leaf sheaths where they are difficult for beneficials to access.

- Promote biological control of thrips by using insecticides and fungicides only when necessary. Monitor for thrips to evaluate the need for insecticide treatments. Scout carefully for disease signs, and use alternative methods of disease management to reduce fungicide applications and enhance natural biological control.

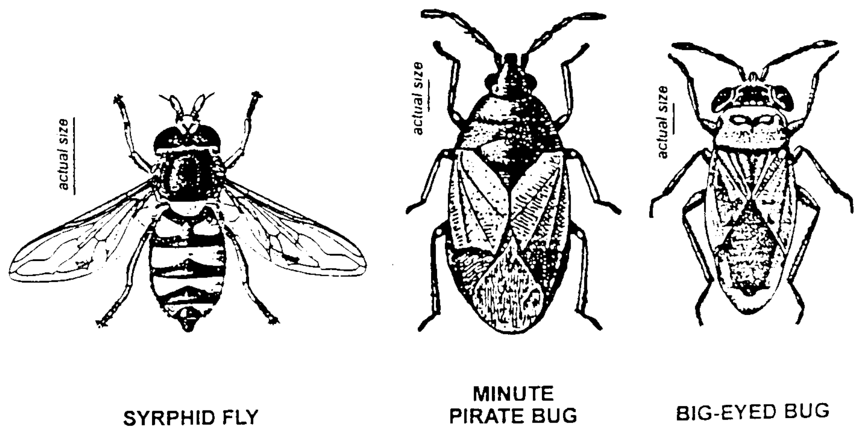

Figure 5.
Benficial insects effective against thrips found in onions
(Syrphid fly: after Metcalf, from *Ohio Naturalist*. Minute pirate bug and big-eyed bug: copied with permission from Div. of Agric. and Natural Resources, U.C., Oakland, CA.)

- Refer to the Extension publication, *Beneficial Organisms Associated with Pacific Northwest Crops*, for life cycles and photographs of these important biological control organisms.

Chemical

- Contact insecticides do not effectively control thrips because the pests typically live in the tight spaces between the leaf sheath and stem and are protected from the spray. For this reason it is suggested that spraying be done with ground rigs using high pressure and/or high volume.[9] Sprayer pressures of 35-40 psi are commonly used without causing crop damage. However, caution is needed because at some point (second half of growing season) ground rigs can damage the crop mechanically by the weight of the tractor in the tire rows.

- Wetting agents (which increase the spreading and penetrating power of the pesticide by lowering the surface tension of the solution) are considered to be quite helpful.[9] Many materials are used as wetting agents, including long-chain alcohols, petroleum sulfonates, acid sulfates, sulfonated aromatic derivatives, esters of fatty acids, and clays.[16]

- Thrips rapidly develop pesticide resistance. If sprayed too often, effectiveness of a pesticide against thrips can decrease from 90 percent control to 40 percent in one season. It is recommended that pesticide sprays only be used against thrips if monitoring shows it is warranted (and never on a calendar basis) due to the limited number of approved pesticides and high potential for resistance development.

- Thrips, especially western flower thrips, have demonstrated some resistance to organophosphate insecticides. This has been documented in other states and is suspected in California.
- Malathion 8 is the only PUP-approved insecticide for thrips control. Of the insecticides currently registered on onions for thrips control in California, permethrin might be considered for approval as a rotation with Malathion to reduce the possibilities of developing resistance. The use of permethrin would require PUP approval.
- Pounce has recently been PUP approved; alternating between Pounce and Malathion 8 may reduce pesticide resistance.

Above-ground cutworm species

♦ **VARIEGATED CUTWORM** *S Peridroma saucia*

♦ **ARMY CUTWORM** *S Euxoa auxiliaris*

Subterranean cutworm species

♦ **PALE WESTERN CUTWORM** *S Agrotis orthogoni*

♦ **BLACK CUTWORM** *S Agrotis ipsilo*

Life Cycle, Host Crops, Seasonal Development

Several species of cutworms may be present on leased lands. Cutworm larvae are rather large caterpillars, reaching 1.5 to 2 inches long when fully grown. Cutworm larvae attack a wide variety of vegetable and field crops, especially in the seedling stage.

All cutworm adults are moths with dark gray forewings, variously marked, and lighter colored hind wings. They feed at dusk on flower nectar and are attracted to lights. They tend to lay their eggs on plants in grass sod or weedy fields. Larvae go though several molts and eventually enter the soil to pupate.

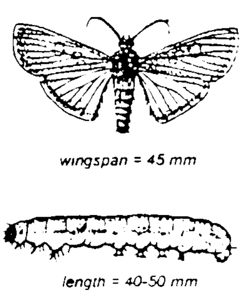

Figure 6. *Variegated cutworm* *Top:* adult. *Bottom:* larvae. (after Iowa Agric. Exp. Stn., Circ. 101)

Each species has somewhat different habits. The army cutworm is a surface feeder that does little burrowing. It completes one generation annually, and lays its eggs on the soil. The variegated cutworm (an above-ground feeder) may complete two generations a year in the Northwest, and commonly overwinters as a pupa. The pale western cutworm is largely an underground (subterranean) feeder, which lays its eggs on the soil and completes a single generation annually.[17]

Black cutworms are also subterranean species, feeding mostly underground during the night. Young larvae (less than 0.5 inch long) feed above ground. Larger larvae feed at, or just below the soil surface, although in fields with very dry soil conditions, the larvae may be found 2 to 3 inches deep.[18]

Generally, black cutworm moths will not lay eggs in fields that have already been planted. Oviposition (egg-laying) is typically concentrated on low-growing vegetation such as chickweed, curly dock, mustards, or plant residue from the previous year's crop. As a result, heavy spring weed growth, newly broken sod, previous crop, and plant debris all increase the risk of black cutworm infestations.

Most cutworms overwinter as larvae in cells in the soil, in crop residues, or in clumps of grass. Feeding begins in spring and continues to early summer when the larvae burrow more deeply into the soil to pupate. Adults emerge from the soil 1 to 8 weeks later, or sometimes overwinter. Most species deposit eggs on stems or behind the leaf sheaths of grasses and on weeds. Eggs hatch from 2 days to 2 weeks later.

The worms are gray to dull-brownish, smooth-skinned, with various markings depending on species. They readily curl into a C-shape when disturbed.[19] They are known to feed on nearly all non-woody plants, and are serious pests on corn, beans, cabbage, cotton, tomatoes, tobacco, and clover, in addition to onions.[17]

The abundance of cutworms fluctuates considerably from year to year and is affected primarily by rainfall. Rain may prevent the moths from laying their eggs, or force the larvae to the soil surface during the daytime where predators will consume most of them. Conversely, populations will be higher in dry years.

Damage and Symptoms

Age of the onion crop is the most important factor in determining the severity of cutworm damage; seedling and young onion plants are most susceptible to damage. Most cutworms are either nocturnal or subterranean and are rarely seen, even when their damage becomes obvious. Variegated cutworms feed above ground, cutting the plants off at or above the soil line. Pale western and black cutworms are subterranean species, feeding mostly underground during the night. The larvae cut young plants off below the soil line; this damage is often the first sign of an infestation. The black cutworm is especially active, and will often work its way down a row of onions, cutting off one plant after the next in a line.

Short- and Long-term Management Recommendations

▶ *Monitoring*

- Timely detection is critical if insecticidal treatment is to be effective. Look for the presence of cutworm larvae early in the season, and after destruction of adjacent habitats and grain windbreaks. Check along ditches, roads and in areas that are grassy, low, damp, or weedy. Also check small grain windbreak strips in the field.

- Look for cut off or damaged seedlings. Larvae remain hidden in the soil during the day, so if cutworm damage is suspected, look for the larvae by sifting through the soil around the cut plants within a radius of about 2 inches to a depth of about 3 inches. Note and record if the larvae are small or large. Estimate and record the size (in feet of row) and location of any areas damaged by cutworms.[9]

- There are no established economic threshold levels. U.C. IPM guidelines suggest basing the need for treatment on the size of the worms observed, the amount of damage, and the crop stage.[20] Older plants can tolerate more damage.

- Metcalf [17] suggests an interesting technique for estimating spring larval infestations:

  "Place rather large, compact bunches of freshly cut clover, dock, or chickweed on well-plowed soil. If cutworms are present in the soil, they will collect under such vegetation. Scouts can then look under the bunches in 2 or 3 days, and count the number of cutworm larvae found as an indication of whether there is a large population in the field."

▶ *Cultural*

- Clean tillage to remove all weedy vegetation, at least 10 days prior to planting, reduces the number of cutworm larvae.[10] Control of weedy vegetation at field borders also reduces the number of invading larvae.

- Crop rotation is an important control tool for cutworms. Avoid planting fields to onions if monitoring shows high populations of cutworms in previous crops, especially if onions are following alfalfa or cereals in a rotation, since they are especially good hosts for cutworms.[20]

▶ *Biological*

- Cutworm larvae have a number of natural enemies. Several species of ground beetles prey on them. Several types of flies (tachinids) and wasps (braconids and trichogrammatids) parasitize cutworm eggs and larvae. Cutworms may also be attacked by fungi, bacteria, nematodes, and birds.[17]

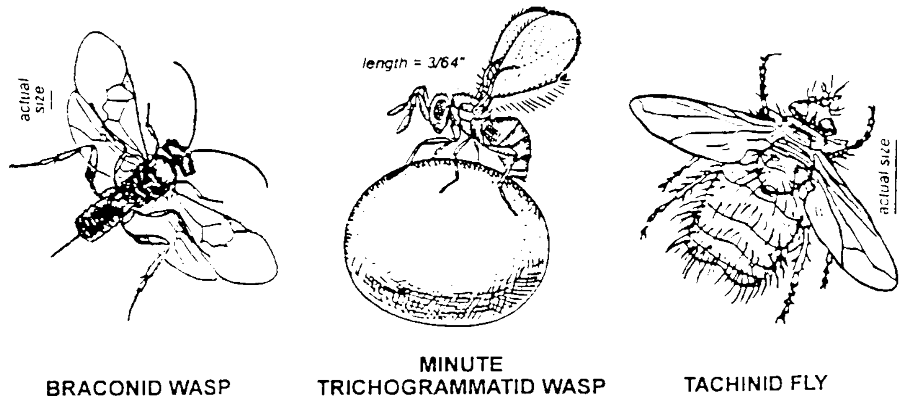

Figure 7.
Beneficial insects effective against cutworms found in onions
(*Handbook of the Insect World*, Hercules Powder Co.)

- Predators and parasites are more effective against the above-ground species of cutworms (e.g., the variegated and army cutworms). Pale western and black cutworms are not as susceptible to control by these agents due to their subterranean nature. However, they are more susceptible to control by soil-dwelling beneficials such as nematodes, fungi, and bacteria than are the above-ground feeders.

- Refer to the Extension publication, *Beneficial Organisms Associated with Pacific Northwest Crops*, for life cycles and photographs of these important biological control organisms.

Chemical

- Cutworm larvae are most vulnerable to pesticides when they are small (less than 1.5 inches long). Monitor fields closely when crop and pests are young.

- Lorsban is PUP approved only for the onion maggot, which is reported as a more serious pest problem than cutworm. Incidental suppression of cutworm populations may result from use of Lorsban.[11]

- Bait formulations (banded over the seed row) are the most effective treatments against cutworms (Cheryl Norton, Abbot Labs, personal communication, January 7, 1997). Baits will be considered for use on the refuges, once PUP approved, if they do not cause harm to fish and wildlife. Baits made from the bacteria *Bacillus thuringiensis* var. *kurstaki* (*B.t.k.)*(such as Dipel or Javelin products) would control cutworms and would not pose this hazard. Unfortunately, there are no bait formulations of *B.t.k*. available at this time. If a bait formulation of *B.t.k*. becomes available, it should be considered for PUP approval. Foliar applied formulations of *B.t.k*. (which are available) are basically ineffective against cutworms in seedling row crops because the larvae do extensive damage prior to ingesting a lethal dose. They also lose effectiveness within 24 to 48 hours.[19]

DISEASES

♦ DOWNY MILDEW *S Peronospora destructo*

Life Cycle, Host Crops, Seasonal Development

The incidence of downy mildew disease is very erratic in California (including Refuge lands), and is largely promoted by cool, moist weather conditions. The fungus overwinters in infected bulbs in the field, cull piles, and perennial onion species often grown in home gardens. In spring, it invades new leaves as they emerge. Spores produced on these new leaves are the source of downy mildew epidemics later in the season.

During the spring and summer, spores are produced and carried by wind to infect new plants. Spore production occurs between midnight and sunrise on heavily colonized onion leaves. Weather conditions required for spore production are: 1) low-to-moderate temperatures during the preceding day; 2) temperatures between 39 and 77 degrees F at night with continuous high relative humidity (about 95 percent) between midnight and sunrise; and 3) no rain after 1 am.[21] High daytime temperatures and low humidity at night prevent spore production. Spores can live for about 4 days, but are quickly killed by dry conditions. They also require free water and temperatures between 34 and 82 degrees F to germinate. Optimum temperatures for germination are between 45 and 61 degrees F.[9]

High thrips populations increase susceptibility to downy mildew, since they break through the protective waxy cuticle of the onion blade while feeding, providing easy entry for infection.[16]

Damage and Symptoms

Disease symptoms first appear as a fine, furry, grayish-white to purple growth on older leaves. Under this growth, the leaf tissue becomes first pale green and eventually turns yellow and finally collapses. Downy mildew results in heavily blighted leaves and reduced bulb growth. Spongy neck and bulb tissue often occurs, and infected bulbs may not store well.

Short- And Long-Term Management Recommendations

▶ *Monitoring*

- Scout fields and record any signs of infection. Monitor weather conditions to determine potential infection periods (i.e., times of high night-time relative humidity coupled with low-to-moderate daytime temperatures and night-time temperatures of 39 to 77 degrees F). Pay special attention if these conditions exist since disease may develop rapidly if spores are present. Large circular clumps of yellowish plants (of a few to many feet in diameter) are often the first field symptoms.

▶ *Cultural*

- Use only disease-free onion seed.[16]

- Remove culls, crop debris, and volunteer onions to reduce sources of infection. Do not grow winter onions and other host crops in fields and home gardens near summer production fields.[9]

- Rotation to a non-onion family crop for a minimum of 3 years may reduce (but not eliminate) the disease. Downy mildew spores have been known to survive up to 25 years in the soil.[22]

▶ *Biological*

- There are no effective biological controls to recommend at this time.

▶ *Chemical*

- Dithane, Ridomil MZ72, and Ridomil Bravo are PUP-approved fungicides for downy mildew prevention on Refuge leased lands. Dithane is also effective against neck rot. Applied on a 7-day schedule, Dithane is less expensive, but also less effective, than the alternatives, and is suitable for less-serious outbreaks. It may be applied up to eight times per season either via aerial or ground application, or by chemigation. Dithane demonstrates lower toxicity to mammals than the alternatives, but greater toxicity to fish, requiring additional care.[24]

- Ridomil MZ72 is a premix of metalaxyl and mancozeb, requiring only a 14-day application schedule. It may be applied by aerial means up to four times a season. Ridomil Bravo is a premix of metalaxyl and chlorothanil. Like Ridomil MZ72, it requires only a 14-day application schedule, is aerially applied, and limited to four applications per season.[24]

♦ DAMPING OFF S *Pythium* spp. and others

Life Cycle, Host Crops, Seasonal Development

Damping off is caused by a number of soil-borne fungal organisms, such as *Pythium* spp., which are found in most soils. These cause seed and seedling decay. Infected plants typically die in the seedling stage or fail to germinate altogether. Those that survive develop poorly and exhibit a brownish rot. Yield reductions are most severe in precision-seeded stands. Damping off is a problem in a wide range of plants. Outbreaks are aggravated by cool temperatures, wet soil, overcast weather, and limited air movement.[9]

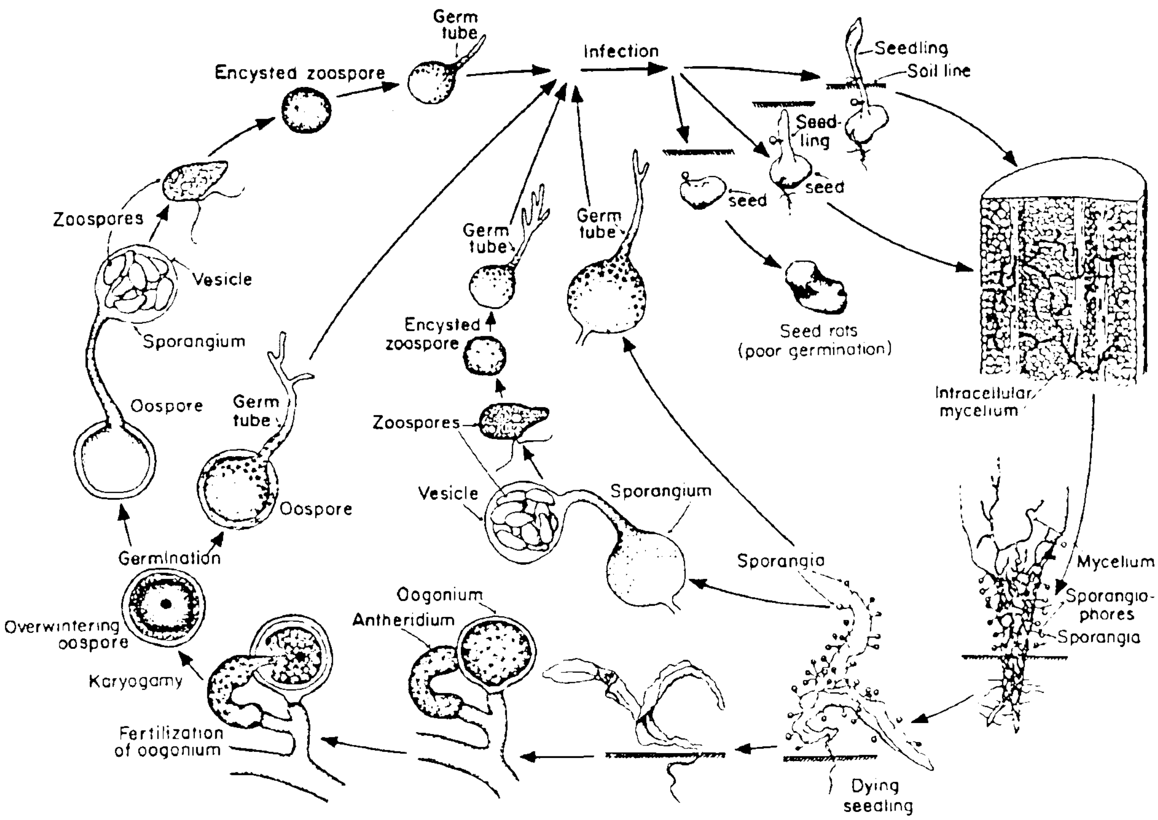

Figure 8.
Disease cycle of damping off and seed decay caused by Pythium *spp.*
(copied with permission from Academic Press)

Short- and Long-Term Management Recommendations

▶ ***Cultural***

- Use cultural practices that promote good drainage (e.g., ripping the soil with a shank every 2 to 3 years and planting in raised beds).

- Crops grown in rotation with onions that have deep roots, such as sorghum-Sudangrass, also help to break up the soil and improve drainage. Growers in New York say that planting a cover crop of sorghum-Sudangrass every 3 to 5 years can significantly increase yields. The grass helps reduce soil-borne disease as well as nematode problems.

- Flooding would probably reduce damping off pathogens in the soil.

Biological
- There are no effective biological controls to recommend at this time.

Chemical
- Seed-coat treatments with fungicides, such as thiram, are an effective control measure.

♦ WHITE ROT *S Sclerotium cepivorum*

Life Cycle, Host Crops, Seasonal Development

White rot disease causes serious losses in onions when present. It poses the greatest threat to the future of onion production in the Klamath Basin if it continues to spread.

The pathogen survives in the soil as small dormant structures called sclerotia. These may live for 20 years, even in the absence of a host plant. As little as one sclerotia per 10 kg of soil will cause disease and result in measurable crop loss; and 10 to 20 sclerotia per kg result in all plants being infected.[24]

Sclerotia are spread by water, equipment, and plant tissue of onion family relatives, including wind-blown scales. The disease remains dormant until exposed to substances from onions or their relatives. It is favored by the same cool, moist conditions favorable to onion growth, and inhibited at soil temperatures above 78 degrees F.

Damage and Symptoms

White rot causes the roots and base of developing bulbs to rot and become covered with a whitish mold. Infected plants yellow and wilt, and can be easily pulled. Infected bulbs continue to rot in storage.

Short- and Long-Term Management Recommendations

Cultural
- Avoid planting onions in infected fields.

- Sanitation is critical to continued onion production in the Klamath Basin. Prevent movement of culls, plant litter, and soil (on equipment or boots) from infested to clean fields.

- Rotation of fields to non-onion crops for at least 4 to 5 years will reduce, but not eliminate, sclerotia (these can live in the soil for 20 or more years). The impact of crop rotation is limited in the face of severe outbreaks due to the persistence of sclerotia in the soil.

- Manage onions for maximum vigor and minimum stress to increase plant resistance and survival from infection in contaminated fields.[9] Cessation of irrigation, once the disease is observed, helps to minimize the disease.[24] However, if irrigation reduction results in drought stress, yields could be reduced and thrips problems increased (since onions are less able to tolerate thrips damage under drought-stressed conditions).

▶ *Biological*

- Beneficial fungi such as *Coniothyrium* have been researched for their ability to control white rot sclerotia. Results, however, have been variable, and no specific recommendations can be made at this time.[25]

▶ *Chemical*

- At present, there is no totally effective chemical control.[9] The fumigant, metam sodium, has demonstrated moderate effectiveness against this fungus. It is cleared for use on potatoes on the Refuge, but research has shown it too sporadic on white rot to warrant recommendation.[24]

♦ BOTRYTIS NECK ROT *S Botrytis alli*

Life Cycle, Host Crops, Seasonal Development

Botrytis neck rot is caused by a fungus that attacks only onions and their relatives. It overwinters in infected onion crop debris, unharvested onions, and cull piles. It spreads through wind-blown spores. Sclerotia are also produced, and are known to survive for many years in soils and cull piles. Infection is favored by cool, wet conditions, and by poor drying and curing of harvested onions.[9]

Damage and Symptoms

A healthy onion with a well-cured neck is rarely affected by neck rot after storage.[26] For dehydrating onions, neck rot is a minor problem since the varieties grown have small necks and typically dry well. Fresh market varieties grown on the Refuge have larger necks, so the disease may be more of a problem with this crop.

In infected bulbs, a brownish soft rot spreads through the scales from the neck to the base, usually when in storage. If humid, a gray mold may also develop between and around the infected scales. Infection may also lead to subsequent invasion by soft-rot bacteria, resulting in a soft, watery and foul-smelling breakdown of the tissue.

Mechanical topping or other tissue injury provides sites for infection, as can damage during harvest. Infection may also occur through the neck as the leaves begin to yellow and die. Thick-necked bulbs that are slow to dry down are especially susceptible. Neck rot infection is believed to be facilitated by previous infection with downy mildew and/or leaf blight.[16]

Short- and Long-Term Management Recommendations

Fall plowing to bury culls and destroy overwintering sites is a practical method, allowed on Refuge leased lands.

▶ *Cultural*

- Plant only disease-free seed.
- Use proper sanitation procedures in destroying crop debris and culls.
- Crop rotation may reduce the number of sclerotia.
- Avoid excessive and late-season nitrogen applications, which delay senescence and encourage thick-neck development.
- Avoid harvesting during wet weather.
- Undercut and windrow onions to encourage thorough drying of the neck tissue prior to topping and storing.
- Cure well before storage to allow healing of wounded tissue. Sort carefully before storage and remove damaged onions and those harvested from wet areas.

▶ *Biological*

- There are no effective biological controls to recommend at this time.

▶ *Chemical*

- Dithane, Rovral 4F, and Rovral are current PUP-approved fungicides for neck rot prevention on Refuge leased lands. Researchers at Cornell University note that fungicidal control of Botrytis leaf blight and other foliar diseases does not result in control of Botrytis neck rot.[9]

♦ BOTRYTIS LEAF BLIGHT *S Botrytis squamos*

Life Cycle, Host Crops, Seasonal Development

The fungus *Botrytis squamosa* only infects members of the onion family (*Allium* spp.). The disease is favored by warm, humid weather, and is most prevalent during mid- to late-season. During prolonged rainy periods when leaves remain wet for 24 hours or more, blighting is likely to follow.[26] Disease is minimized during relatively dry conditions when the only leaf wetness periods are short nightly dews.

Sclerotia overwinter on culls, crop residue, and in the soil. These produce spores that infect the leaves of onions grown the next year. Spore production and dispersion are favored by high rainfall and relative humidity, and moderate temperatures.

Spores are carried by wind currents and infect leaves if sufficient leaf wetness exists (6 hours or more) and temperatures are below 24 degrees C. Infection frequency and disease symptoms increase as leaf wetness duration increases.[26]

Several "flushes" of spores may be produced annually, resulting in an extended period of primary infection. A number of secondary infection cycles may also occur. Sometimes the sclerotia reproduce sexually, increasing the potential for new, fungicide resistant strains.

Damage and Symptoms

The leaf-blight lesion is the first symptom of disease. The lesion is characteristically white, with a necrotic center surrounded by a light green halo. The presence of the halo is useful for diagnosing leaf blight and for differentiating it from other diseases or physical injury due to herbicide burn or other causes.[26] Infected leaves brown and prematurely die, causing small bulbs and reduced yields. Spanish-type onions are most susceptible. Blighting is especially severe near windbreaks or in other spots where air circulation is limited.[9]

Short- and Long-Term Management Recommendations

▶ *Cultural*

- Reduce overwintering sites by destroying onion culls and debris. Rotations with nonhost crops helps prevent build-up of sclerotia in the soil. Time sprinkler irrigations so leaves have adequate time to dry after the irrigation period is stopped.[26]

▶ *Biological*

- Naturally-occurring fungi also suppress this disease. Limiting fungicide applications helps preserve these beneficials and reduces the chances of developing resistant strains of the pathogen.[9]

▶ *Chemical*

- Rovral (iprodione) is the only fungicide PUP-approved specifically for use on Botrytis leaf blight on Refuge lands. It may be applied at 14-day intervals. Dithane (mancozeb), Bravo (chlorothanil), and Ridomil (metalaxyl), are effective, but not specifically PUP-approved for leaf blight.[16] These are applied for the control of downy mildew, considered a more serious problem. They may also function in suppressing blight. Where *Botrytis* spp. are the sole problem, the use of Rovral is encouraged as it is believed to kill fewer beneficials.

◊ ONION SMUT S *Urocystis colchic*

Life Cycle, Host Crops, Seasonal Development

A disease of onions and onion relatives, onion smut is caused by a fungus. It is a soil-borne organism that thrives under cool soil conditions. Spores survive many years in contaminated soil, and can only infect young plants between germination and formation of the first true leaf. When plants germinate rapidly in warm dry weather, they often escape infection.

Factors favoring this disease include: a history of disease in the field, soil temperatures above 70 degrees F, planting susceptible varieties, and delayed emergence.

Damage and Symptoms

Symptoms appear as grayish streaks and blisters on leaves and leaf sheaths. Bulbs become filled with black, dusty spores.

Short- and Long-Term Management Recommendations

▶ *Cultural*

- Disease problems can be avoided or reduced by following a 3-to-6- year crop rotation, shallow planting, scouting to locate and selectively remove infected plants,[9] and using clean seed. Promote root vigor and rapid emergence of seedlings.

▶ *Biological*

- There are no effective biological controls to recommend at this time.

▶ *Chemical*

- Seed-coat treatments with fungicides such as thiram are an effective control measure.

◊ BASAL ROT S *Fusarium oxysporum cepa*

Life Cycle, Host Crops, Seasonal Development

Caused by a fungus, basal rot is soil-borne and very persistent. It is favored by soil temperatures in the range of 57 to 90 degrees F, with optimum temperatures being 79 to 82 degrees F.[27] Spores persist for many years in the soil and on crop residues.[9]

Damage and Symptoms

The organism infects through the roots (or damaged tissue) early in the growing season causing them to decay and die. Subsequently, the plants turn yellow and wilt. Infection may also occur later causing rotting at the plant base along with leaf wilting and death. Symptoms may be apparent at any stage in the growing cycle and in storage.

Short- and Long-Term Management Recommendations

▶ *Cultural*

- Three-to-six year rotations out of onions, garlic or leeks are encouraged; and complete avoidance of seriously infected fields.[28] Avoid mechanical damage to plants and bulbs. Sort carefully, and store in a dry, well ventilated environment. Plant resistant varieties.[9] Deep tillage at planting time or post-emergence "ripping" with a shank is also believed to reduce the problem.[29] Growing onions in soil amended with alfalfa residues may increase seedling growth and reduce bulb rotting.[30]

▶ *Biological*

- There are no effective biological controls to recommend at this time.

▶ *Chemical*

- No fungicides are available that are effective against basal rot.[9]

◊ BACTERIAL SOFT ROT *S Erwinia* spp.

Life Cycle, Host Crops, Seasonal Development

Bacterial soft rots are caused by a number of bacteria: *Erwinia carotovora*, *Erwinia chrysanthemi*, *Pseudomonas gladioli*, and *Enterobacter cloacae*. The organism survives in the soil and on crop residues. It may be spread by rain, insect vectors, and farm implements. It is favored by warm, wet weather.[9] The bacteria are not seed-borne.

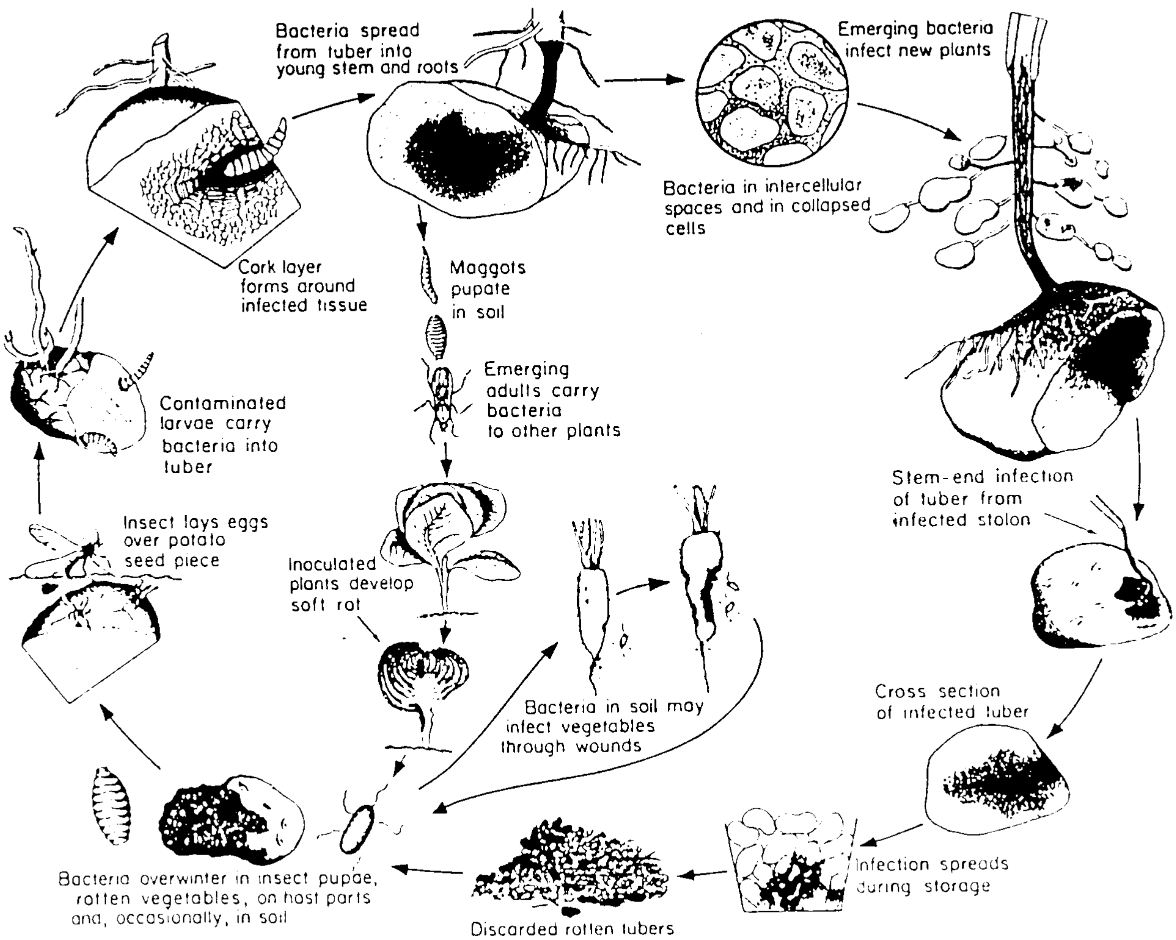

Figure 9.
Disease cycle of bacterial soft rot of vegetables caused by soft-rotting Erwinia *spp.*
(copied with permission from Academic Press)

Damage and Symptoms

Damage is characterized by softening and water-soaking of the inner fleshy scales of the bulb. Disease generally appears at harvest and in storage. Wounds and aging leaves are the chief sites of bacterial entry.[23]

Short- and Long-Term Management Recommendations

▶ *Cultural*

- Manage irrigation carefully and prevent insect injury to the neck. Crop rotations are ineffective since the bacteria are in the soil throughout the region. Allow onion tops to mature well before harvesting. Dry onions well prior to storage.[9]

▶ *Biological*

- There are no effective biological controls to recommend at this time.

▶ *Chemical*

- Chemical controls are generally considered ineffective.

◊ PINK ROOT *S Phoma terrestri*

Life Cycle, Host Crops, Seasonal Development

Pink root is a minor disease of onions in the Klamath Basin since it primarily occurs in warm production regions. Factors that favor this disease include: history of disease in the field, soil temperatures above 82 degrees F, planting susceptible varieties, and mechanical injury to the roots. The fungus is soil-borne and overwinters in the field. It survives on a wide variety of host plants, but may also persist for several years in their absence.[9]

Damage and Symptoms

Most damaging in hot, dry years, pink root increases the plant's susceptibility to other diseases such as basal rot and white rot. Infected roots turn bright pink to red and typically shrivel and die. Leaves may also turn yellow and wilt. Symptoms are more obvious on mature onions than on younger plants, and more severe under higher temperatures and water stress. The disease affects both bulb size and total yield.

Short- and Long-Term Management Recommendations

▶ *Cultural*

- The pathogen builds over time in fields where onions are grown year after year. Rotations to a non-onion crop for 3 to 6 years will help prevent the increase of the pathogen, though rotation will not eliminate the fungus since it has a wide host range. Planting onions after cereals can be hazardous because the inoculum generally becomes greater with cereals than with onions.[31]

- Use resistant varieties, and manage irrigation, drainage and fertilization to promote root vigor and minimize crop stress. Use only clean seed. Flooding may help reduce pink root pathogen in the soil,[9] though the fungus can be spread in water and on dirty equipment.

▶ *Biological*

- There are no effective biological controls to recommend at this time.

▶ *Chemical*

- Fumigation with Vapam (metam sodium) is effective,[31] but is not PUP approved for use on onions and probably not economical in the Klamath Basin since this is a minor disease. Seed treatments used for smut control are not effective against pink root.[30]

◊ PURPLE BLOTCH *S Alternaria porri*

Life Cycle, Host Crops, Seasonal Development

Purple blotch is caused by a fungus. The disease is most common following prolonged periods of wetness, and is often seen in association with other foliar diseases. The fungus overwinters in residues and on wild onion family species. It also can be seed-borne. Spores spread by wind and rain, and infection is enhanced by warm, wet conditions.

Damage and Symptoms

Symptoms of purple blotch are water-soaked spots on the leaves, which enlarge and become brown, with purple along the edges. Infected leaves and stalks often shrivel and die, or break at the lesion. Bulbs may develop a dark yellow or red rot in storage. When seed-borne, purple blotch attacks the young seedling, but more typically, the symptoms appear on older leaves. It can also infect the plant via the neck or mechanical injury sites.[9]

Short- and Long-Term Management Recommendations

▶ *Cultural*

- Rotate to non-onion family crops for 2 to 3 years. Remove crop debris and wild onion relatives. Plant only disease-free seed, and avoid injuries during field operations and at harvest. Harvest in dry weather, and air-dry bulbs prior to storage.[9]

▶ *Biological*

- There are no effective biological controls to recommend at this time.

▶ *Chemical*

- Seed treatments with the fungicide, thiram, are helpful. Sprays with fungicides, such as Dithane, that are used to prevent downy mildew and Botrytis leaf blight often contribute to the control of purple blotch.

◊ **STEM & BULB** *S Ditylenchus dipsac*
◊ **NORTHERN ROOT-KNOT** *S Meloidogyne hapl*
◊ **COLUMBIA ROOT-KNOT** *S Melodogyne chitwood*

Life Cycle, Host Crops, Seasonal Development

Nematodes are microscopic roundworms that feed on plant roots or other tissues. The ***stem and bulb nematode*** *(Ditylenchus dipsaci)* is composed of a number of races, which are differentiated from each other by their host range. The onion-garlic race of the stem and bulb nematode attacks onions, garlic, leeks, chives, Shasta pea, parsley, celery, miners lettuce, hairy nightshade, and salsify.[26]

Stem and bulb nematodes can spread in infested soil, onion crop debris, on other materials and on equipment. They also can be seed-borne. They are capable of living without water and can tolerate desiccation for several years.[32] Populations in the soil fluctuate depending on the soil type and host plants. Optimum survival conditions are a combination of low soil moisture with soil temperatures near or below freezing.[26]

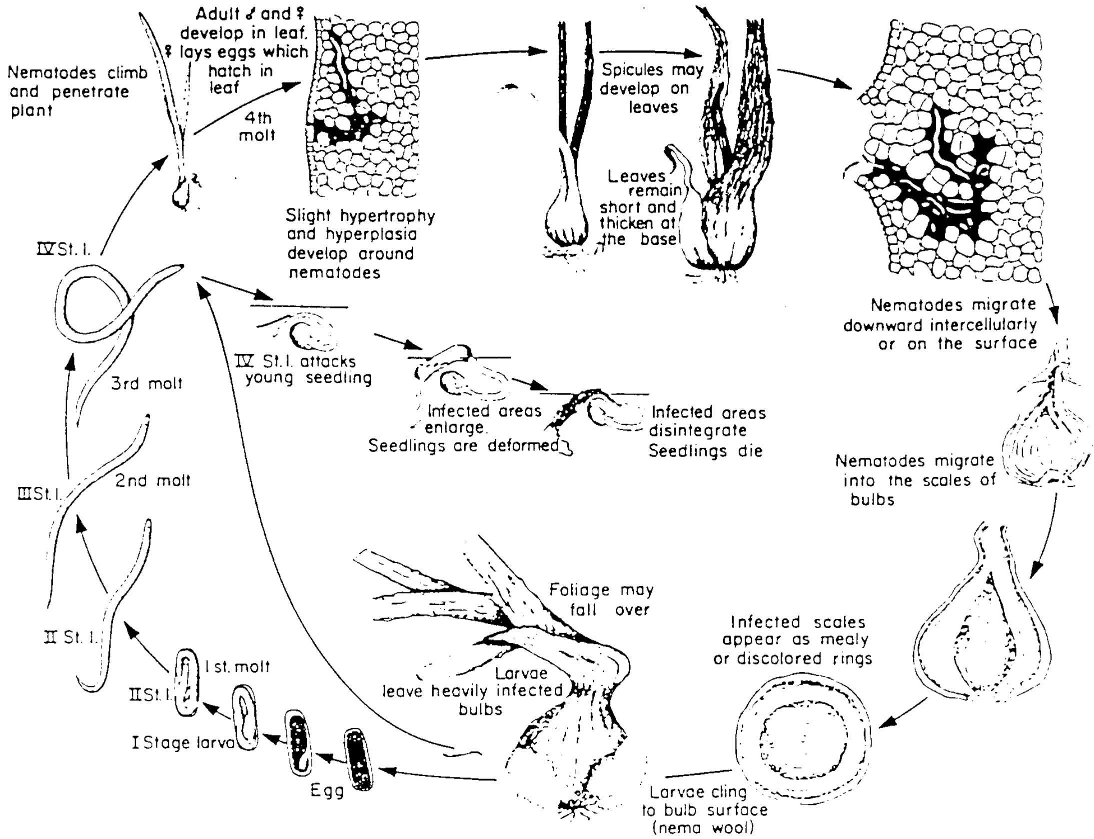

Figure 10.
Disease cycle of the stem and bulb nematode Ditylenchus dipsaci
(copied with permission from Academic Press)

Root-knot nematodes generally have a wide host range and are well-adapted to surviving harsh environments. Egg masses may be attached to host plant roots, or free in the soil. The infective stage hatches from the egg and migrates through the soil towards host plant roots. Generally, root-knot nematodes are more severe in sandy-textured and muck soils than in clay soil. When soil moisture is maintained at levels adequate for onion growth, the nematode may have less effect on the crop.[26]

Root-knot nematodes can be found quite deep in the soil; the Columbia root-knot nematode has been found 5 to 6 feet below the surface. The number of generations per year, usually 1 to 5, is related to soil temperature. Generations are produced in 20 to 60 days.

Damage and Symptoms

Nematodes can sometimes reduce onion yields. Root-knot nematode damage can be severe, but is usually patchy. Root-knot nematodes produce characteristic galls on the onion roots and affected plants produce smaller than normal bulbs. The stem and bulb nematode typically causes swollen and misshapen bulbs that may crack or split. A severe infestation can ruin an entire crop. In general, symptom severity depends on the growing conditions, age of the plant, and type of nematode.

Symptoms of nematode damage are useful for indicating a problem, but they are not sufficient for diagnosis. Similar symptoms may result from other factors such as nutrient deficiencies. Infestations may occur without causing any above-ground symptoms.

Short- and Long-Term Management Recommendations

▶ Monitoring

- If nematode species and densities previously have not been identified, take soil samples and send them to a diagnostic laboratory. Sample soil from within the root zone just before harvest of the previous crop. Divide the field into sampling blocks of 5 to 20 acres, and take several samples from within each block. Include some roots in each sample if possible. Mix all samples together to make a composite sample of about 1 quart of soil for each block. Place samples in labeled, sealed, plastic bags, and keep them cool prior to sending them to a diagnostic laboratory as soon as possible.[32]

▶ Cultural

- Prevent introduction of nematodes to new sites. Avoid transferring infested soil (on equipment or boots), or bulbs from infested to clean fields.

- Although the ***stem and bulb nematode*** has a large number of host races, it can be controlled effectively by a 4-year rotation to a nonhost crop. Eliminate volunteer onions and weed hosts to assure a host-free rotation.[26]

- Crop rotation to nonhost crops can reduce root-knot populations below damaging levels, but will not eliminate them. Alfalfa is a nonhost of Columbia root-knot nematode (*M. chitwoodi*). Race 1 and cereals are nonhosts of the northern root-knot nematode (*M. hapla*).[32] Grasses such as rye also are resistant to root-knot nematodes and are a good rotation crop. A cover crop of sesame has been reported to decrease root-knot nematodes.[33]

- The combination of crop rotations and use of cover crops with winter rapeseed or fall Sudangrass may suppress nematode populations. (See Field Trials Recommendations for discussion of cover crop ideas for nematode control.)

- A cycle of freezing and thawing will also reduce root-knot nematode infestations, as will flooding.[9]

- Onion cultivars differ in their susceptibility to damage from northern root-knot nematodes. For example, 'Downing Yellow Globe' is tolerant.[26]

Biological

- There are no economically viable biological controls to recommend at this time.

Chemical

- No nematicides are PUP-approved for onions on leased lands.

SUMMARY OF PEST MANAGEMENT RECOMMENDATIONS

PREVENTIVE PRACTICES

Pre-Plant and at Planting

- Use crop rotations for basal rot, onion smut, downy mildew, neck rot, white rot (limited) , pink root, onion maggots and purple blotch diseases, and for nematodes.

- Consider field history prior to planting. Avoid sites infested with nematodes, grasses, and white rot.

During the Season

- Avoid plant injury during pesticide applications, cultivations, fertilization and harvest.

- Exclude pests. Avoid movement of contaminated culls, plant litter, soil and water to prevent introduction of white rot, weeds and nematodes into clean fields. Clean equipment.

- A vigorous crop and good irrigation management reduces thrips damage, white rot, bacterial soft rot, and pink root. Avoid excessive and late-season nitrogen applications for neck rot prevention.

- Monitor for and record pests and beneficials throughout the season. Conserve beneficials whenever possible.

Harvest and End of Season

- Avoid injury during harvest. Harvest in dry weather and cure well. Carefully sort and remove damaged onions prior to storage. Clean up and destroy culls and crop debris. Fall plow onion fields postharvest to destroy potential overwintering sites for insects and disease pathogens.

Table 4.
Calendar of control options

Month	Recommended practice	Remarks
March	Clean cultivate ten days prior to planting.	Clean cultivation prior to planting reduces cutworm populations.
April	Plant disease-free, treated onion seed one mile from any field planted to onions the year before. Apply Lorsban at planting for onion maggot control. Monitor emerging crop for cutworm damage. ***Season-long:*** control weeds in fields and around borders.	Disease-free seed reduces purple blotch, downy mildew and neck rot. Treated seed reduces damping-off and smut. One mile buffer from previously planted onion fields reduces onion maggot egg laying on the new crop. Consider baited cone-trap counts, field history and effects of preventative cultural practices in determining need for Lorsban application. Look for cutworm damage and larvae at base of plants.
May	***Early in the month***: Set baited cone-traps; monitor throughout the season.	Baited traps monitor for adult onion maggot flights. Weed control reduces thrips and cutworm infestations.
June	Begin thrips monitoring. Treat for thrips if economic threshold of 30 thrips per plant is reached. Scout for and pull up smut infected plants. Scout for downy mildew, neck rot and botyrtis leaf blight. Use fungicidal treatments if weather conditions are ideal for infection, or if disease is detected. Rotate fungicides.	
July-August	Avoid excessive nitrogen fertilization	Excessive and late season nitrogen promotes neck rot.
September	Prevent damage to onions during harvest and storage. Destroy cull piles and fall plow to destroy crop residue after harvest.	Damage prevention reduces incidence of basal rot, neck rot, bacterial soft rot and onion maggots. Destruction of culls reduces overwintering populations of onion maggots, and downy mildew, purple blotch and neck rot pathogens.

FIELD TRIAL RECOMMENDATIONS

Trials are prioritized under each pest, with the most important trial listed first within each pest. Particularly important field trials are noted with the symbol: ☞

The recommendations below are suggested to help develop new information about biocontrol products, crop rotations and cropping techniques. Most of these trials can be done by any grower who is interested in experimenting with the idea. Results of most of these trials also can be quantified by the grower, such as changes in yields or quality of the harvest. To develop a more detailed picture of what is happening in the field, it is recommended that the grower notify local researchers and the IPM coordinator to inform them of upcoming field trials. In this way, useful trial information may be communicated to others and/or refined and investigated further.

The factors that are reflected in this prioritization include beneficial impact of results, practicality, and success of the trial elsewhere.

Onion Maggots

☞ **1. Use of crop rotations and buffer zones to avoid onion maggot adult egg-laying in the spring.** Where onions are grown in the same field year after year, or in close proximity to the previous year's planting, soil chemicals applied at seeding to control the larvae are necessary. In addition, sprays to control the adult flies during the season may be required. A crop rotation away from onions at least every third year hold excellent potential for reducing pesticide use and costs.

Research at Cornell University has confirmed that as little as a 1-year, area-wide rotation out of onions with a 0.75-mile buffer has eliminated the need for chemical control of onion maggots in the subsequent cropping year.[7] Effective buffer distances are affected by physical barriers (e.g., hedgerows or hills), prevailing winds, and pest population levels. Therefore, the most effective buffer distance should be trialed and confirmed at the Refuge.

If Tule Lake NWR is located 1 mile or more from private lands planted to onions, then this would be an excellent option to consider for reducing both pesticide use and cost of production. Rotations involving shorter distances are still helpful in reducing damage, but benefits diminish as the distance between previous plantings and new plantings decrease. Combining rotation and buffer distance trials with exclusion fencing (see Further Research) might prove useful if the 1-mile buffer required for this option is too great.

☞ **2. Trigard (cyromazine) seed treatments for larval control.** Trigard is an insect growth regulator that prevents maggots from maturing to adults. It is currently used to control leafminer on celery and lettuce in Florida, Texas, and Arizona. It is also used to control houseflies in commercial poultry houses in several states. It is especially active against certain life stages of flies and their relatives, but only mildly active against many unrelated insect groups.

There is minimal hazard associated with the use of Trigard as a seed coat. While rather water soluble, as a seed coating it is used at extremely low rates so dangers of leaching or significant soil residual are minimal. Furthermore, higher organic soils appear to bond the chemical against leaching.[13] To date, no mutation-causing or cancer-causing activity has been noted in any laboratory tests and it is relatively safe to warm-blooded animals, having a lower toxicity level than other commonly used insecticides. The low volume of material, and the manner in which it is applied, also is attractive as it offers minimal chance of wildlife impact.

Trigard would work well in an integrated control strategy employing rotation of chemical controls, sanitation procedures, and crop rotation. At the time of this writing, Trigard has Section 18 clearance for seed coating by three seed companies: Asgrow of Gonzales, California, Incotec of

Salinas, California, and Seed Dynamics of Salinas, California.[34] This clearance is specifically for seed sold in the three states of New York, Michigan, and Wisconsin. At present, Trigard is not cleared for use in California. The manufacturer, Ciba-Geigy, is applying for Section 3 clearance, which would permit usage in all states except California. This state requires its own equivalent "Section 3" clearance. It is understood that application also is underway, and Trigard may be cleared for California use within 1 to 2 years. At the current time, the product is somewhat expensive, but the price is expected to decrease with time.

Once Trigard seed treatments are approved for use in California, they should be considered for PUP approval, since it would provide a pesticide rotation option with Lorsban applications, thus reducing pesticide-resistance potential.

Thrips

1. Alternative pesticides. Trials with the product Align (which is formulated from a botanical extract of the neem tree) might be investigated for thrips control. Align is registered for use on onions in California and should be considered for PUP approval if trials indicate sufficient thrips control.

Trials with neem-based products, such as Align, could be done by growers on their own, or in coordination with the IPM coordinator and local Extension and experiment station researchers.
Suppliers of neem-based products are listed in the Useful Contacts and Resources.

Cutworms

☞ **1. Test beneficial nematodes as an alternative for subterranean cutworm control**. Research on the parasitic nematode species, *Steinernematidae carpocapsae*, has shown it to be a very successful control agent for subterranean cutworms, such as black cutworms.[35][36] Beneficial nematodes enter the bodies of cutworm larvae and release an intestinal bacteria (*Xenorhabdus* spp.), paralyzing and killing the worm within 24 to 48 hours. The nematode then completes several generations within the carcass. During the winter, predatory nematodes burrow deep into the soil for hibernation and return near the surface too late to control early-season larvae, so re-application must be made annually.[37] Beneficial nematodes do not work well against above-ground feeders such as the variegated or the army cutworm.

The nematode product, BioVector: Biological Insecticide for Fruits and Vegetables, is typically used at rates of 1 billion nematodes per acre. Rates of 0.5 billion per acre (roughly $35 to $40/acre) have worked well at times, depending on moisture conditions (Rick Miller, Product Manager for Biosys, personal communication, July 7, 1996). Since nematodes perform best with ample soil moisture, they might provide good control of cutworms in onions because moist conditions are typical of newly emerging onion fields.

According to the manufacturer, the ideal application strategy for using beneficial nematodes would be to apply 0.10 to 0.20 inches of water via overhead irrigation to the crop when the cutworms are still small. Then treat with BioVector at the 0.5 billion nematodes per acre rate, wait 5 to 7 days and monitor for damage. Re-treat only if necessary.

There are no regulations in California restricting the use of beneficial nematodes, but this would require PUP approval. Trials with these organisms could be done by growers in coordination with the IPM coordinator, or by local Extension and experiment station researchers.

Beneficial nematodes are available commercially from the companies listed under Useful Contacts and Resources (see Suppliers of Beneficial Organisms in North America), as well as from a number of other sources.

2. Enhance habitat to increase predation of cutworms by bats and birds. Significant or properly sited bat populations may be especially helpful in managing cutworm adults. A bat can eat its body weight in insects in one night.[38] Bats feed during the same time that cutworm and armyworm adults are active and if numbers are sufficient, can significantly decrease pest populations. Bats may also have a repellant effect, as cutworm and armyworm adults are sensitive to bat echo location (Rachael Long, U.C. Farm Advisor, personal communication, August 6, 1996).

Bat habitat can be dramatically increased by simple modifications of existing farm structures (i.e., adding a board to a beam with 0.75-inch spacers or hanging thin plywood sheets from the ceiling with plastic netting stapled to one side and 0.75-inch spacers between the sheets). It is best to start small and observe what the bats seem to like. Increasing bat habitat in barns or other structures with existing populations is easiest. To attract bats to new habitat, it helps if some diluted guano "paint" is used on the surface of the wood where the bats are to nest. However, barns with owls will not work, and metal surfaces are not appropriate for bats because they conduct too much heat away from the colony during cold weather.

Placing bat houses around fields is also an option. Bat houses need full sun exposure, and should be painted dark brown to black.

Start small and observe what works. Growers would implement this effort. Service personnel could lend support, providing information about the types of bats present in the area of the Refuge and their ecological requirements. See Useful Contacts and Resources for further information about bat predation enhancement.

3. Preirrigation. Preirrigation or heavy spring rainfall forces cutworms from protective burrows where they are more readily exposed to predators and parasites.[17][39] This vulnerability could be exploited by applying extra water in years when cutworm damage is predicted to be high.

Nematodes

1. Nematode-suppressive crop rotations and cover crops. Research at Oregon State and Washington State universities has documented that fall-planted Brassica green manure crops (such as rapeseed) grown over the winter and disced in before spring planting suppress nematodes and weeds and provides winter cover to prevent wind erosion.[40]

The best rotation for Columbia root-knot nematodes involves planting a summer nonhost crop, and a fall or winter cover crop (such as Sudangrass or rapeseed) incorporated as a green manure. A grower could use any of the following nonhosts: Supersweet corn ('Crisp' or 'Sweet 710/711' cultivars), pepper, lima bean, turnip, squash, rapeseed ('Humus' cultivar), canola, mustard, and Sudangrass ('Trudan 8', or 'Sordan 79' cultivars). The diversity of choices increases each year as more varieties are tested.[40]

Sudangrass, rapeseed, some canola cultivars, and mustard release nematode-killing compounds after soil incorporation. In the Columbia Basin, the most benefit is gained from this effect when fall Sudangrass is plowed down after it is stressed (i.e., after the first frost or irrigation is stopped). Mid-March incorporation of winter rapeseed and canola is the best timing for that region. Local trials could be done to determine the best timing for the Klamath Basin. See Useful Contacts and Resources for further information about this on-going work.

FURTHER RESEARCH

The following trials are expected to require significant research prior to implementation or adoption by growers.

Onion Maggots

Exclusion fencing. Canadian research has found low-cost nylon exclusion fencing effective in restricting root maggot adults from new fields.[41] Research demonstrated root maggot reductions greater than 80 percent in early trials. Fence heights to 3.9 feet with a slight overhang exclude most adults. *Delia antiqua* is a weak flyer, but attempts to fly upwards when encountering an obstacle. The majority are trapped by the overhang. Combined with crop rotation, exclusion fencing might serve to overcome the ability of adult flies to migrate to new fields. Canadians found the cost of fencing comparable to that of pesticide treatments. See Useful Contacts and Resources for a research contact for this technique.

Stimulo-Deterrent Diversion (SDD). SDD uses a "pull-push" strategy to control onion maggots.[42] The "pull" or stimulant aspect uses a trap-crop technique. The trap consists of adjacent planting(s) of cull onions that attracts female flies for egg laying. The "push" or deterrent aspect is provided either by repellent materials, such as botanical extracts applied to the main crop, or by planting onion varieties selected for characteristics less attractive to onion maggots.[43]

Promising deterrent materials investigated to date include many low and non-toxic botanicals including black pepper, dill, ginger, and capsaicin (found in hot peppers)[44]—materials readily acceptable to the Refuge environment. The strategy targets the first generation of onion maggots, since the onion plants become increasingly less susceptible to injury as they grow larger.[45] The minimal use of pesticides in this approach, plus the abundance of maggots to be found in the trap crop, present an ideal circumstance for the development of a predator-parasite complex to keep the pest population at modest levels. This might be further supported by habitat enhancement plantings that encourage beneficials.

The SDD concept holds high potential for use on the Refuge, but is still considered to be in its development stages. Its use would require PUP approval. Implementation of on-site tests should not be ruled out, however, as research to date provides considerable detailed results around which trials could be constructed. See Useful Contacts and Resources for a research contact for this technique.

Thrips

Sequential sampling for thrips. Researchers in New York and Michigan have developed and tested a successful sequential sampling method for thrips.[9] This method makes sampling easier and control decisions more reliable. Research and further trials on the leased lands might be conducted to adapt this technique locally.

Cover crops. The choice of cover crops can affect the number of overwintering thrips. Different cover crops could be tried and their effect on thrips populations and onion damage determined.

Cutworms

Determine the effectiveness of monitoring cutworm populations using pheromone traps. This should be combined with positively identifying the species of cutworms causing economic damage to onions.

Montana has had a statewide monitoring program since 1992 for pale western and army cutworms. Adults are monitored using pheromone traps during late summer through fall when they move from oversummering sites and begin mating and egg laying. Continuous, long-term monitoring provides information about population increases, and may indicate potentially damaging outbreaks.

However, this technique is effective only if the correct pheromone trap for a particular species of cutworm is used. This is why it is necessary to determine which species of cutworms are most important in onions. See Useful Contacts and Resources for suppliers of cutworm lures.

Determine appropriate action thresholds for cutworms on onions. In potato crops, the following method is suggested for determining the number of cutworm larvae per foot row and might also prove a useful technique for onion monitoring: shake 5-foot sections of two adjacent rows into the furrow and count the larvae on the soil surface. Divide the number of larvae counted by five. The resulting number is the number of worms per foot row. Repeat in several locations throughout the field since infestations may be restricted to certain areas.[46]

There are no action thresholds now used for cutworms on onions. If appropriate action thresholds were determined for the Klamath Basin, it would provide growers with better guidelines for control.

***Bacillus thuringiensis* var. *kurstaki* trials with bait formulations.** Soilserve Company, in Salinas, California, has a label for a bait formulation of *B.t.k*., but has not received Cal EPA approval for its use. If a bait formulation of *B.t.k*. becomes available, trials should be done with it to determine the best timing and application strategy.

Researchers might consider doing limited trials to make a bait using another formulation of *B.t.k*. (such as a wettable powder) and applying it to a suitable substrate. Such trials would probably require a Research Authorization permit from the Cal EPA, but these can usually be granted within a few weeks.

Adding caffeine to the bait might be another option for increasing the effectiveness of *B.t.k*. against cutworms. A note in New Farm Magazine[47] mentioned that laboratory and greenhouse tests showed caffeine boosted *B.t.* effectiveness by up to 900 percent against armyworms. Much like *B.t.*, caffeine interferes with the pests' digestive and nervous systems. It is most promising for pests that are mildly susceptible to *B.t.* itself. Recipe: dissolve 13 oz. pure caffeine in water. Add the solution to 100 gallons of standard *B.t.* spray and apply as usual. Use of *B.t.k*. would require PUP approval. See Useful Contacts and Resources for further information about *B.t.k*. for cutworm control, and for registration status of *B.t.k*. bait formulations.

White Rot

Germination stimulants (natural and synthetic). U.C. researchers are currently examining the potential for using stimulants to control white rot sclerotia. Onion-like exudates (such as garlic powder or diallyl disulfides [DADS]) are applied to soil. These compounds stimulate sclerotia to germinate. Germinated sclerotia cannot survive without an onion-family host and rapidly die. Experiments with this method look promising. Timing and moisture details still need to be worked out but could be available soon. These products would require PUP approval.

Flooding. Summer flooding shows considerable promise for reducing white rot sclerotia in infested soils. Preliminary research suggests that flooding for two summers reduces fungal sclerotia, providing the seasons are warm enough. Research from Canada[48] indicates that winter and spring flooding regimes also will cause large reductions in sclerotia (55 percent in one 4-month winter flood). While significant, such reductions alone are not adequate to prevent economic damage on highly infested fields. Combined with crop rotation, however, the methodology is much more promising.

Concerns about flooding primarily involve the possible effects on beneficial organisms, including those which compete with white rot. An integrated approach involving flooding and crop rotation, with sanitation and other preventive measures, deserves further investigation. These trials should be coordinated with the on-going sump rotation research that is being conducted on the refuges.

Planting density and spacing. Researchers have noted that white rot infection may be transmitted between growing plants in the field. Consequently, rows with denser plant spacings result in higher rates of disease development.[(49)] Entwistle[(25)] suggests this might be exploited by planting configurations employing a grid arrangement and increasing the distance between individual plants.

This strategy could prove useful in slowing infection on lightly infested soils. It would have limited impact on heavily-infested sites. Additional considerations would be the increased reliance on herbicides for weed control, and adaptations needed for planting on a grid pattern, and other equipment required to produce and harvest the crop. Though research results have shown a correlation between planting density and incidence of white rot disease, further research is required to determine optimum planting densities and configurations for commercial production situations.

Downy Mildew

Disease forecasting. Disease forecasting systems used in onion production in other regions have significantly reduced fungicide use. Forecasting systems typically combine various weather data, crop development stages, previous fungicide scheduling, and related information, to determine the optimum time for spraying. This usually improves the efficiency of applications and reduces unnecessary impact on beneficial organisms. DOWNCAST is a model developed in Ontario, Canada.[(9)] In addition to weather monitoring equipment, a simple calculator should be adequate for making the necessary calculations.

DOWNCAST has been trialed in the central valley of California, with poor results. To use disease forecasting on the leased lands would require significant research and changes to the current DOWNCAST model to adapt it to local conditions.

Basal Rot

Compost to increase biological control. U.C. on-farm research trials have demonstrated up to a 60 percent reduction in Fusarium rot in onions, using compost at approximately 2.5 tons/acre. Direct predation of disease organisms by beneficial microbes, and the production of biochemical products that act as natural disease suppressants[(50)] were investigated. Compost from domestic birds (e.g., poultry litter) will not be allowed as it is a source of disease for waterfowl and other birds.

Damping Off

Biofungicides. W.R. Grace has developed a new biofungicide based on the beneficial fungus, *Gliocladium virens*, that is effective for control of common damping off and root rot diseases, caused by *Pythium* and *Rhizoctonia* spp. The granular formulation is called SoilGard 12G, and would require PUP approval. This product is not currently registered for use in California. If it does become registered, it should be tested for its effectiveness against seedling damping off on the Refuge.

Calcium as a soil amendment. There is considerable research supporting the notion that calcium, added to the soil as gypsum or similar forms, can suppress *Pythium* spp., and increase host resistance.[51] Where infestation is severe, trials using a calcium-rich soil amendment might be warranted.

Botrytis Leaf Blight

Disease forecasting. Three forecasting systems for Botrytis leaf blight have been developed elsewhere that might be adapted to the Klamath Basin.[9] BLIGHT-ALERT was developed and tested in New York, the Spore Index Predictive System was developed in Michigan, and BOTCAST was created in Ontario. The New York system requires access to a programmable calculator and computer. The Michigan system can be done on computer or on an automated field weather station. BOTCAST system calculations may be executed with a simple calculator. All systems do require some form of meteorological instrumentation in or near the fields. Adaptation of any of these models to the leased lands would require significant research and field trials.

Nematodes

Cover crops. The use of certain crops and cover crops in rotation can actively suppress nematodes. In a New York study, sorghum-Sudangrass was planted and mowed when it reached 3 feet. After re-growth, the crop was plowed down in the fall. This decreased nematode populations, and increased onion seedling vigor. Onion production increased 20 to 25 percent.[52]

USEFUL CONTACTS AND RESOURCES

Bat predation and enhancement research

- Dr. Steve Cross, Southern Oregon State College, 1250 Siskiyou Blvd., Ashland, OR 97520-5071; (541) 552-6749

  Dr. Cross has done extensive work increasing bat habitat.

- Jim Kennedy, Bat Conservation International; (512) 327-9721

  BCI has a wealth of information concerning bats and bat habitat.

- Rachael Long, Farm Advisor, U.C. Cooperative Extension, 70 Cottonwood St., Woodland, CA 95695; (530) 666-8143

Ms. Long is working with growers in Yolo County to increase bat populations and study the positive effects in increased bat populations.

Beneficial insect habitat/strip cropping

- W.E. Chaney, U.C. Cooperative Extension, 1432 Abbot St., Salinas, CA 93901; (408) 759-7350

  Bill Chaney has done work on enhancing biological control of aphids and other pests through the use of insectary plants grown in vegetables.

Beneficial nematodes for cutworm control

- Rick Miller, product manager, Biosys, 10150 Old Columbia Rd., Columbia, MD 21046; (410) 381-3800

Nematode-suppressive crop rotations and cover crops

- Russ Ingham, Dept. of Botany and Plant Pathology, Oregon State University, 2082 Cordley Hall, Corvallis, OR 97331-2902; (541) 737-5255

Researchers and other contacts

- Steve Orloff, Field Station, 1655 South Main St., Yreka, CA 96097; (530) 842-2711

Research on onion cultural practices

- Jim R. Miller, 210 N. Kedzie Hall, Michigan State University, East Lansing, MI 48824; (517) 432-1490

  Dr. Miller has researched onion maggot egg-laying deterrence and "stimulodeterrent diversionary cropping" for managing onion maggots.

- Fred Crowe, COARC (Central Oregon Ag. Research Center), 850 N.W. Dogwood Lane, Madras, OR 97741; (541) 475-7107

Research on onion diseases, especially flooding and white rot control

- Michael Davis, Dept. of Plant Pathology, University of California, Davis 95616; (530) 752-0303 or (530) 752-3831

- Don Kirby, University of California Intermountain Experiment Station, Tulelake, CA 97634; (530) 667-5117

- Larry Godfrey, Entomology Department, University of California, Davis 95616; (530) 752-0473

- Charles Eckenrode, Agricultural Experiment Station, Cornell University, Geneva, NY 14456; (315) 787-2011

Mr. Eckenrode is an onion entomologist, especially knowledgeable about onion maggot research.

- R.S. Vernon, Agric. Canada, Research Station, 6660 NW Marine Dr., Vancouver, BC V6T 1X2, Canada

Onion maggot exclusion fences research

- Ron Voss, Dept. of Vegetable Crops, University of California, Davis 95616; (530) 752-1249

  Mr. Voss is an agronomist who has worked extensively in Klamath, especially with onions and potatoes.

Suppliers of beneficial organisms and other pest control products

The publication Suppliers of Beneficial Organisms in North America lists 132 commercial suppliers of beneficial organisms including parasites, predators, nematodes, bacteria, fungi, protozoans and viruses useful for biological pest control.

One free copy of the above document is available from:

- California EPA, Dept. of Pesticide Regulation, Environmental Monitoring and Pest Management Branch, 1020 N Street, Room 161, Sacramento, CA 95814-5604; (916) 324-4100

The Directory of Least-Toxic Pest Control Products is updated and published yearly by the Bio-Integral Resource Center (BIRC). It lists over a thousand pest control items including products, services and beneficial organisms. Descriptions and contact information for manufactures and suppliers are given for each product.

Contact BIRC at the following address to request a copy:

- BIRC, P.O. Box 7414, Berkeley, CA 94707; (510) 524-2567

***Bacillus thuringiensis* var. *kurstaki* (registration status and bait formulations):**

- Cheryl Norton, Abbot Laboratories, Northern California Sales Rep., 8125 Bailey Rd., Yuba City, CA 95993; (530) 673-7537

Neem-based products:

- Biosys (Align manufacturer), 10150 Old Columbia Rd., Columbia, MD 21046; (410) 381-3800

Local suppliers of BioVector Biological Insecticide for Fruits and Vegetables (beneficial nematodes for cutworm control):

- United Horticulture Society, 1000 S. Central, Medford, OR 97501; (501)779-0121

Supplier of cutworm lures:

- Scenturion, 4809 E. St. Hwy 525, Clinton, WA 98236; (360) 341-3989 (Contact: Joan Fisher, owner)

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<u>**APPENDIX O-1**</u>

Note: this appendix is not available. See the Executive Summary for further information.